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

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OUTLINE

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

OBJECTIVE

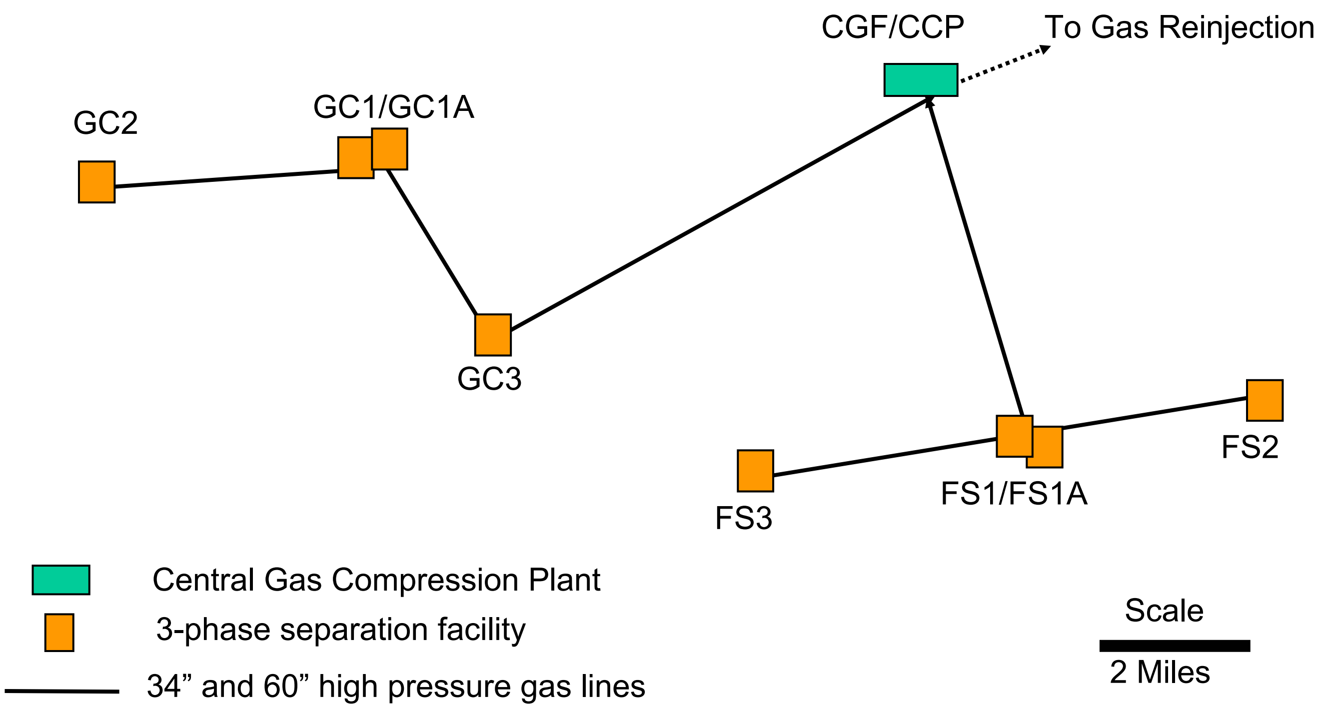
- The objective of this study is to develop a tool to assist engineers in maximizing total field oil production by optimizing the gas discharge rates and pressures at the separation facilities.

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



BACKGROUND

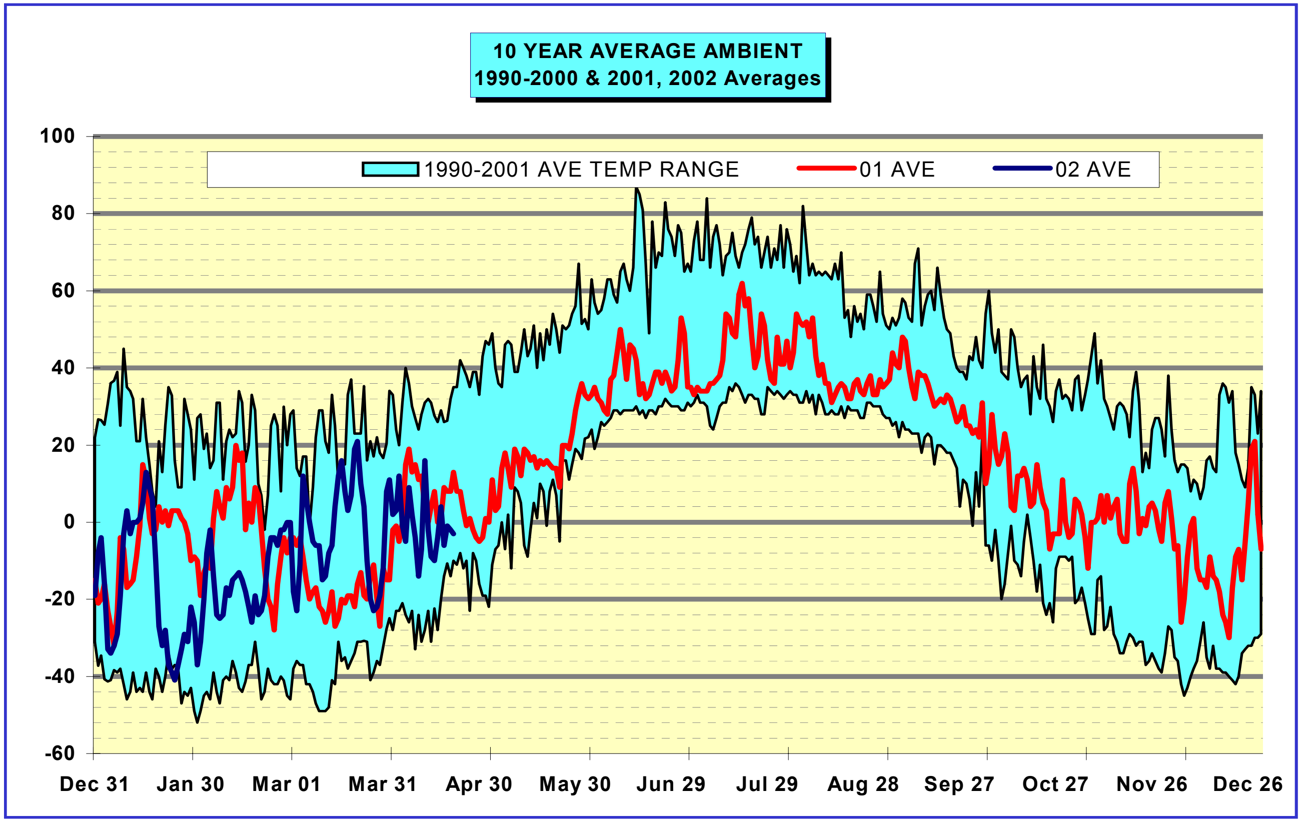
- Fuel gas supply (at the flow stations and gathering centers) and artificial lift gas supply for the lift gas compressors at GC1 are taken off the gas transit line upstream of the compression plant.
- This reduces the feed gas rate and pressure at the inlet to the compression plant.

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.

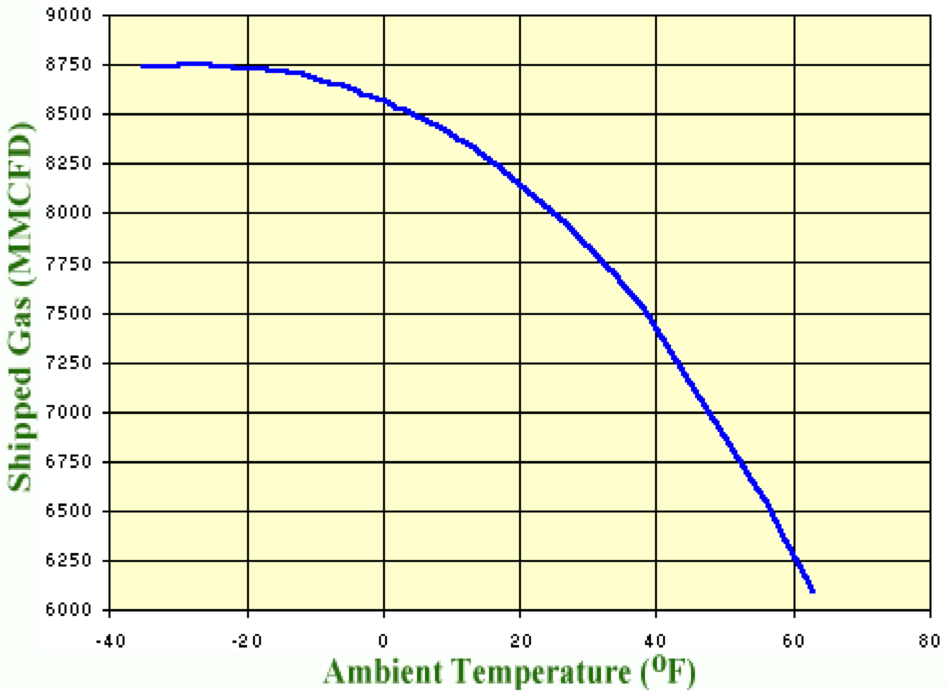
BUSINESS MOTIVATION

- **Ambient temperature has a dominant effect on compressor efficiency and hence total gas handling capacity and subsequent oil production.**



BUSINESS MOTIVATION

- A significant reduction in gas handling capacity is observed at ambient temperatures above 0 ^{o}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 ^{o}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 ^{o}F in one day equates to an approximate oil volume reduction of 40,000 bbls, or 1000 bopd per ^{o}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 ^{o}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.

METHODOLOGY

- 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.

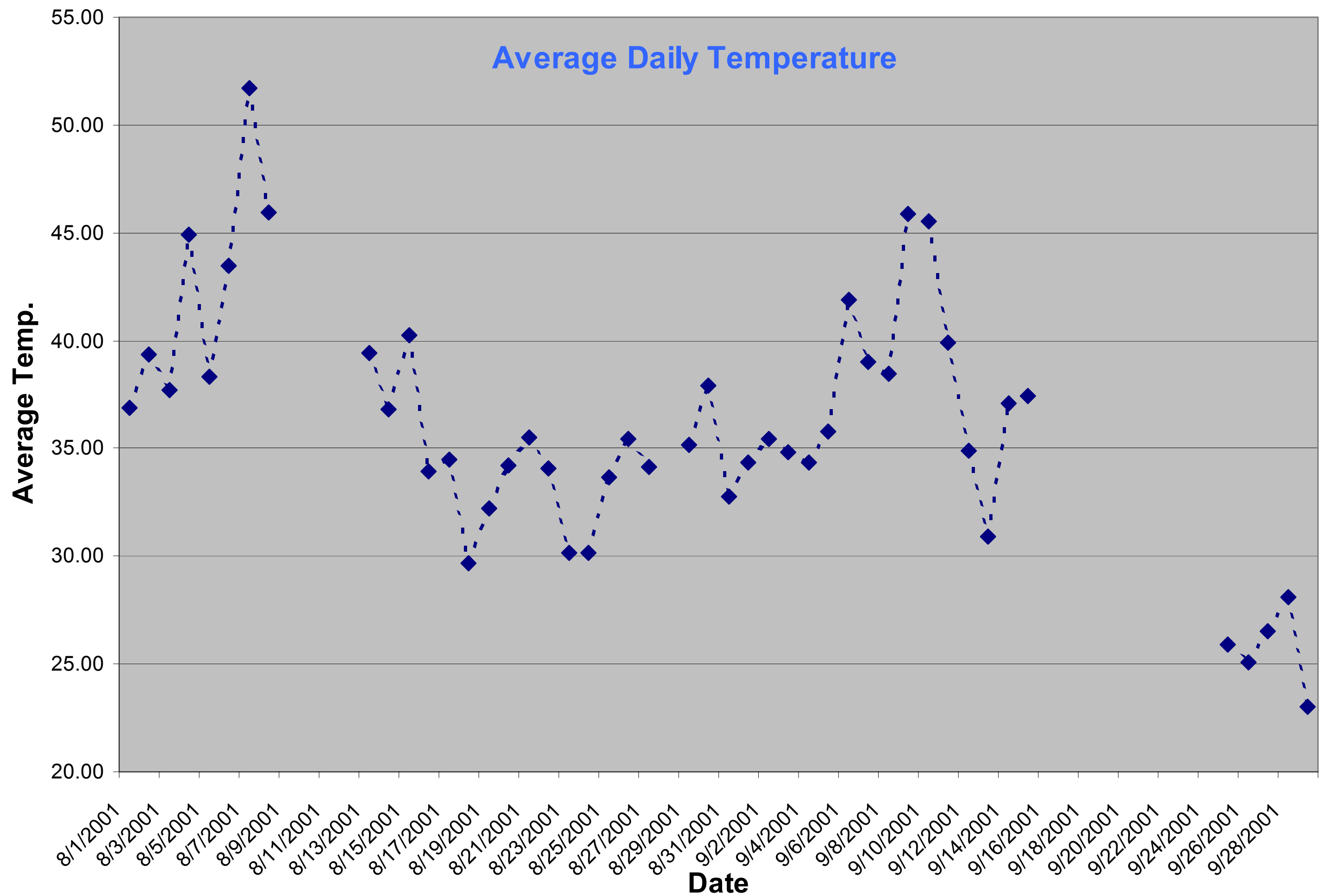
METHODOLOGY

- **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.

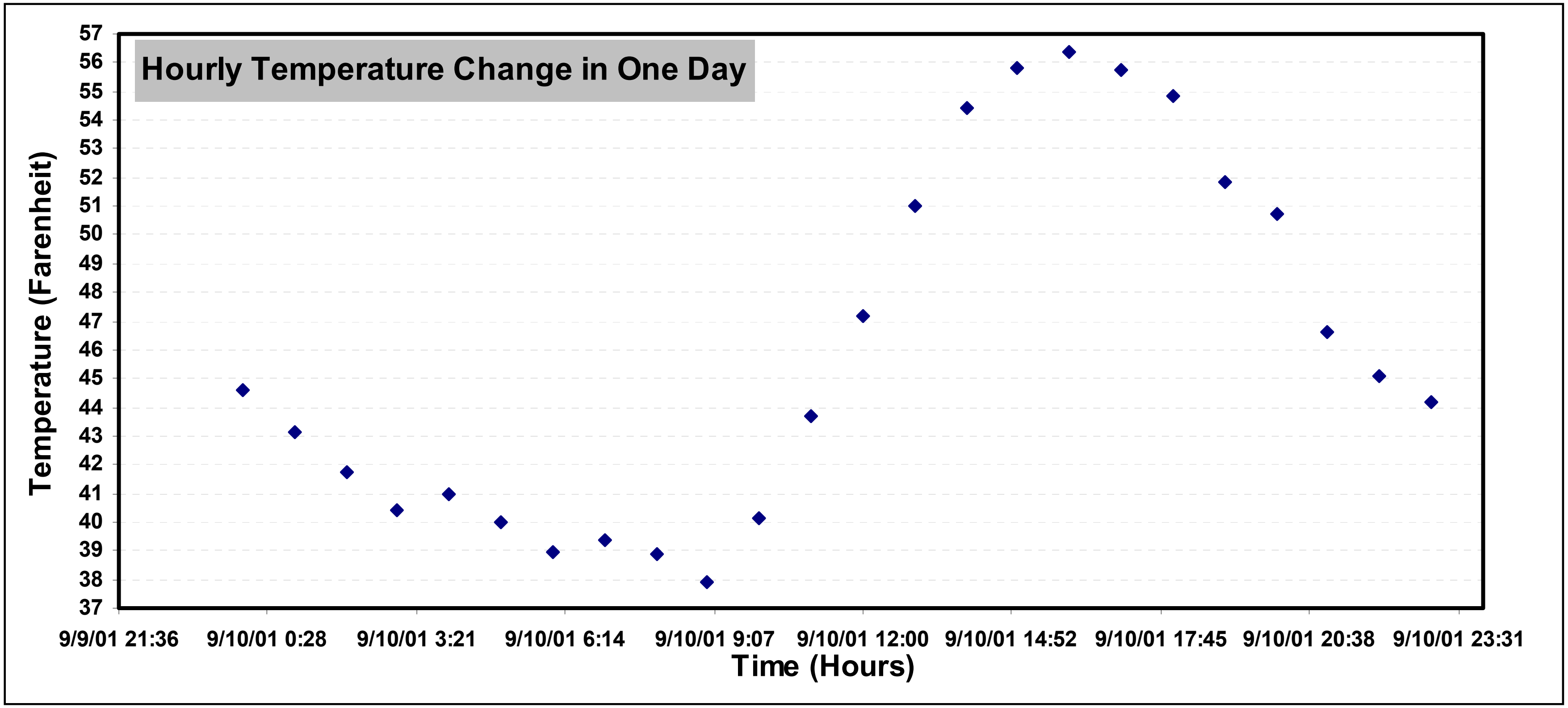
METHODOLOGY



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



METHODOLOGY

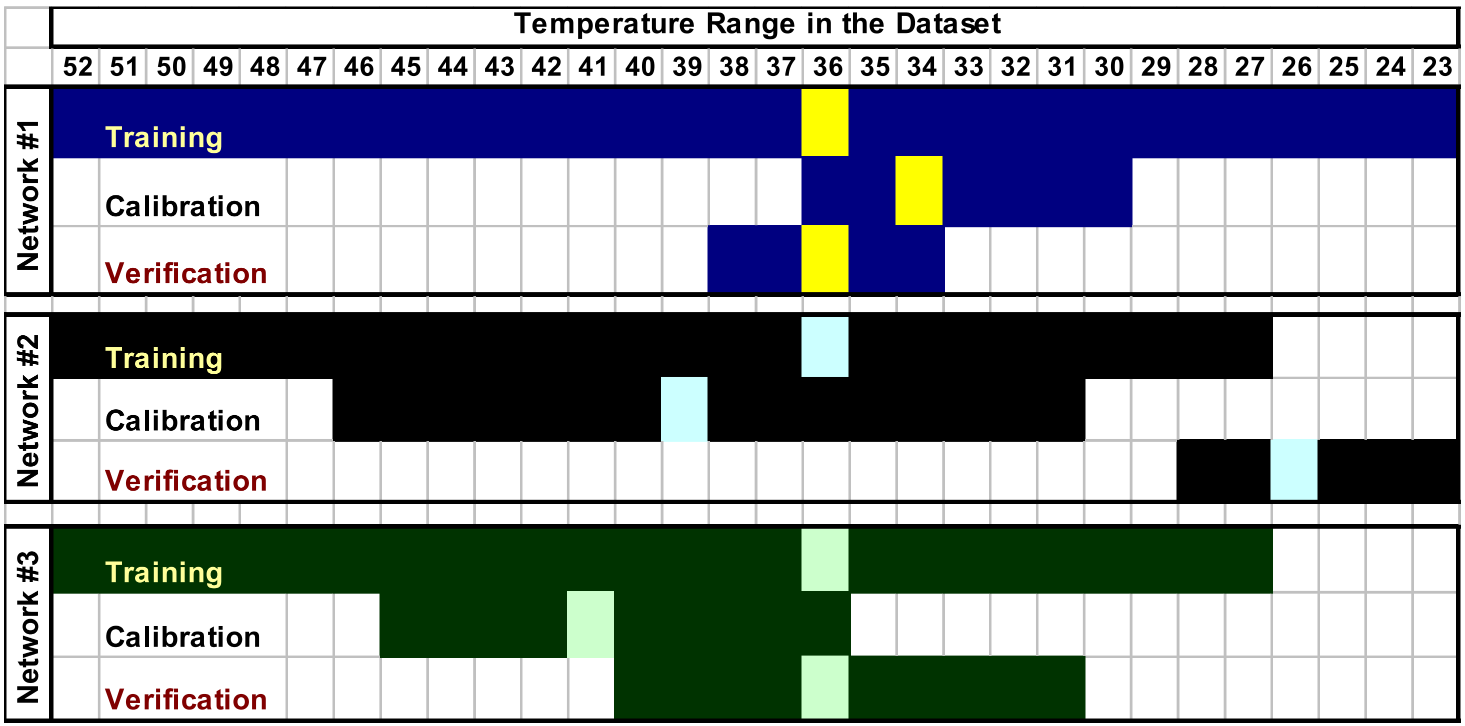
- ***Central Compression Plant Inlet Model***

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

	Min	Average	Max	Std. Dev.
Ambient Temperatur	20.23	35.85	57.33	6.44
GAS DISCHARGE RATES				
Total Fuel Gas	38.92	46.61	53.46	2.79
Gas-Lift Gas at GC1	401.23	809.30	923.09	152.29
FS1	895.75	1,137.61	1,304.96	76.10
FS2	428.09	704.69	769.89	63.35
FS3	382.06	786.61	1,066.79	164.15
FS1A	907.18	1,273.55	1,530.64	136.96
GC1	456.85	964.30	1,127.55	214.05
GC2	807.91	998.21	1,080.00	55.59
GC3	490.54	1,011.01	1,131.89	112.28
GC1A	944.00	1,353.91	1,438.83	73.24
Feed Gas Rate to CCP	6,473.64	7,370.93	7,832.34	234.48
GAS DISCHARGE PRESSURES				
FS1	592.47	603.46	624.02	7.39
FS2	563.67	626.76	650.03	11.43
FS3	625.98	640.73	669.42	10.64
FS1A	560.75	602.37	625.66	10.47
GC1	574.95	611.38	634.87	11.54
GC2	578.68	610.47	634.62	12.16
GC3	581.66	600.94	622.99	9.66
GC1A	572.04	601.64	627.60	13.20
Inlet Pressure to CCP	536.03	559.82	588.60	10.81

METHODOLOGY

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



METHODOLOGY

	Day	Date	Temp.	Network#1	Network#2	Network#3
1	Wednesday	8/1/2001	36.89	Training	Training	Training
2	Thursday	8/2/2001	39.35	Training	Training	Training
3	Friday	8/3/2001	37.71	Training	Training	Training
4	Saturday	8/4/2001	44.94	Training	Training	Training
5	Sunday	8/5/2001	38.30	Training	Training	Training
6	Monday	8/6/2001	43.47	Training	Training	Training
7	Tuesda	8/7/2001	51.68	Training	Training	Training
8	Wednesday	8/8/2001	45.92	Training	Training	Training
	Thursday	8/9/2001				
	Friday	8/10/2001				
	Saturday	8/11/2001				
	Sunday	8/12/2001				
9	Monday	8/13/2001	39.44	Training	Training	Training
10	Tuesda	8/14/2001	36.79	Training	Training	Training
11	Wednesday	8/15/2001	40.27	Training	Training	Training
12	Thursday	8/16/2001	33.93	Training	Training	Training
13	Friday	8/17/2001	34.49	Verification	Training	Training
14	Saturday	8/18/2001	29.69	Training	Training	Training
15	Sunday	8/19/2001	32.21	Calibration	Training	Training
16	Monday	8/20/2001	34.18	Calibration	Training	Training
17	Tuesda	8/21/2001	35.51	Calibration	Training	Training
18	Wednesday	8/22/2001	34.10	Training	Training	Training
19	Thursday	8/23/2001	30.15	Training	Training	Training
20	Friday	8/24/2001	30.14	Calibration	Training	Training
21	Saturday	8/25/2001	33.67	Calibration	Training	Training
22	Sunday	8/26/2001	35.42	Calibration	Training	Training
23	Monday	8/27/2001	34.11	Training	Training	Training
	Tuesda	8/28/2001			Training	Training
24	Wednesday	8/29/2001	35.18	Training	Training	Training
25	Thursday	8/30/2001	37.90	Verification	Training	Training
26	Friday	8/31/2001	32.80	Training	Training	Training
27	Saturday	9/1/2001	34.36	Calibration	Training	Training
28	Sunday	9/2/2001	35.44	Calibration	Training	Training
29	Monday	9/3/2001	34.85	Calibration	Training	Training
30	Tuesda	9/4/2001	34.35	Verification	Training	Training
31	Wednesday	9/5/2001	35.76	Verification	Training	Calibration
32	Thursday	9/6/2001	41.92	Training	Training	Calibration
33	Friday	9/7/2001	39.03	Training	Calibration	Calibration
34	Saturday	9/8/2001	38.47	Verification	Calibration	Calibration
35	Sunday	9/9/2001	45.87	Training	Calibration	Calibration
36	Monday	9/10/2001	45.54	Training	Calibration	Calibration
37	Tuesda	9/11/2001	39.90	Training	Calibration	Verification
38	Wednesday	9/12/2001	34.89	Training	Calibration	Verification
39	Thursday	9/13/2001	30.91	Training	Calibration	Verification
40	Friday	9/14/2001	37.10	Training	Calibration	Verification
41	Saturday	9/15/2001	37.46	Training	Calibration	Verification
	Sunday	9/16/2001				
	Monday	9/17/2001				
	Tuesda	9/18/2001				
	Wednesday	9/19/2001				
	Thursday	9/20/2001				
	Friday	9/21/2001				
	Saturday	9/22/2001				
	Sunday	9/23/2001				
	Monday	9/24/2001				
42	Tuesda	9/25/2001	25.90	Training	Verification	NOT USED
43	Wednesday	9/26/2001	25.10	Training	Verification	NOT USED
44	Thursday	9/27/2001	26.50	Training	Verification	NOT USED
45	Friday	9/28/2001	28.08	Training	Verification	NOT USED
46	Saturday	9/29/2001	23.01	Training	Verification	NOT USED

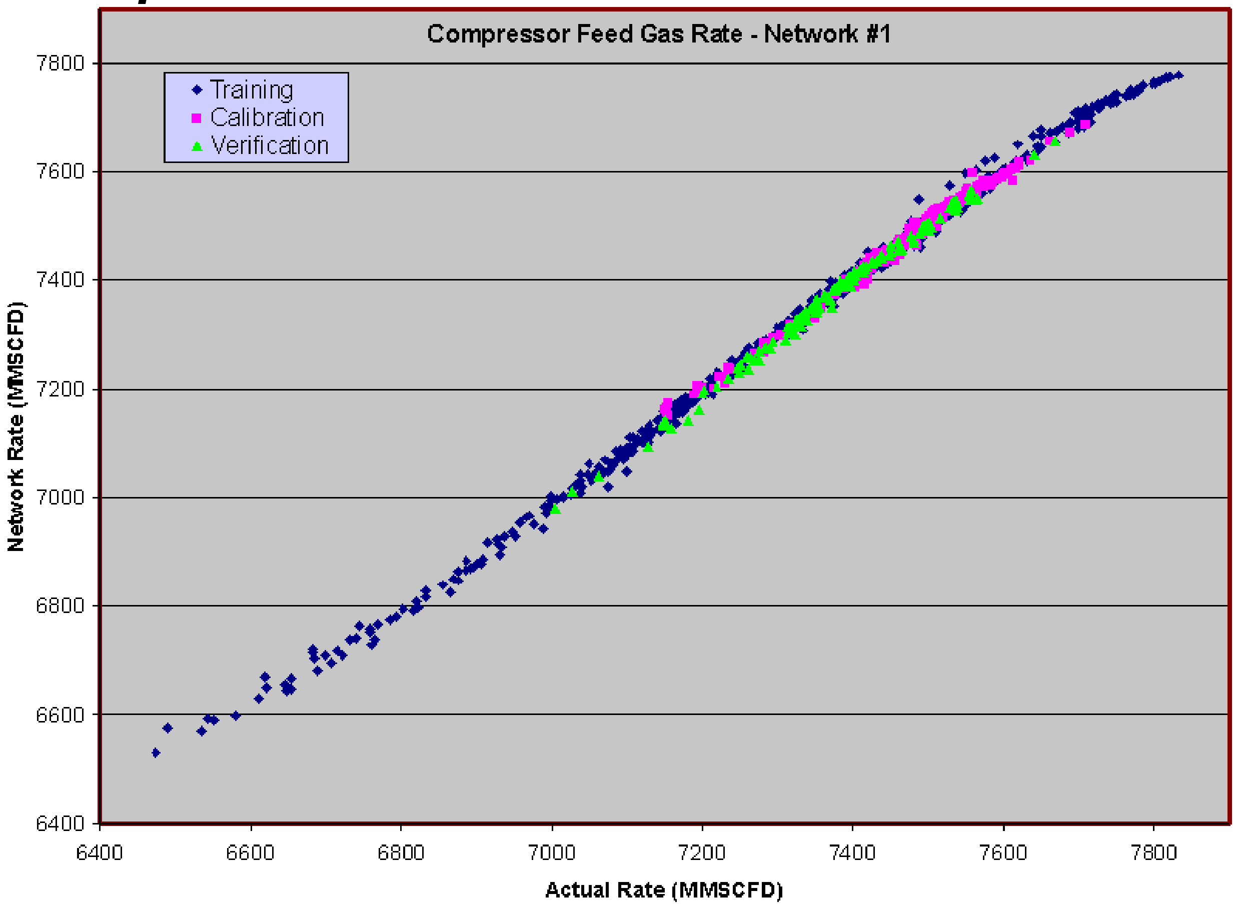
METHODOLOGY

- ***Central Compression Plant Inlet Model***

		Training		Calibration		Verification	
	Output:	Rate	Pressure	Rate	Pressure	Rate	Pressure
Network 1	Cases:	660		210		118	
	R squared:	0.9968	0.9975	0.9919	0.9959	0.9907	0.9958
Network 2	Cases:	693		192		103	
	R squared:	0.9972	0.9987	0.9827	0.9943	0.6336	0.9742
Network 3	Cases:	645		143		94	
	R squared:	0.996	0.9977	0.9862	0.992	0.9471	0.9924

METHODOLOGY

- ***Central Compression Plant Inlet Model***



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METHODOLOGY

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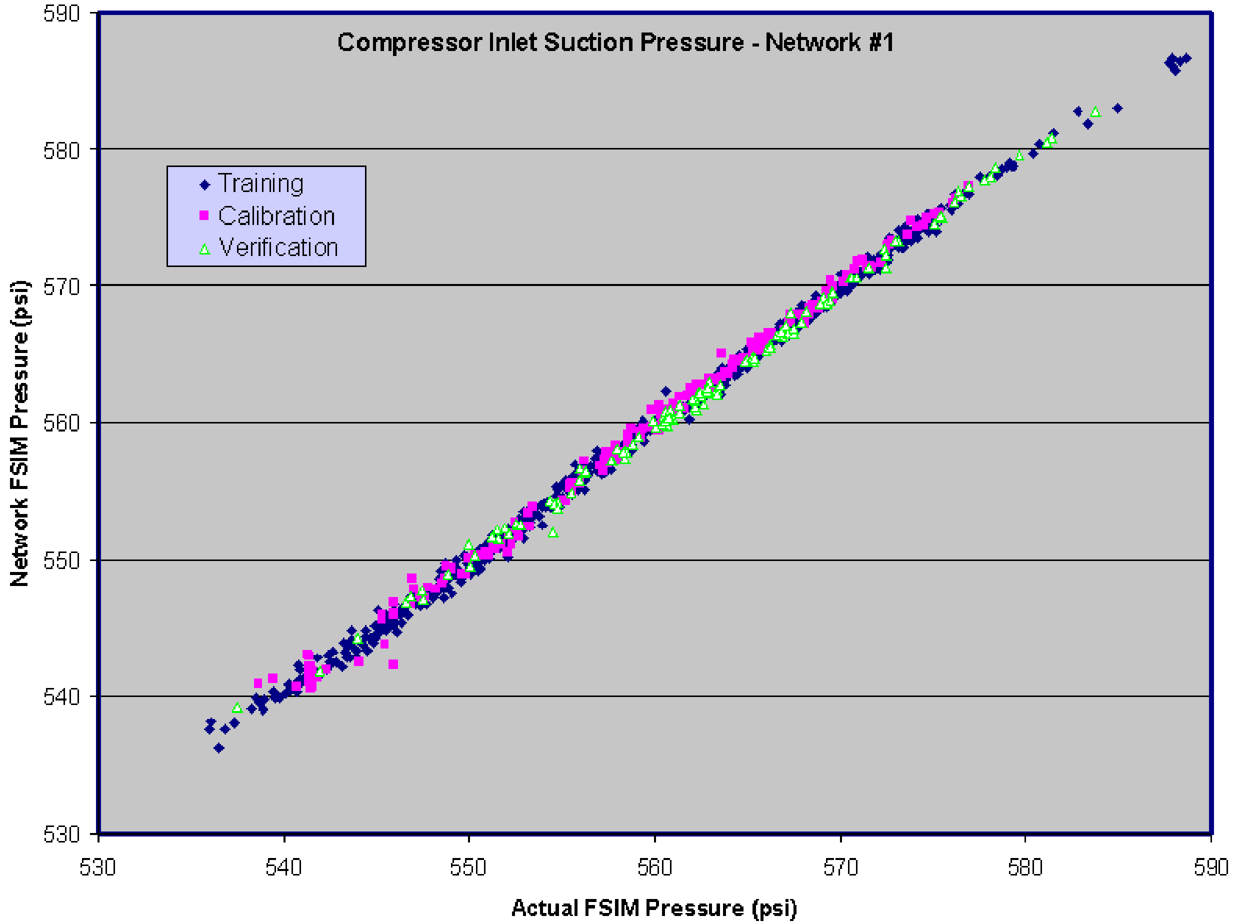

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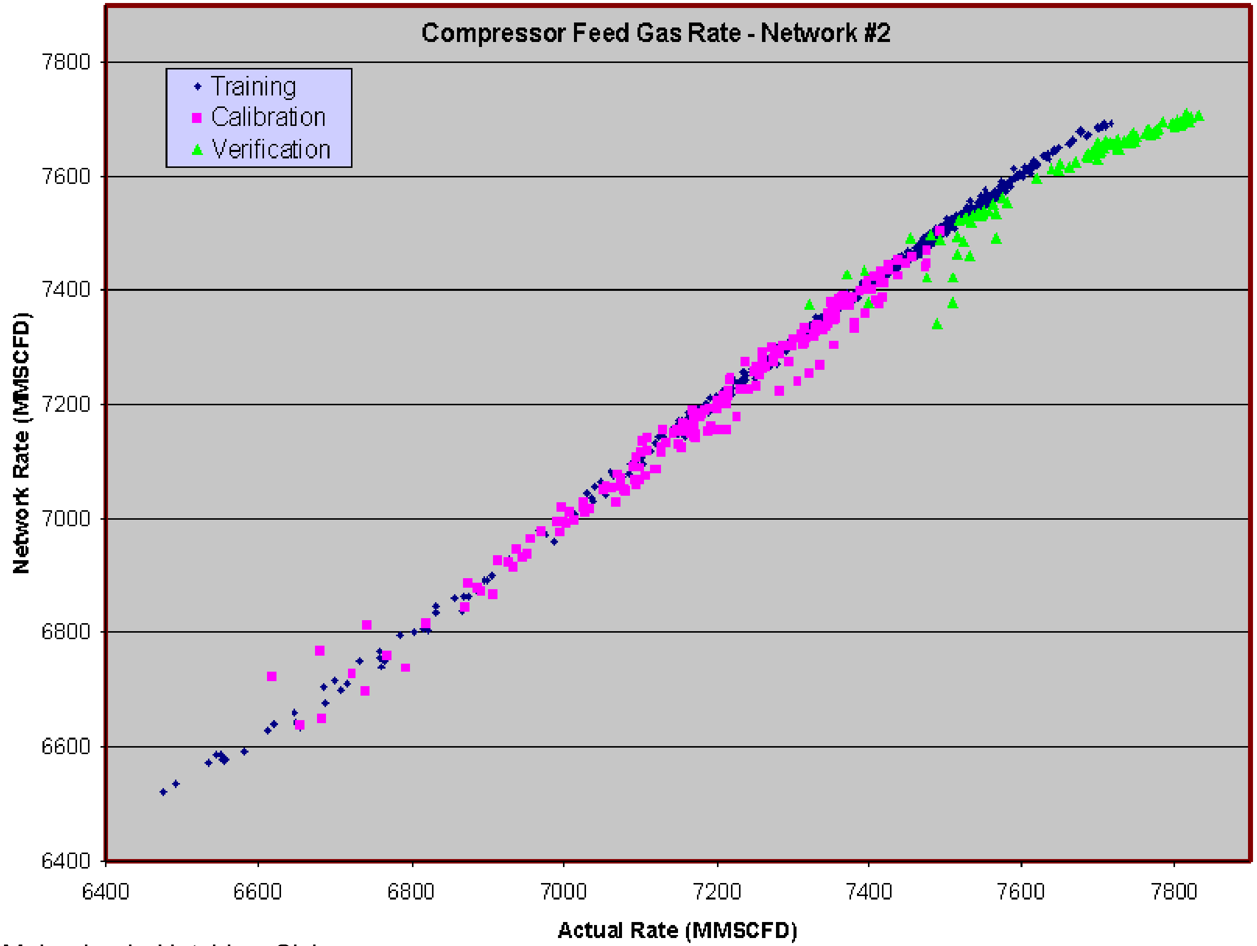

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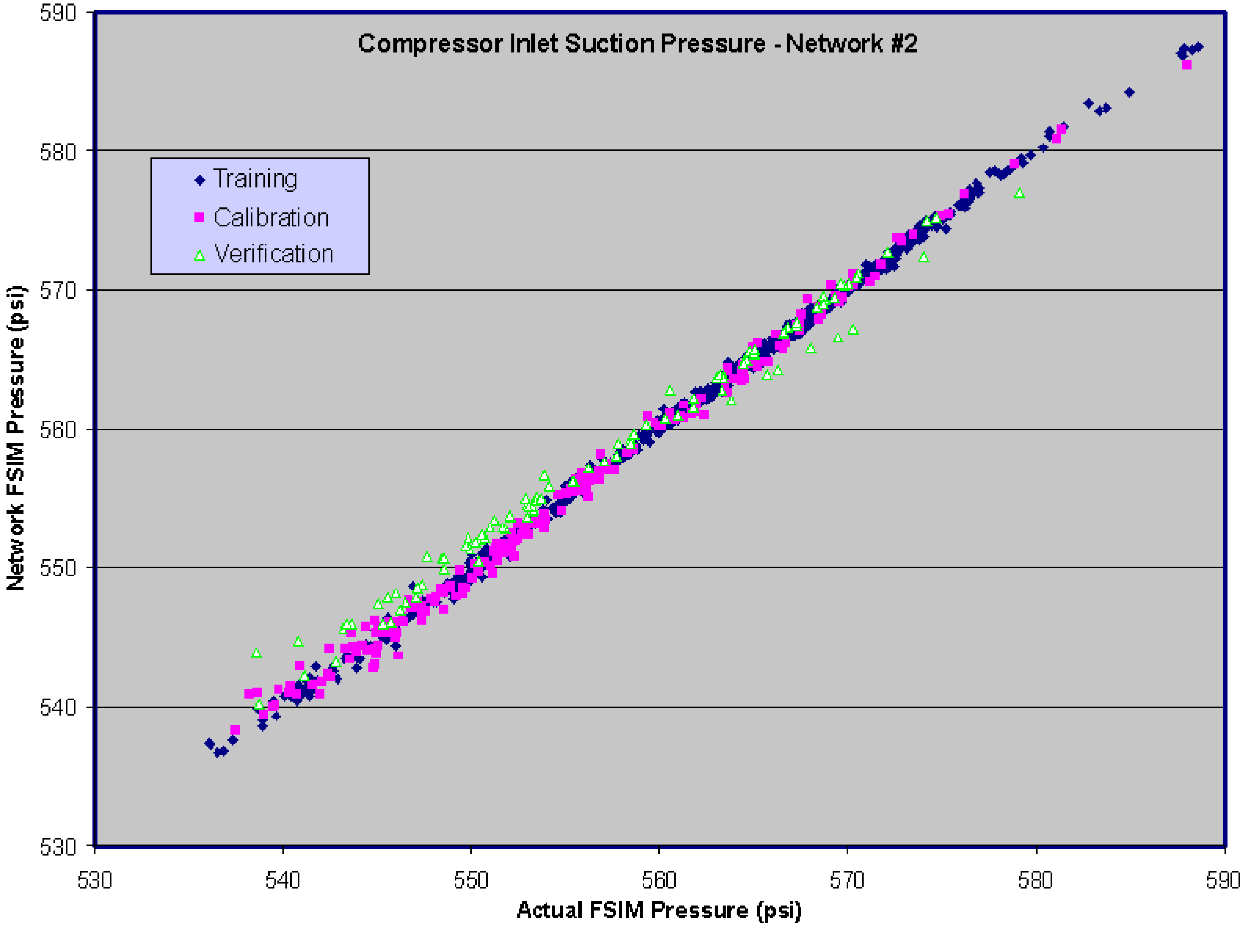

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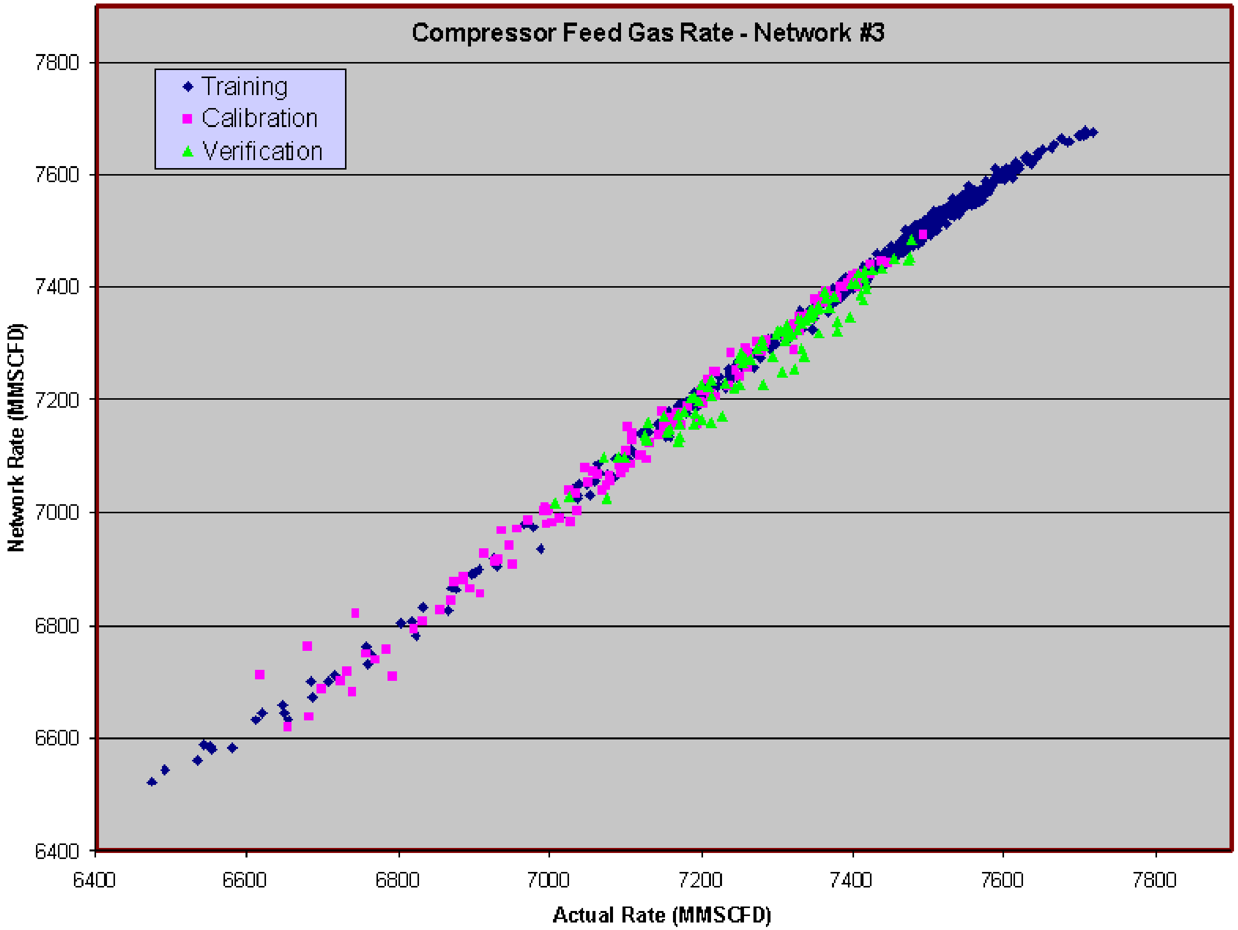

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METHODOLOGY

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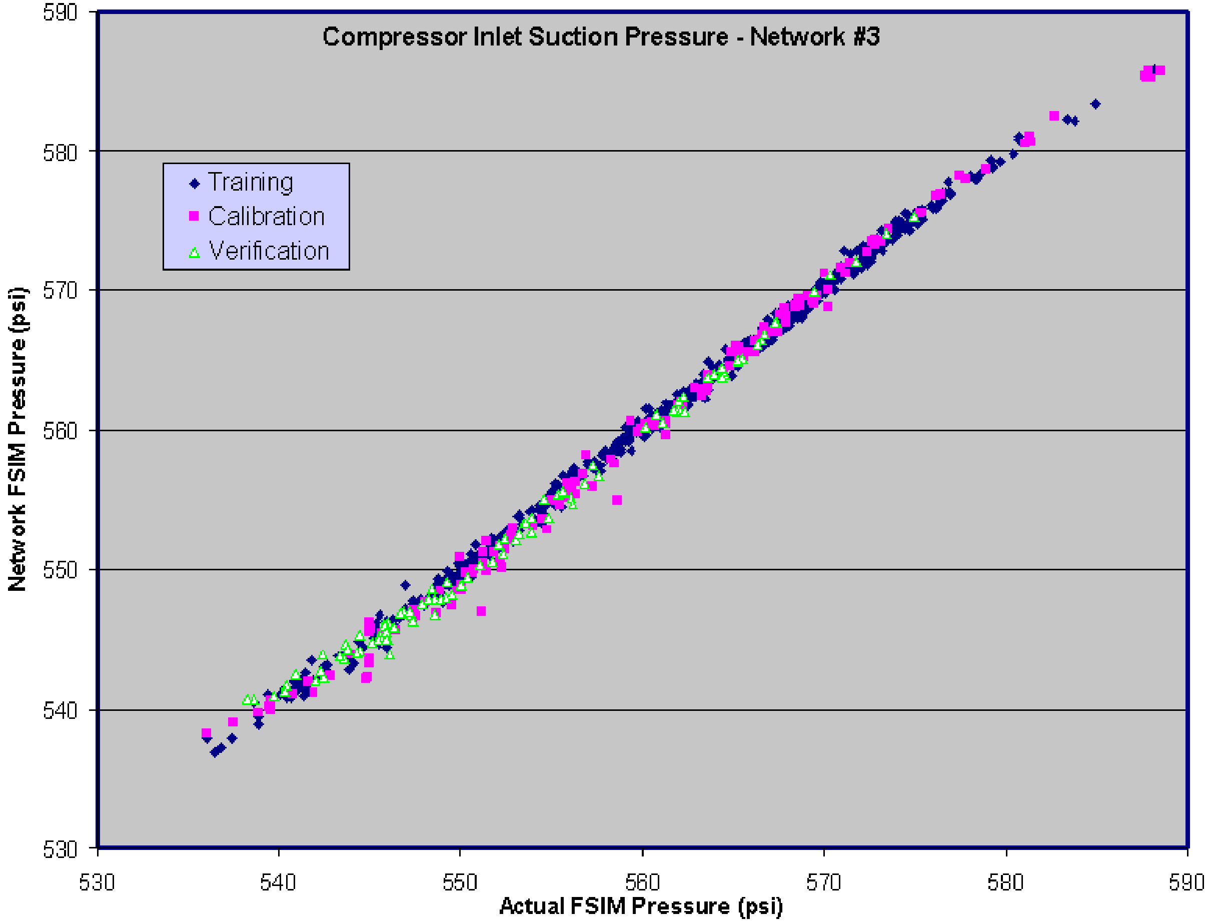


METHODOLOGY

- ***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***

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

METHODOLOGY

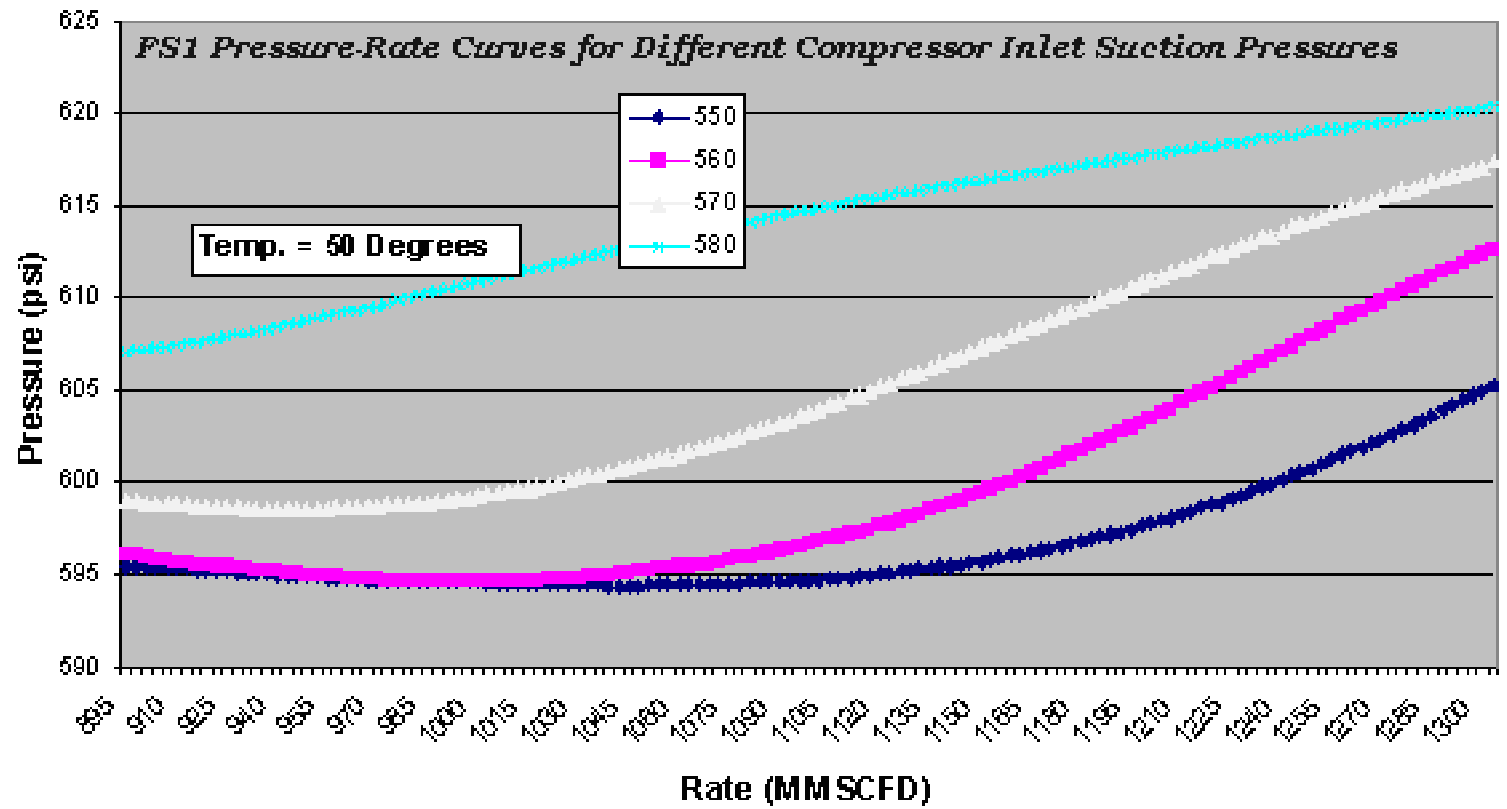
- ***Separation Facility Gas Discharge Model***
  - These models are not built based on theoretical understanding of the system, rather by building representative functions that can approximate the data present in the dataset.
  - The nature of the data being studied in this study is discrete.
  - These 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***



METHODOLOGY

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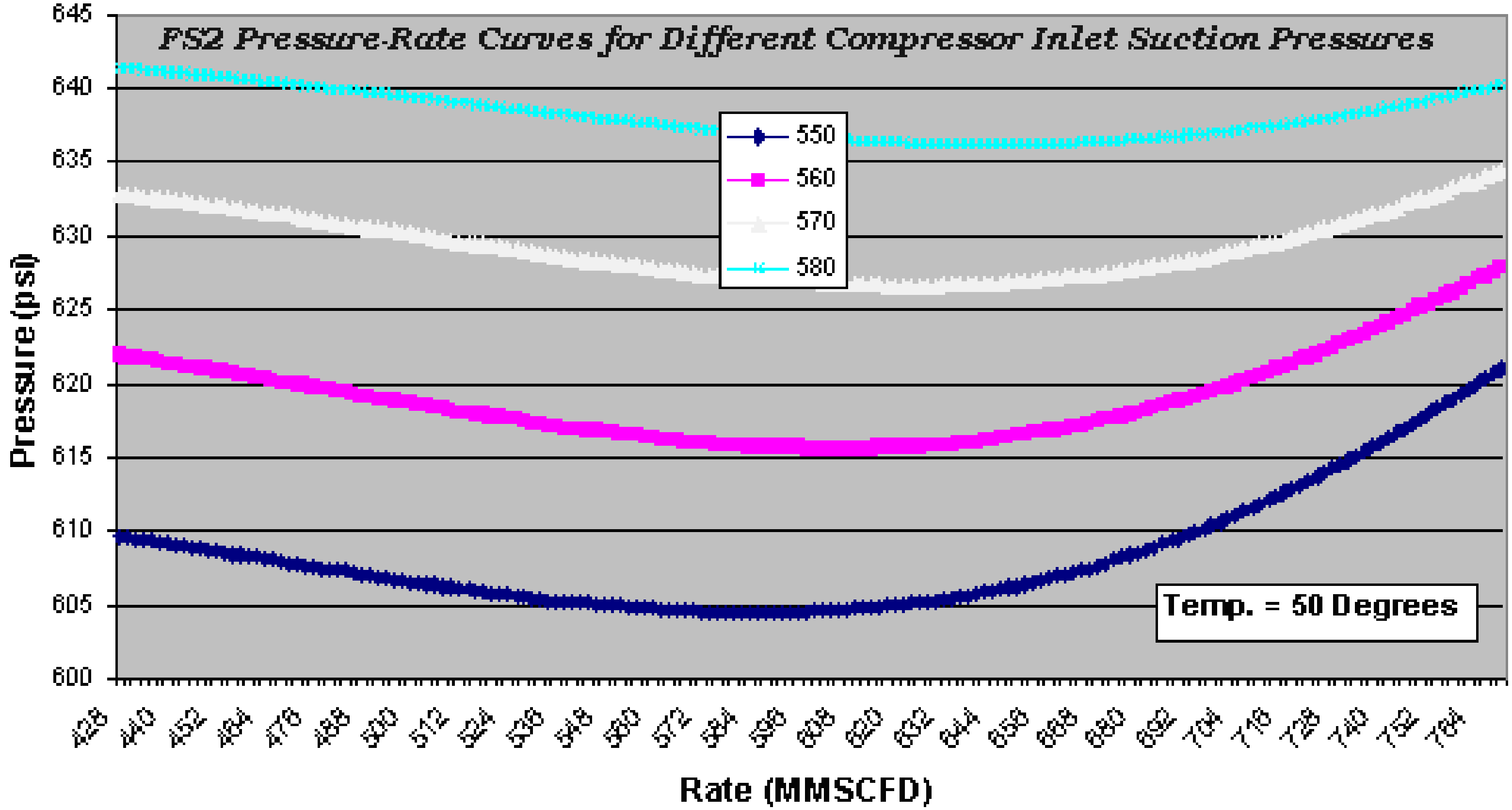

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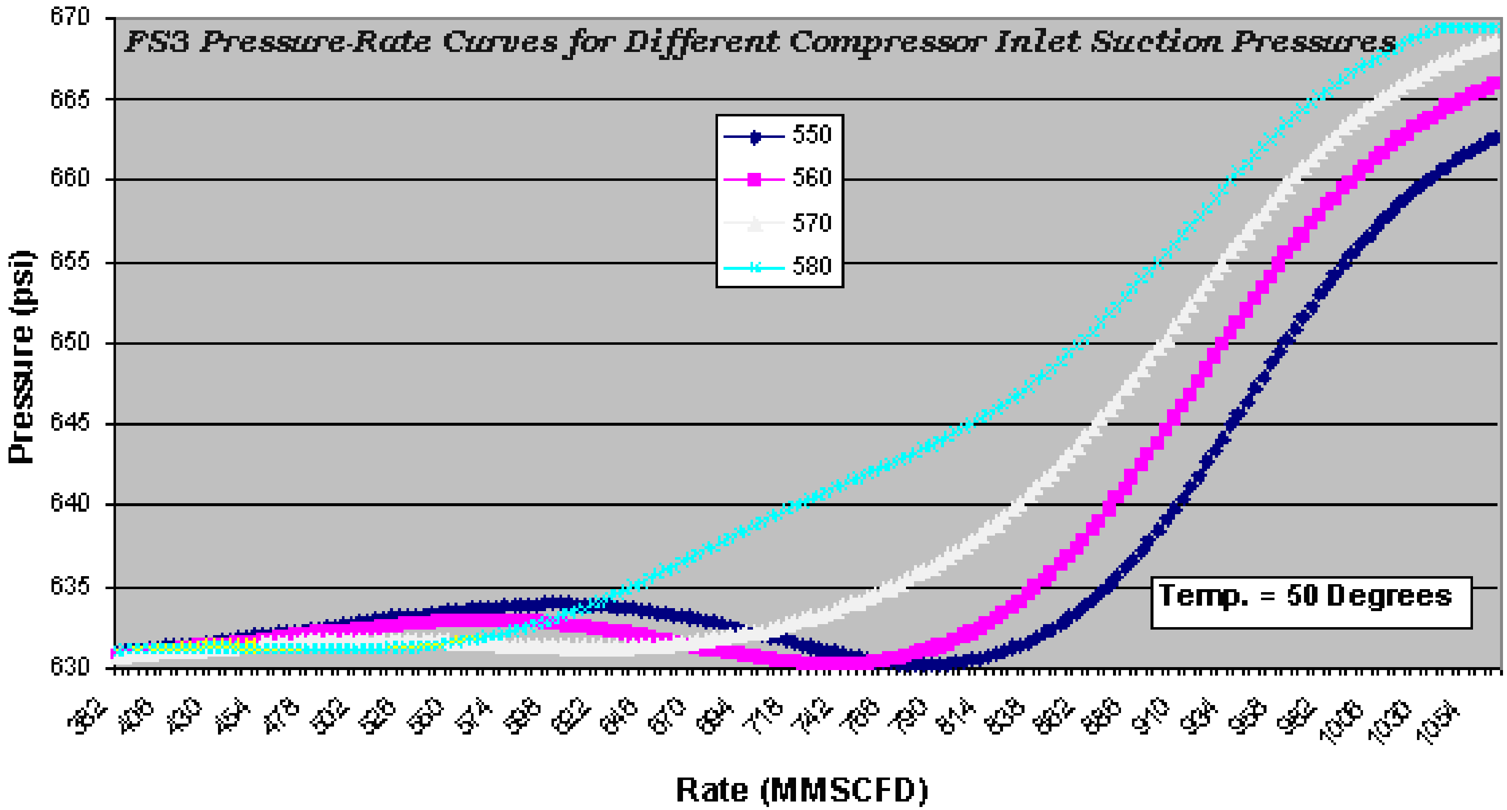

METHODOLOGY

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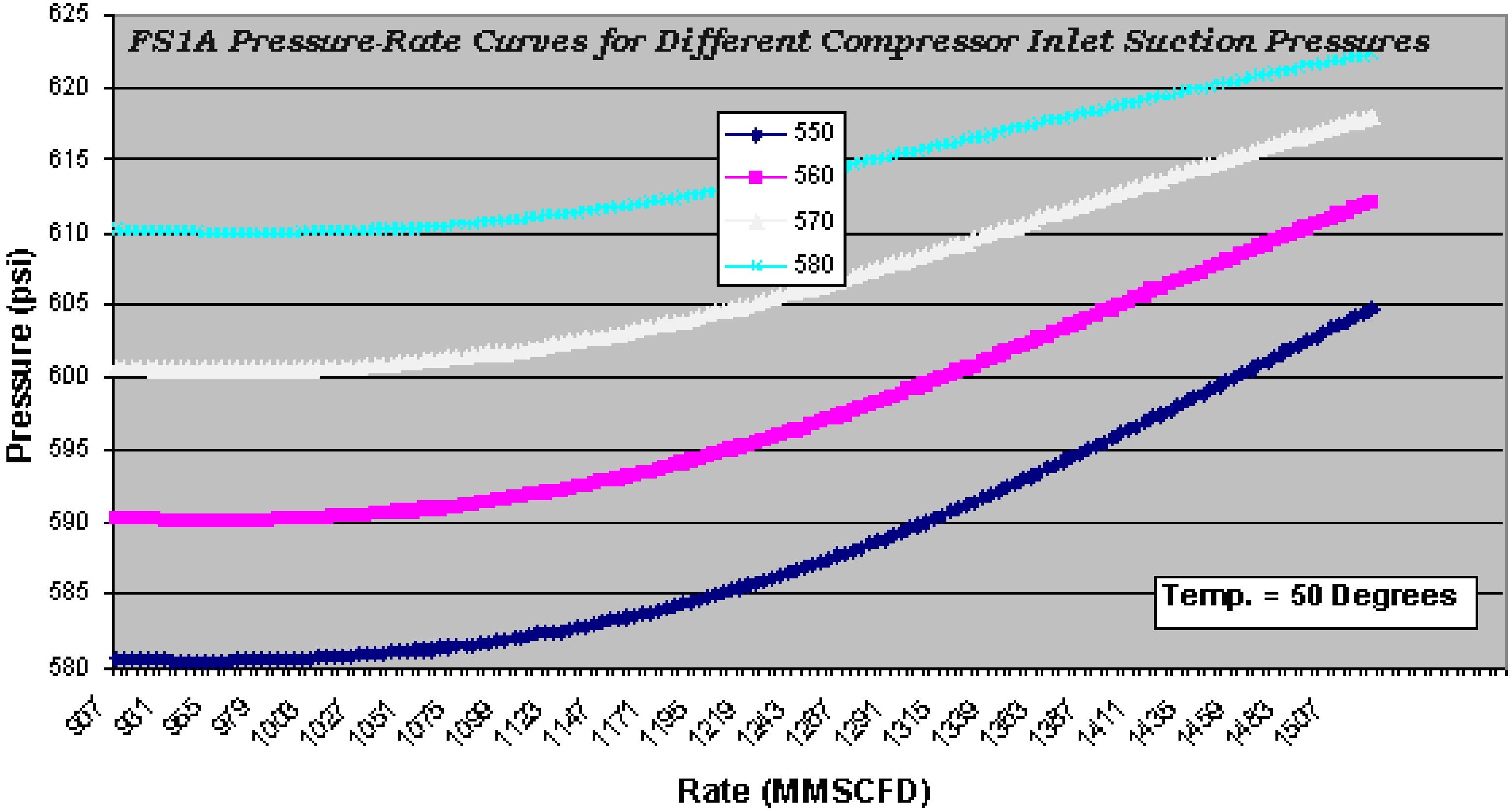

METHODOLOGY

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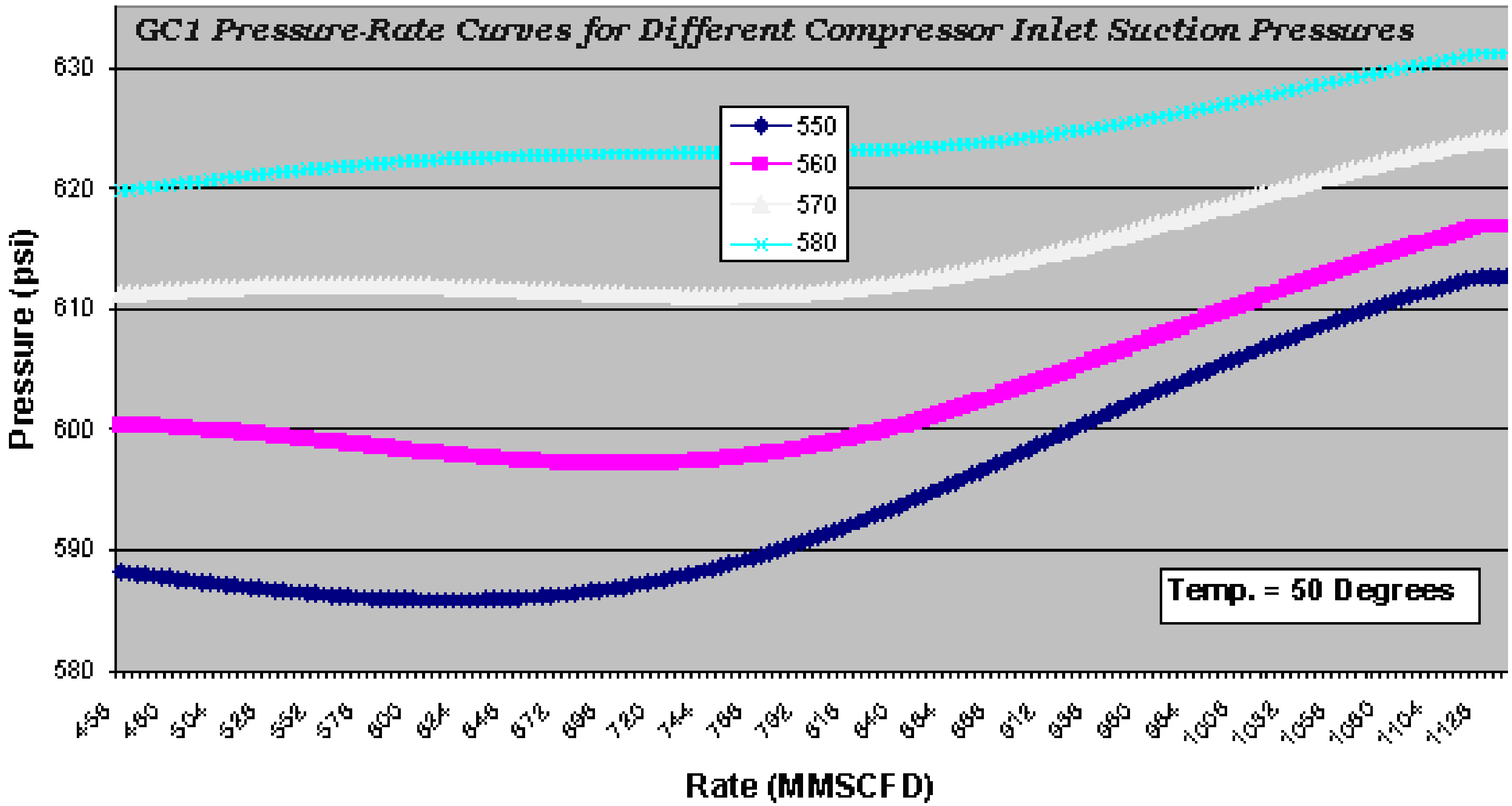

METHODOLOGY

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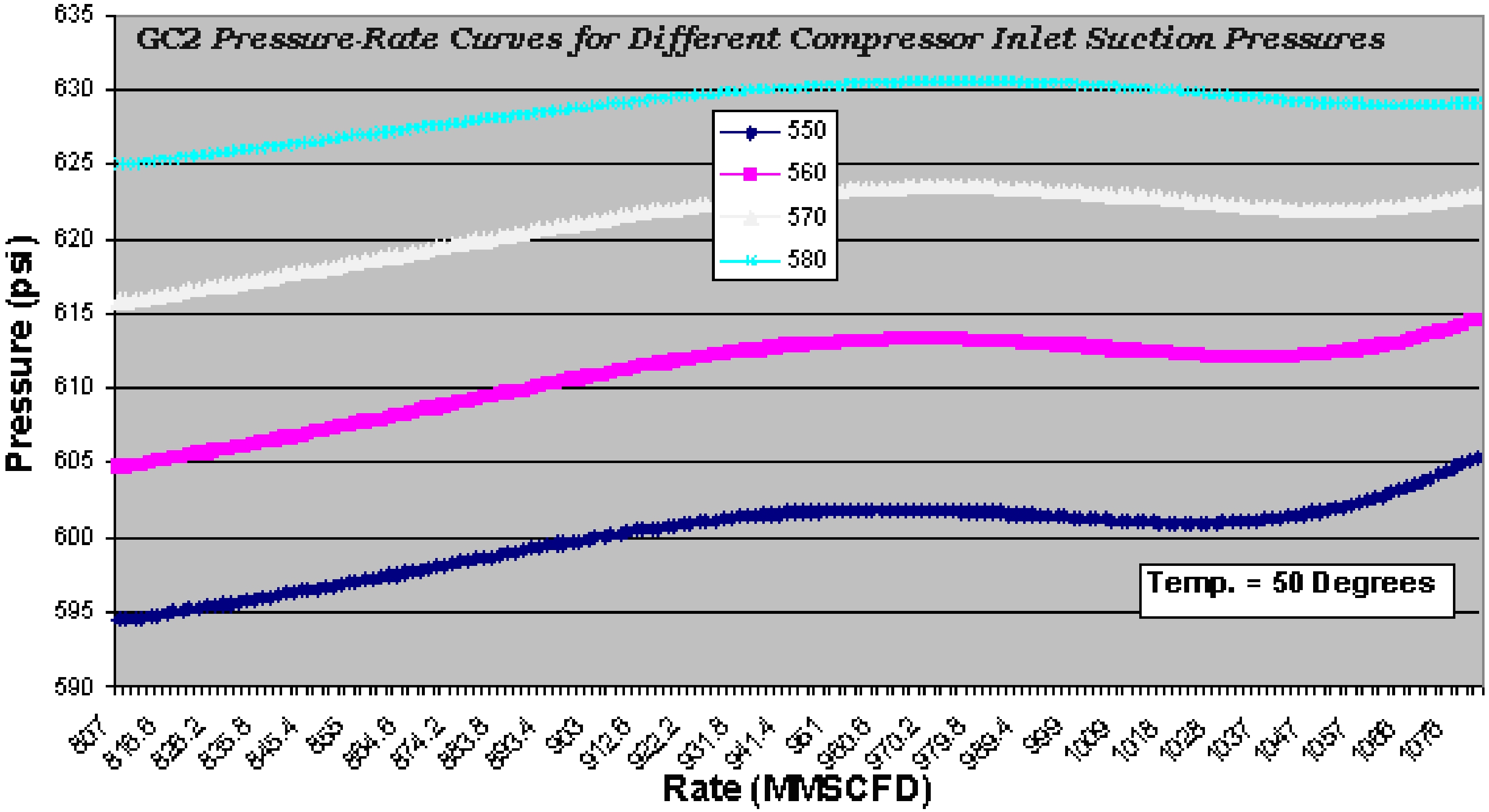

METHODOLOGY

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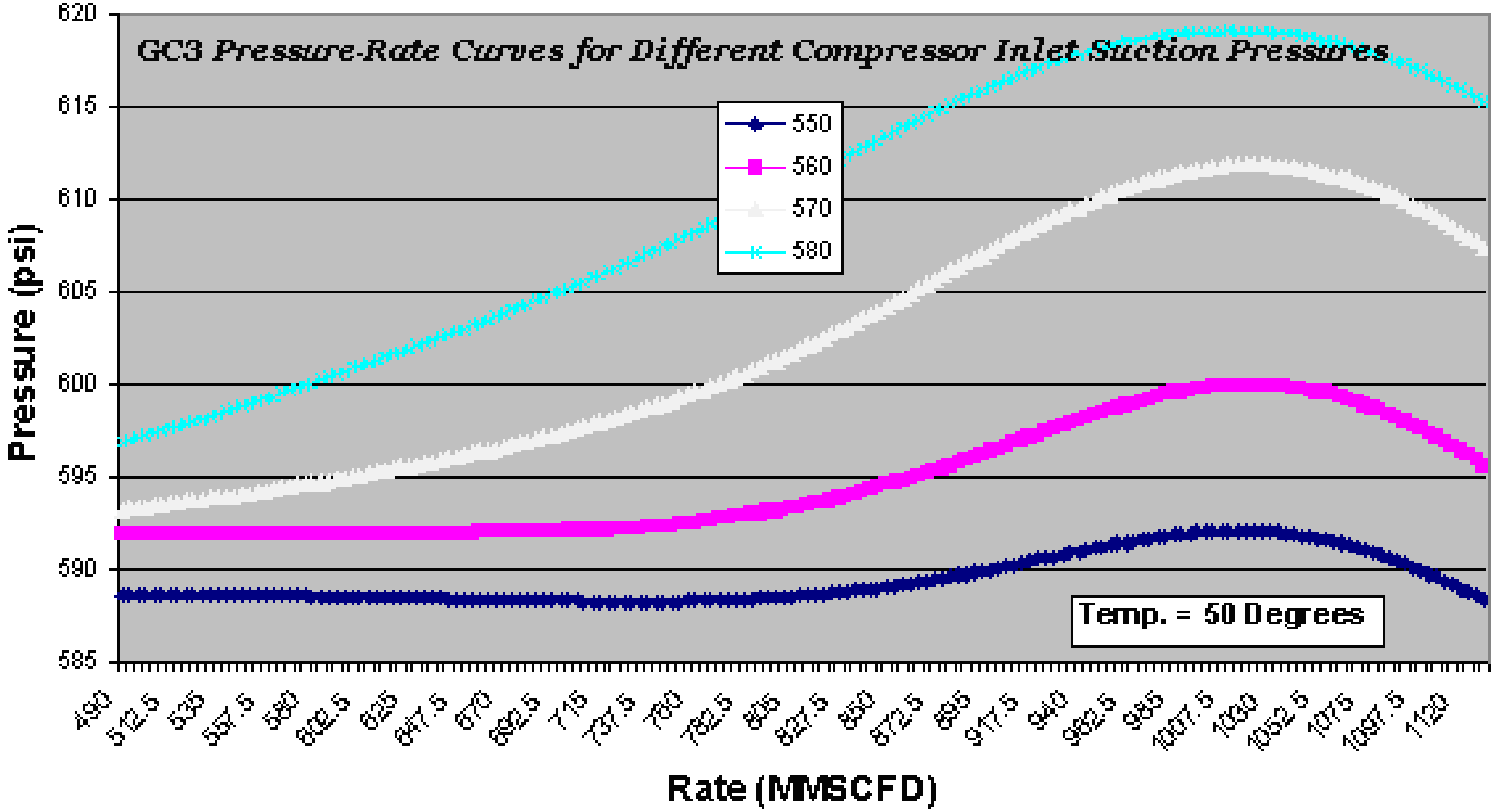

METHODOLOGY

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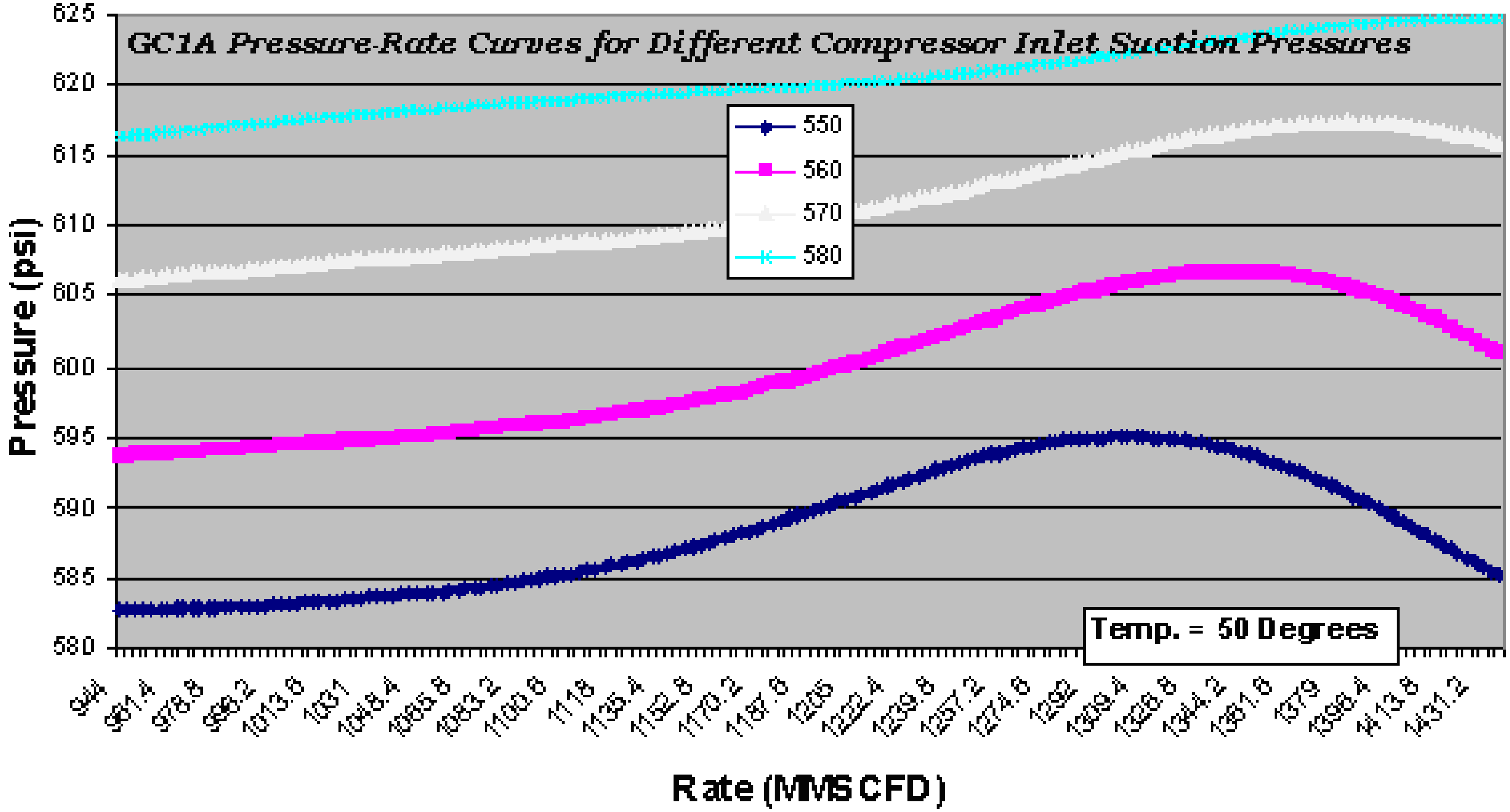

CONCLUSIONS

- 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.

ACKNOLEDGEMENT

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