Herrick Laboratories
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Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

A Comprehensive Evaluation of Regression Uncertainty and the Effect of Sample Size on the AHRI-540 Method of Compressor Performance Representation

Optimized Thermal SYSTEMS

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- AHRI Project 8013 Committee Members
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Agenda

- Background and Goals
- Compressor Data
- Uncertainty Analysis
- Method of Representation and Sampling
- Conclusions

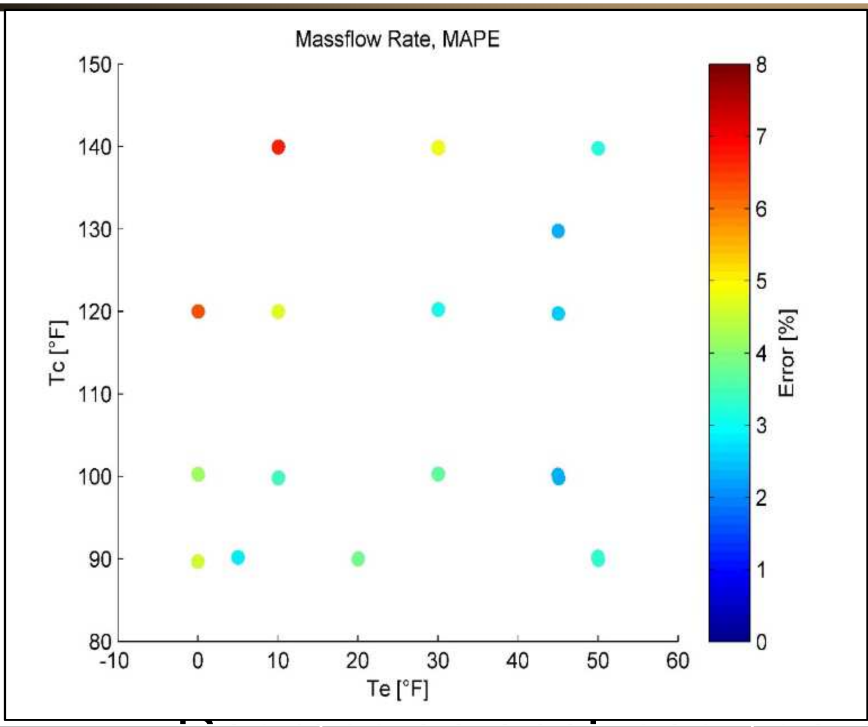
Background

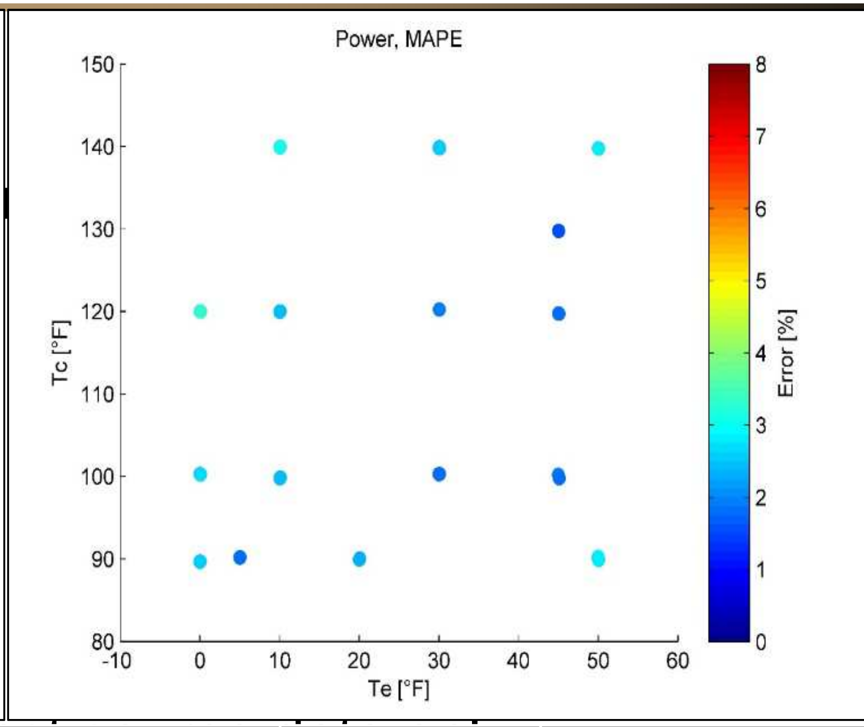
- Background
  - » AHRI Standard 540 (2015)
  - » Data for positive displacement compressors represented in tabular format, 10-coefficient third order polynomial equation
  - » Coefficients derived from measured and/or extrapolated values using “Least Squares”
- Goals
  - » To assess current approach and determine the optimal method to represent performance data
  - » Develop an estimate of the level of uncertainty

Compressor Data

Compressor Type	Application	Refrigerant	Capacity [Btu/hr]	# of Data Sets	# of units/ Model
Reciprocating	A/C & HP	R410A	2,285 – 65,099	9	2-3
Reciprocating	A/C & HP	R22	5,075 – 36,079	2	3
Reciprocating	Medium Temp	R404A	1,825 – 13,483	2	1
Reciprocating	High Temp	R134A	2,930 – 12,740	1	1
Reciprocating	High Temp	R407C	5,610 – 40,900	1	1
Scroll	A/C & HP	R410A	6,013-776,125	8	1
Scroll	Low Temp	R404A	4845-19970	1	1
Rotary	A/C & HP	R410A	3840-44430	2	1
Rotary	A/C & HP	R134A	1525-18595	2	1
Rotary	A/C & HP	R407C	4815-20850	1	1
Total Complete Data Sets Available for Analysis:				29	

Uncertainty Analysis

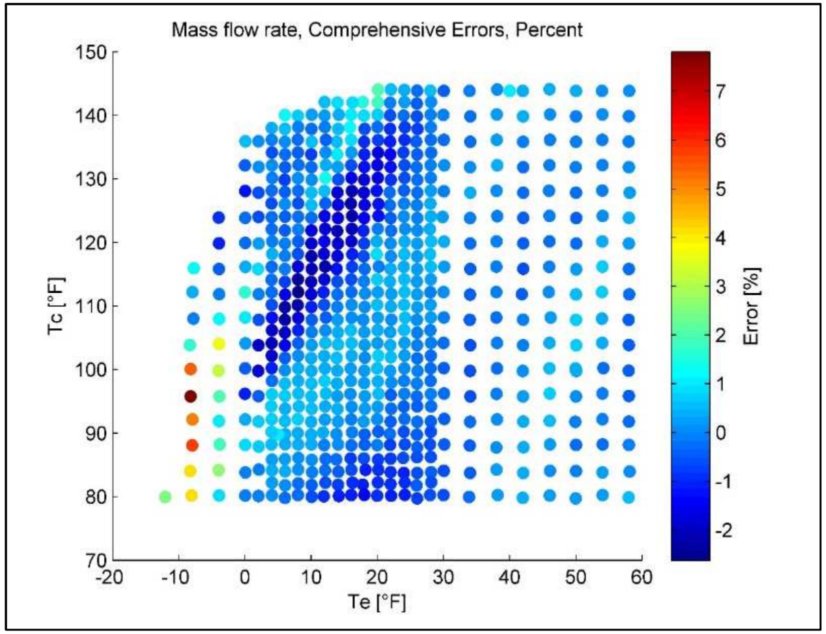


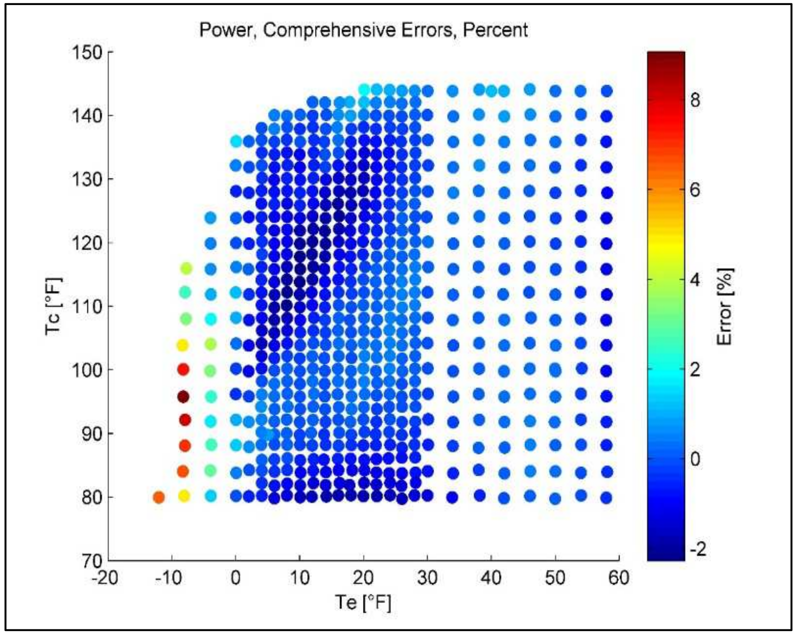


	Minimum Absolute Error in Predicted Mean	Maximum Error in Predicted Mean	Maximum COV	Worst Case Maximum Absolute Error
Power	0.2%	5%	1.7%	9%
Mass Flow Rate	0.4%	4.3%	3.5%	17%

AHRI 540 Analysis

- Map data (16 points) used to fit the 10-coefficient polynomial
- Verification data (600+ points) measured at finer increments over entire envelope





AHRI 540 Analysis Summary

	Map Generation Data	Verification Test Data
Points	16	611
Power AAPE	0.153	0.684
Power MAPE	0.492	9.068
Power RRMSE	0.00193	0.01160
Mass flow AAPE	0.312	0.595
Mass flow MAPE	0.6777	7.812
Mass flow RRMSE	0.004	0.009

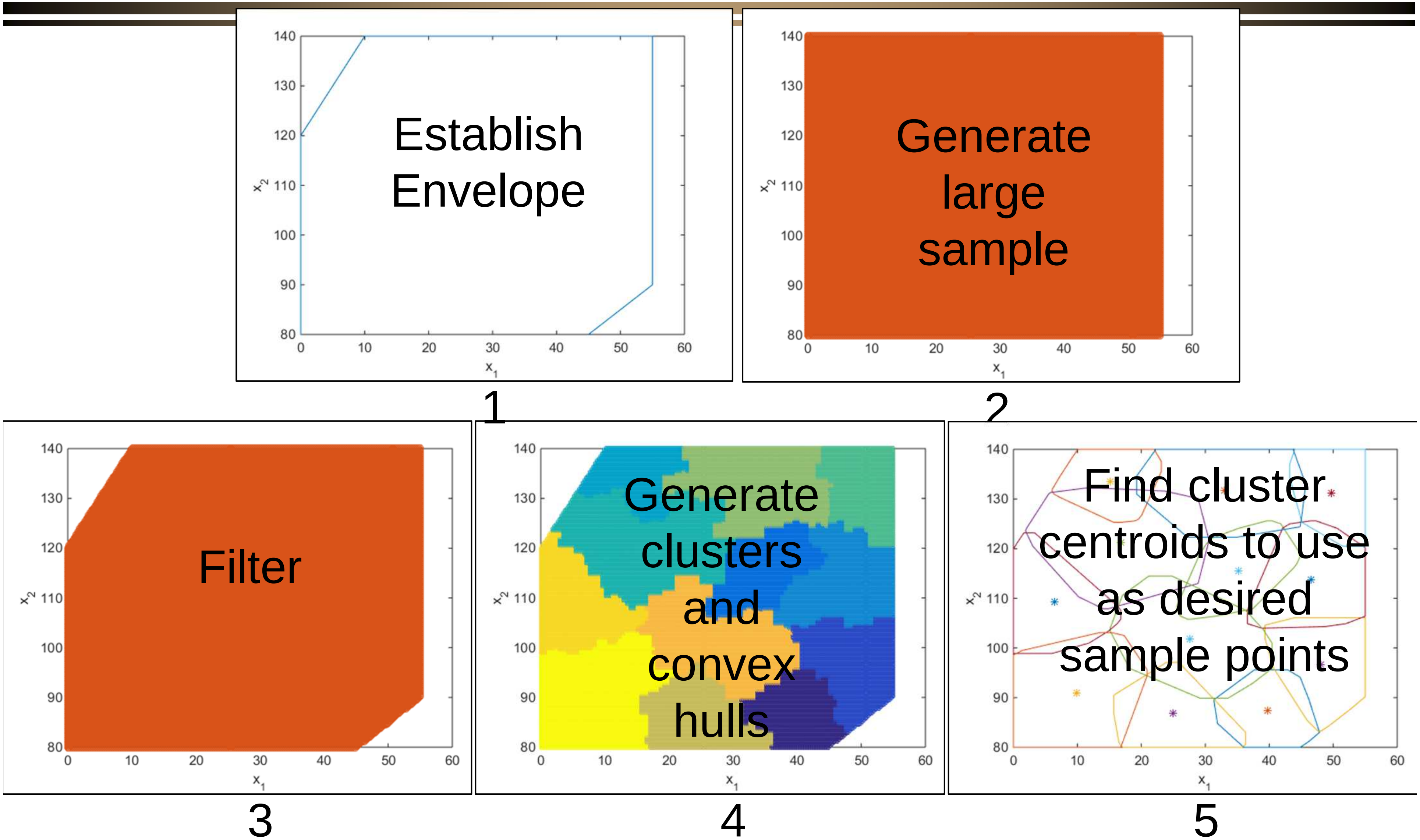
- Map predicts source data within ±0.5%
- Highest errors in third quadrant (low suction / discharge dew point temps.)
- Regions with error >1% have insufficient data points → guide future testing sampling plans

- AAPE: Average Absolute Percent Error
- MAPE: Maximum Absolute Percent Error
- RRMSE: Relative Root Mean Square Error (RMSE, but normalized with actual value)

Sampling Analysis

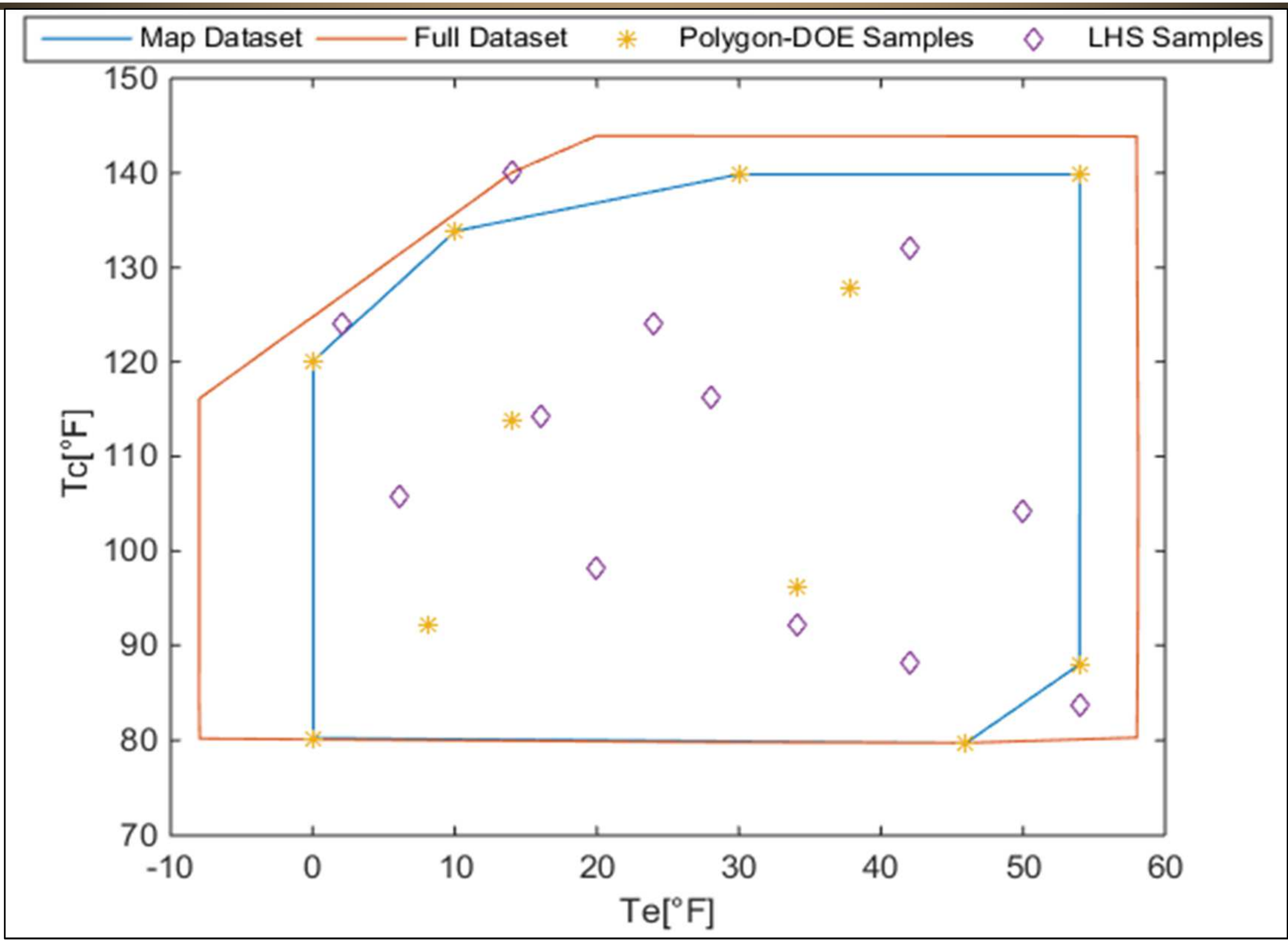
- Goal: Analyze various sampling techniques and methods of representation to find the best combination
- Sampling Methods
  » Latin Hypercube Sampling (LHS)
  » Polygon DOE (PDOE)
- Methods of representation
  » AHRI 540
  » 3 Alternatives (discussed shortly)

PDOE Sampling Method*



*approach originally proposed by Lekivetz and Jones (2014)

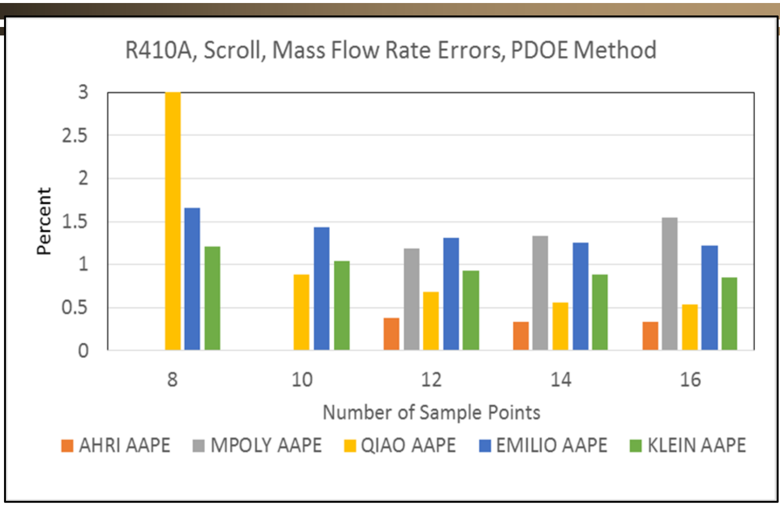
Comparison of Samples

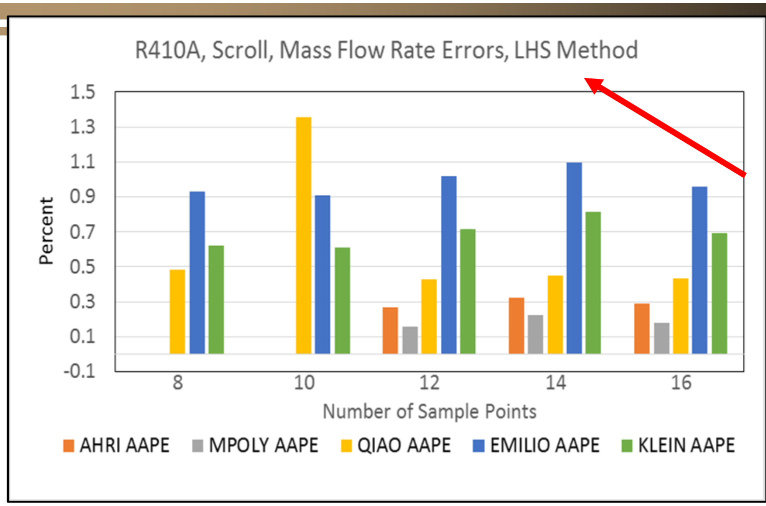


Alternative Methods

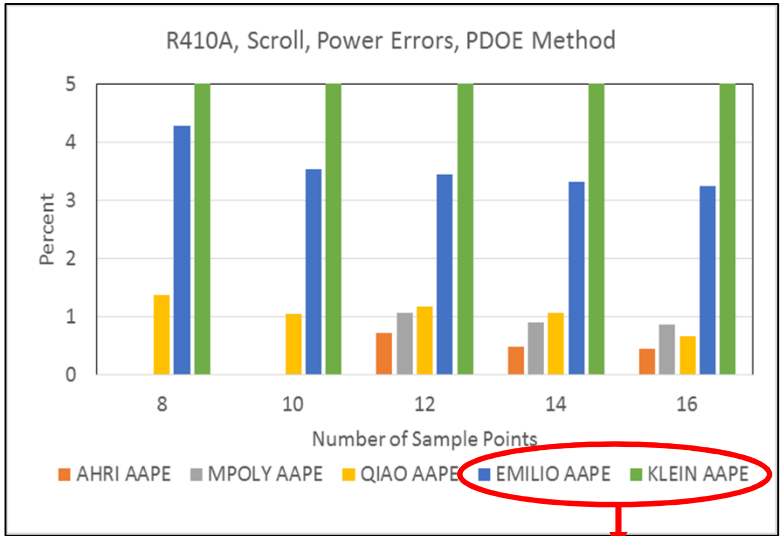
Model/Method	Min. # of Data Points Needed	Regression Type	Comments
AHRI540 (baseline)	11	Linear	Easy to solve, no guess values
MPOLY	11	Linear	Variation of the AHRI-540 method; easy to solve, no guess values required
QIAO (Qiao et al.)	7	Mixed	Requires guess values; capable of handling variable speed, with 19 points
KLEIN (Jahnig et al.)	6	Non-linear	Most comprehensive and popular model from literature; requires guess values
EMILIO (Navarro et al.,)	6	Non-linear	Can handle superheat; requires guess values

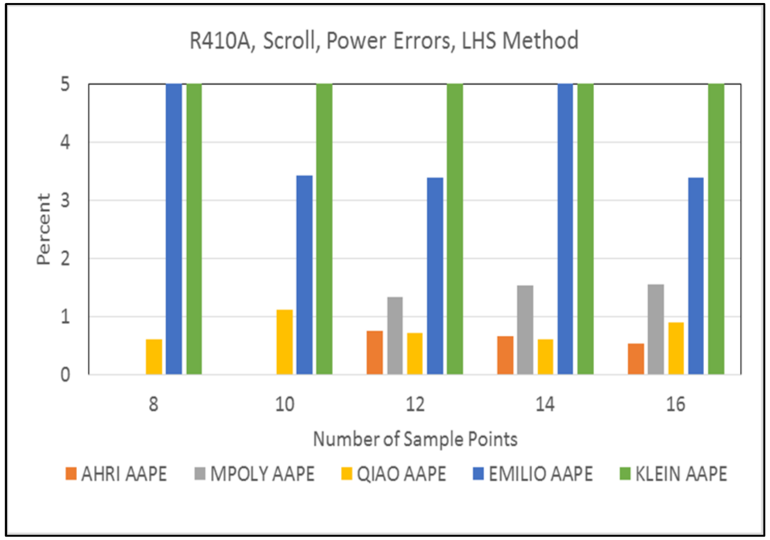
Sample Analysis for Select Methods





Generally better for mass flow rate





Unacceptably high errors in power, regardless of sampling method

Conclusions – 1

- Manufacturer's survey indicated that >14 points tested, typically for 3+ compressor units
- Largest sources of uncertainty from measurement and regression during model development
  - » Average uncertainty as high as 5% for power and 4% for mass flow rate
  - » Highest errors occur in region with low suction and discharge dew point temperatures
- Comprehensive analysis shows that AHRI-540 method predicts mass flow rate and power within 1% (errors of 9% in extrapolated regions)

Conclusions – 2

- Analysis of various methods showed that
  - » Average errors in predicting mass flow rate < 2%; power < 4%, for AHRI-540 and 2 other methods
  - » Linearly regressed models have better performance
- Opportunities exist to reduce the number of test samples
- Future Work: It is possible to develop a model with 16 samples that would handle superheat correction as well, comprehensive test data required

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Thank You!

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