CARBOB Model

Western States Petroleum Association

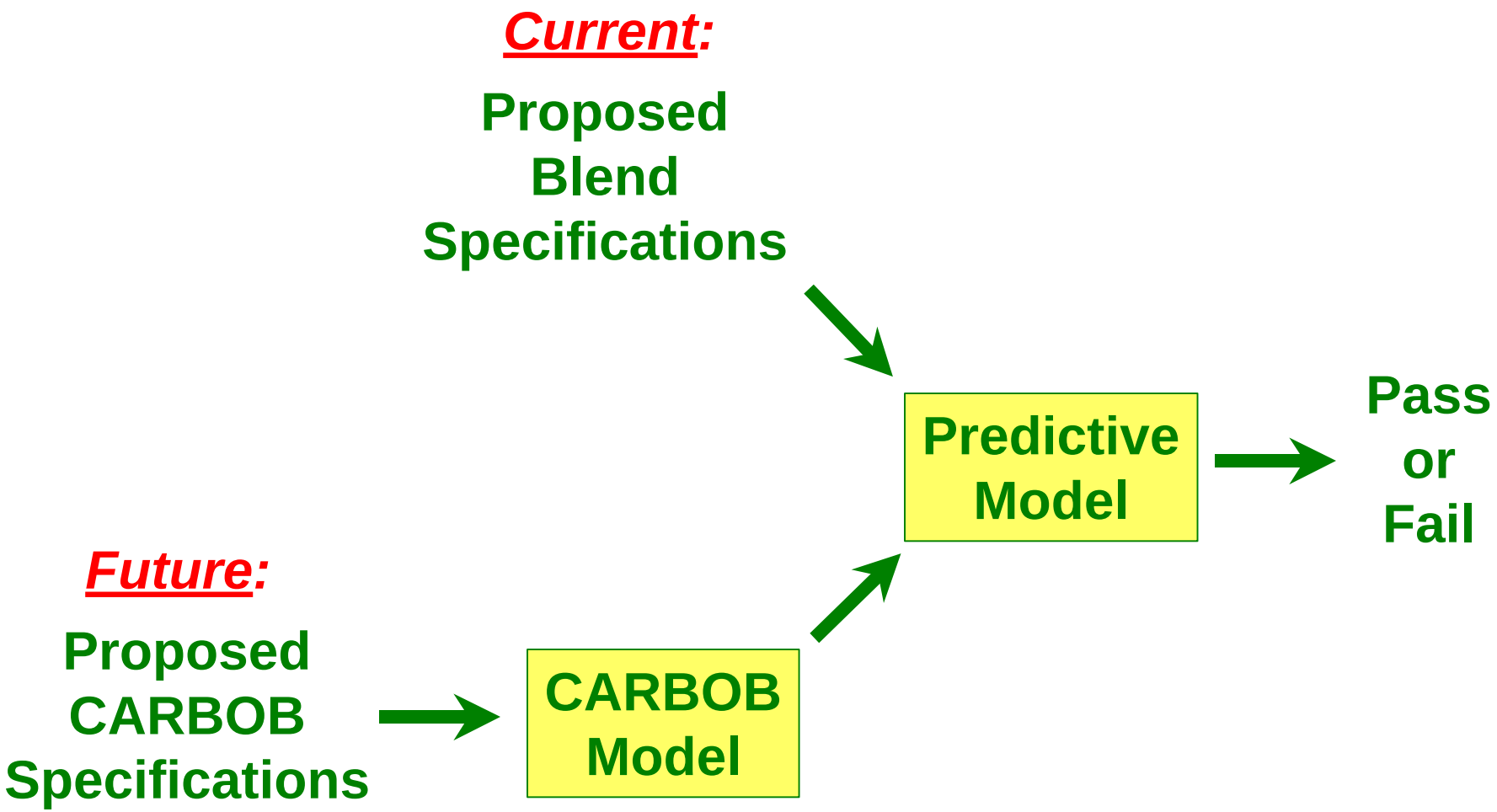
July 25, 2000

Why A CARBOB Model?

- Current Regulations (2266.5) Require CARBOB To Be Hand Blended With Ethanol Before Testing
- CARBOB Model:
  - Provides An Alternative To Hand Blending
  - Is Compatible With In-Line Analyzers
  - Streamlines Enforcement

CARBOB Model

- Front End To Predictive Model
  - Input CARBOB Specifications
  - Predict Equivalent Blended Fuel Specifications
  - Perform Emissions Calculations
- Model RVP, T_{50} And T_{90}
- Calculate Aromatics, Olefins, Sulfur, Benzene And Oxygen


Current:
Proposed
Blend
Specifications
Future:
Proposed
CARBOB
Specifications
CARBOB
Model
Predictive
Model
Pass
or
Fail

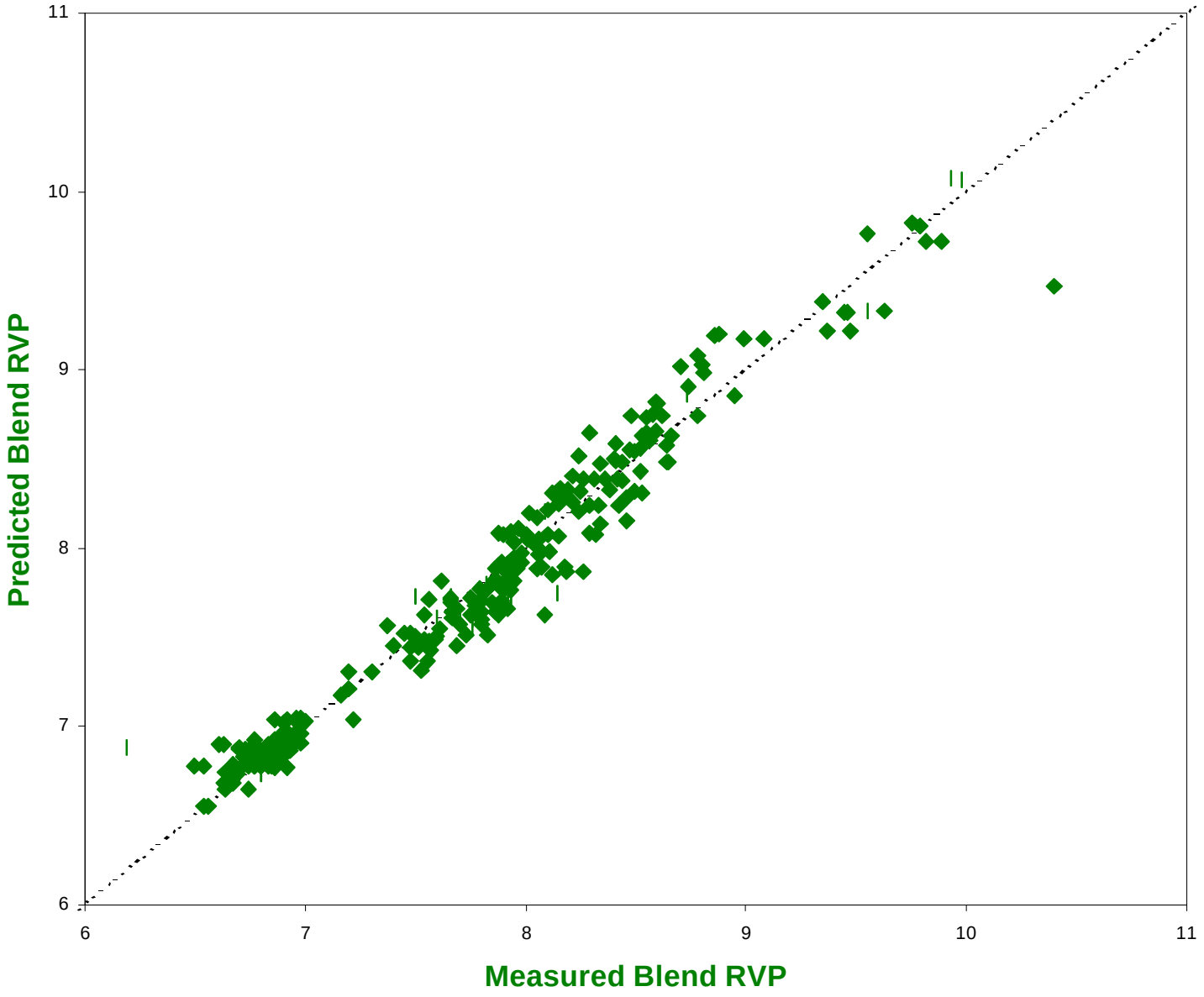
Analysis Methodology

- SAS Least Squares Multiple Regressions
  - Blended Property = *f*(Base HC Property)
  - "All Possible Subsets" Of Primary And Interaction Terms
  - True Stepwise (Forward + Backward) Elimination
- Include Only Significant Terms And Exclude Terms That Increase R^2 / Decrease RMSE By A Small Amount
- Diagnostic Plots For Checking Non-Random Patterns And Goodness-Of-Fit

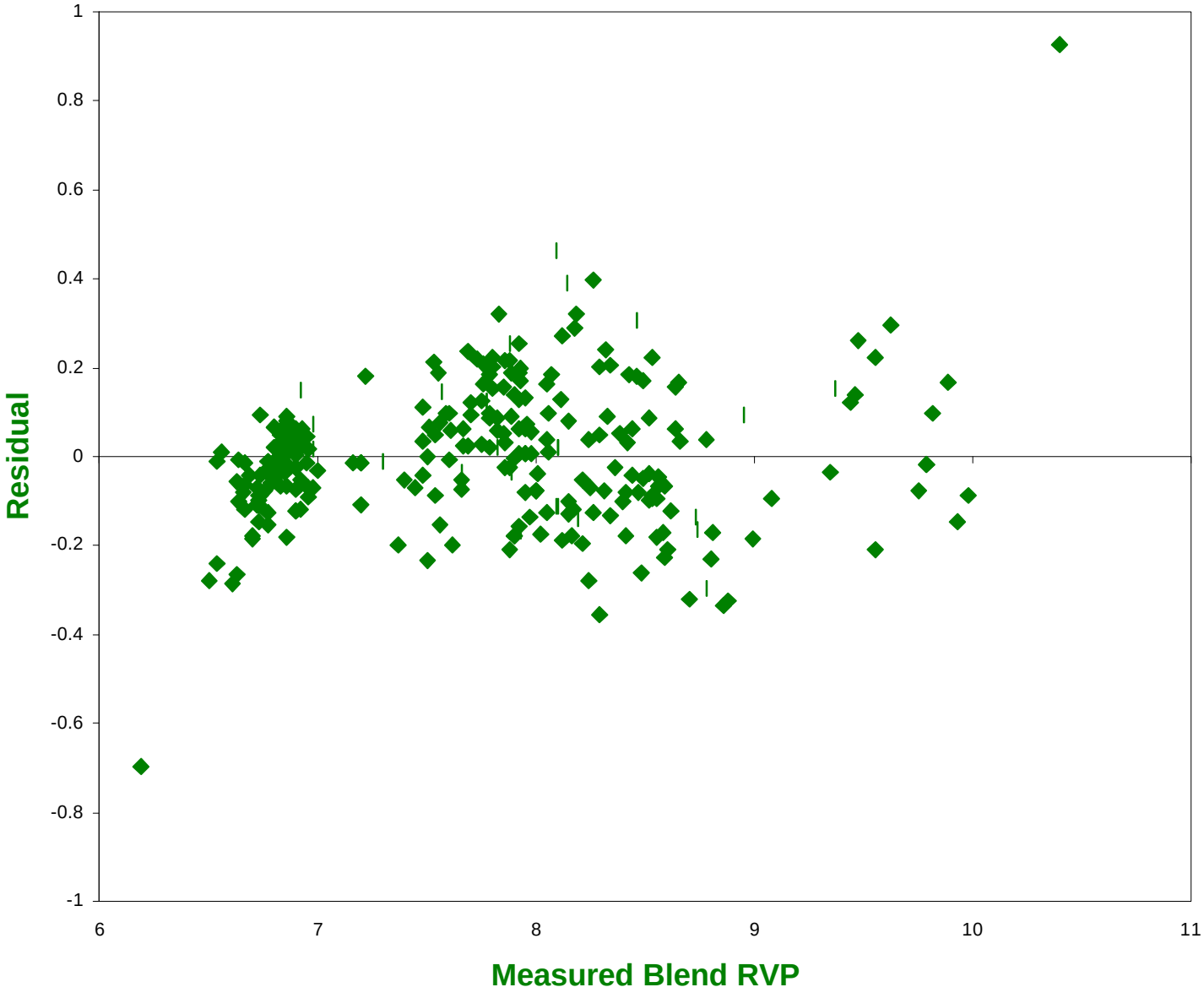
RVP Model

- Data Basis:
  - $RVP_{Base} \leq 9.0$
  - Ethanol Contents From 4% To 10%
  - 297 Observations
- $RVP_{Blend} = 1.446 + 0.961 * RVP_{Base}$
- RMSE = 0.152
- $R^2 = 0.966$

Blend RVP: Predicted vs. Actual



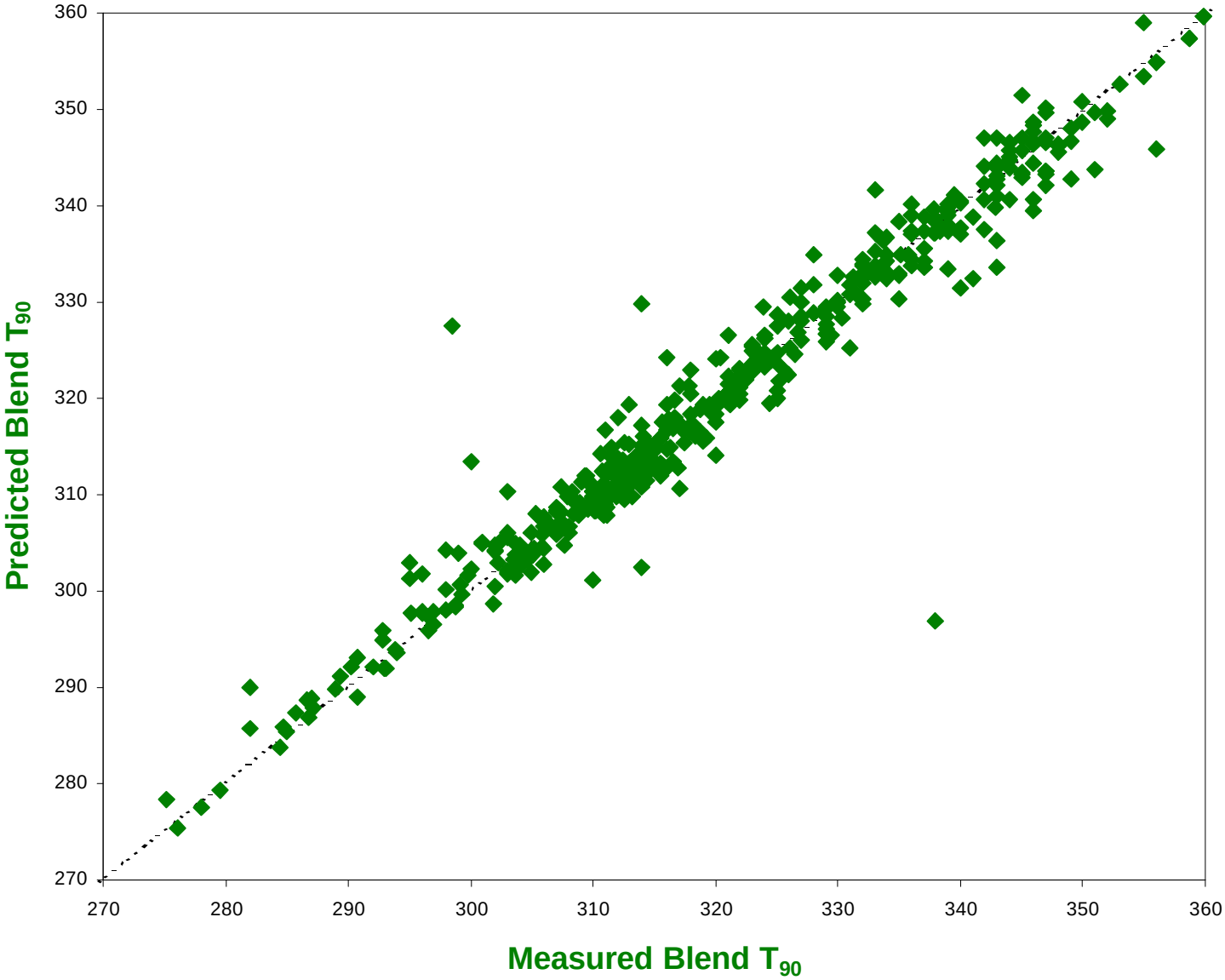
Blend RVP: Residuals



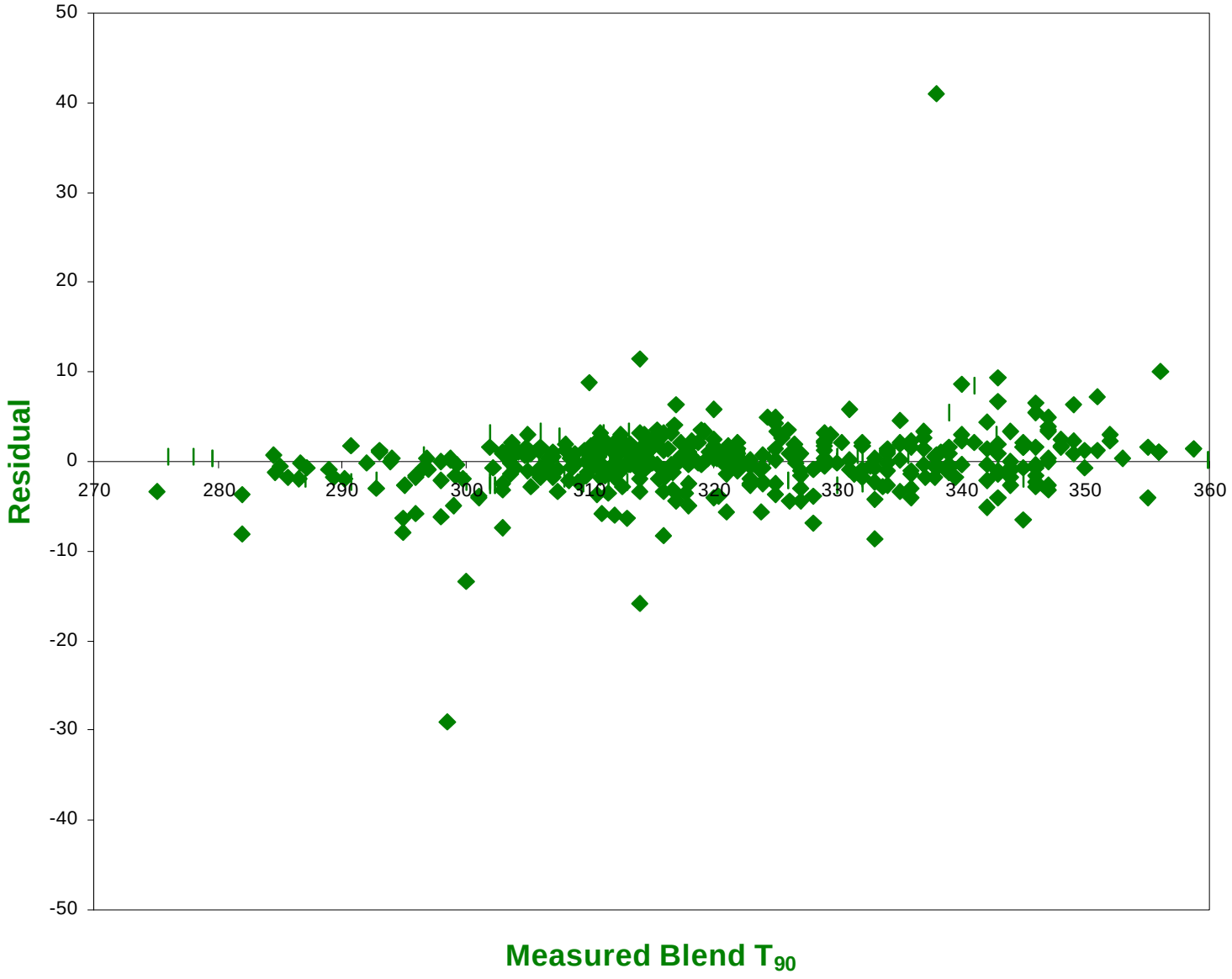
T_{90} Model

- Data Basis:
  - All Data With RVP Data (464 Observations)
- $T_{90\ Blend} = 1.493 + 0.964 * T_{90\ Base} + 0.0468 * T_{50\ Base} - 0.473 * Ethanol$
- RMSE = 3.66
- $R^2 = 0.954$

Blend T_{90}: Predicted vs. Actual

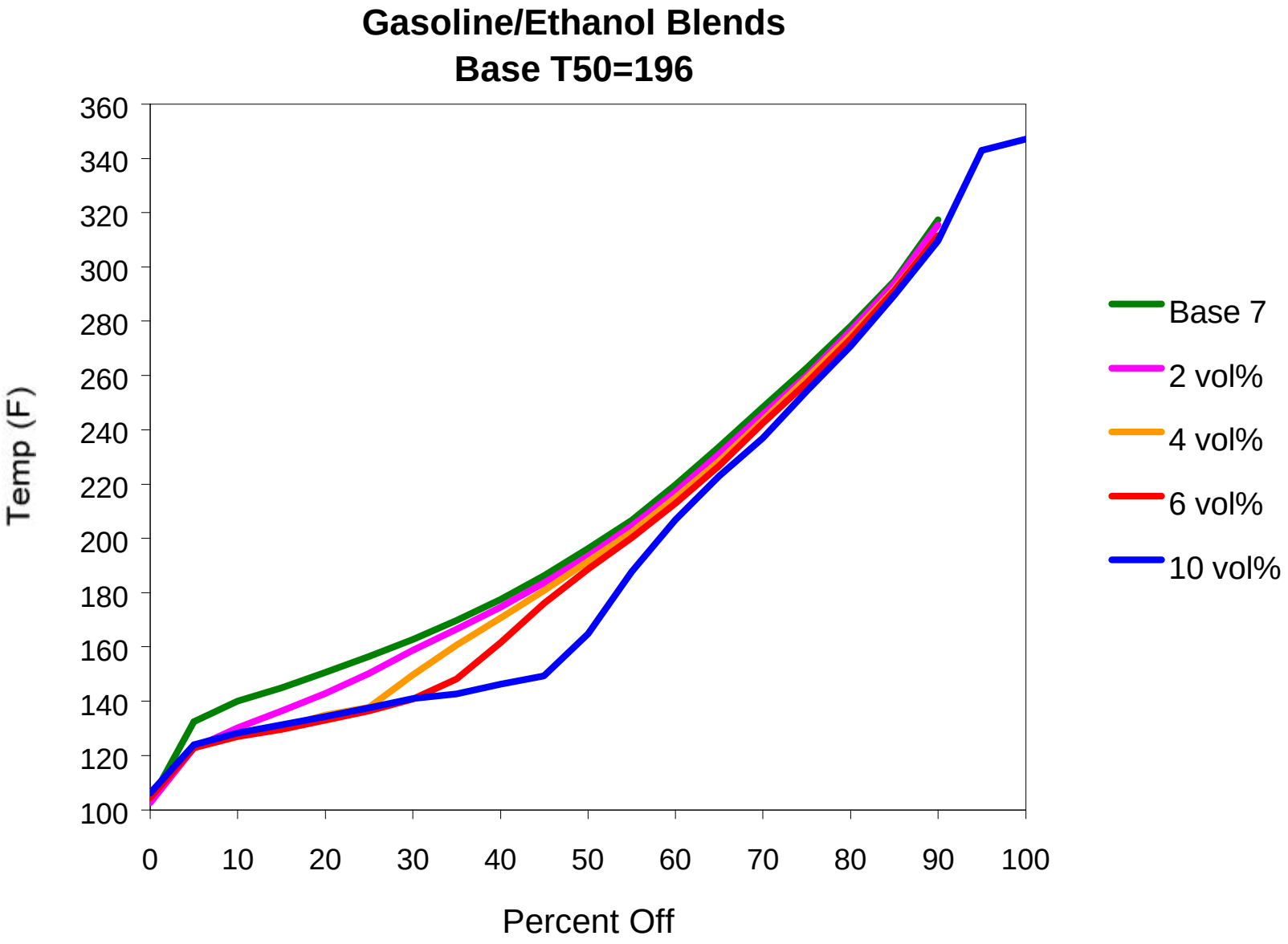


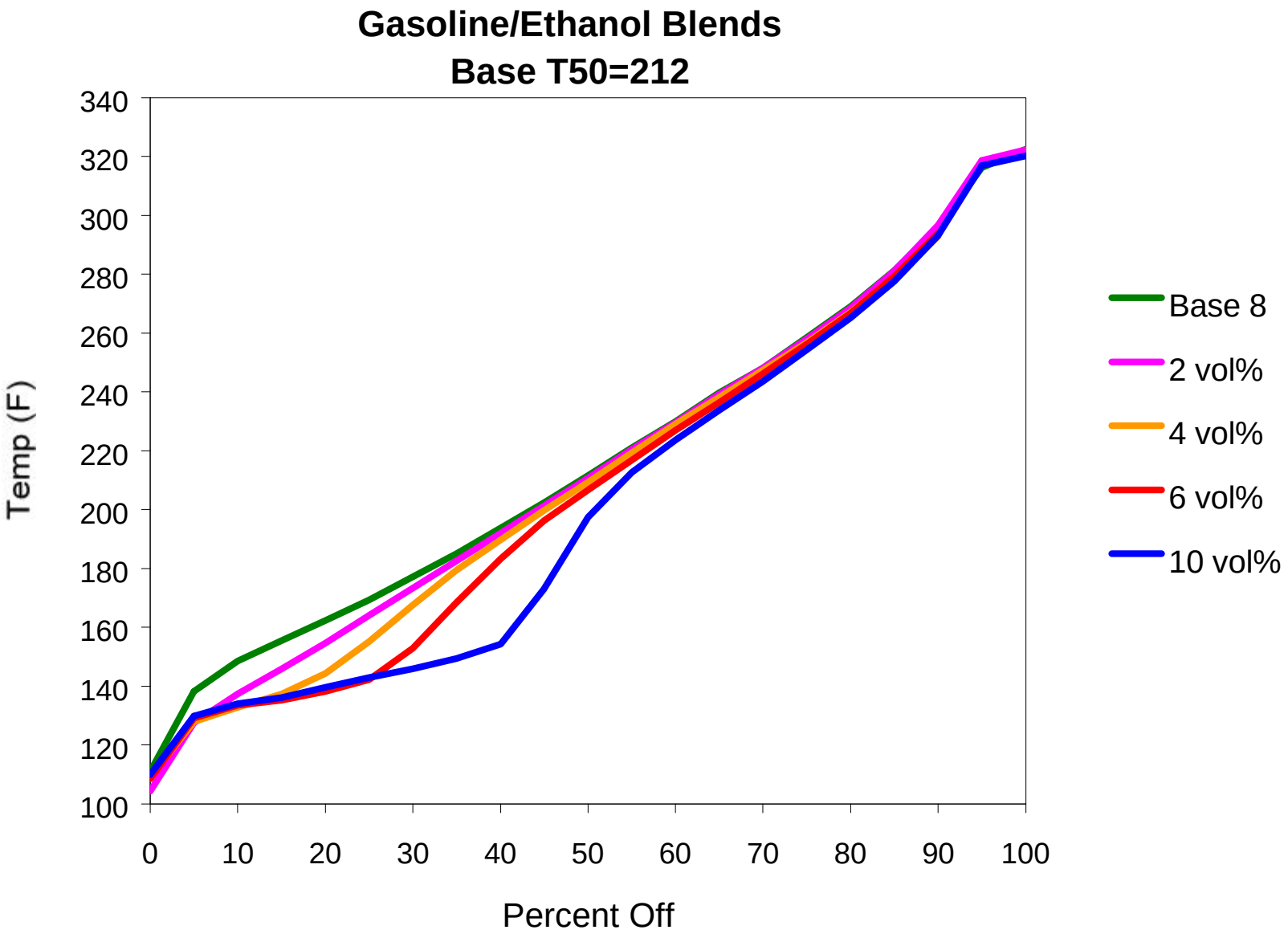
Blend T_{90}: Residuals

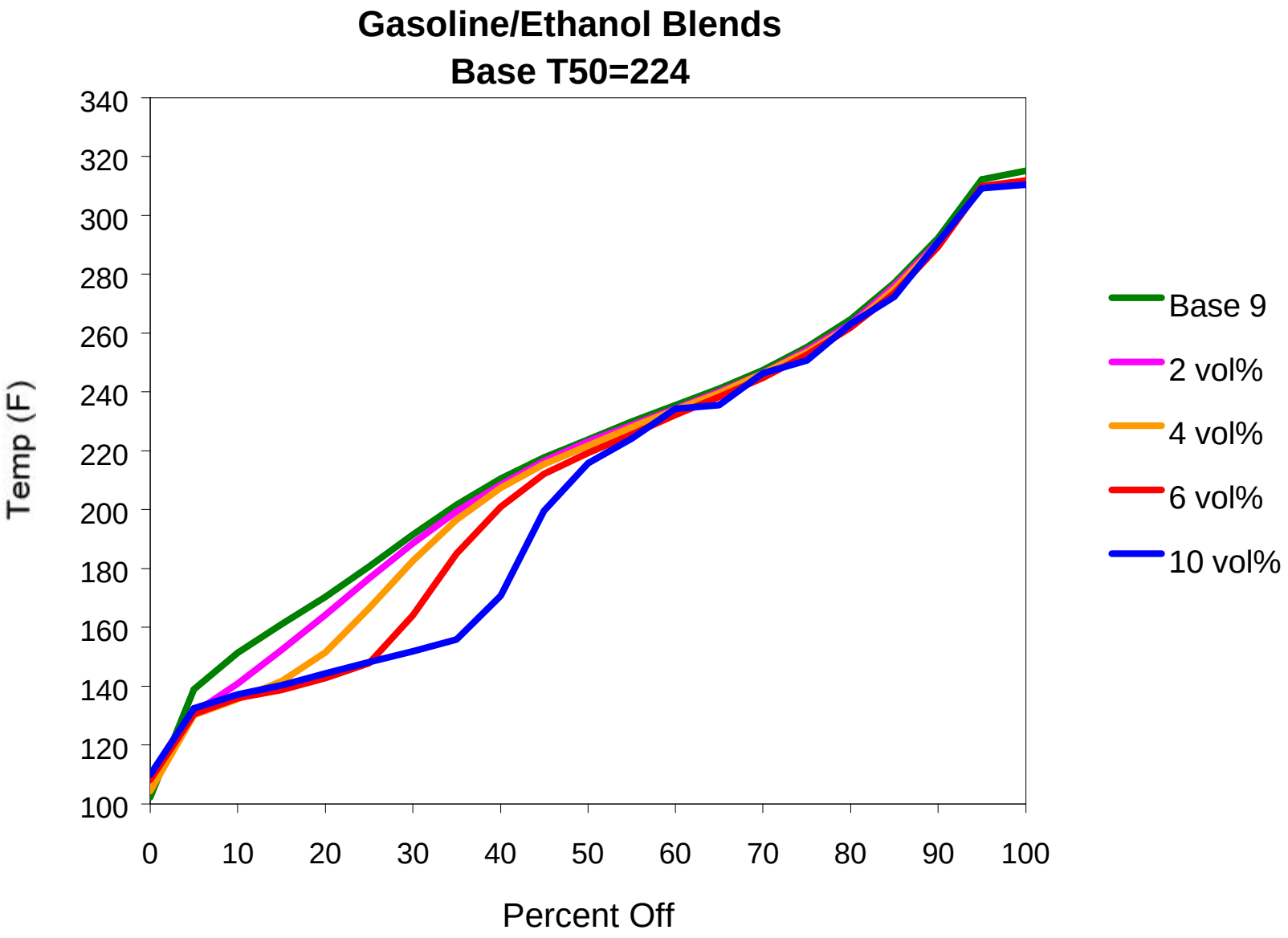


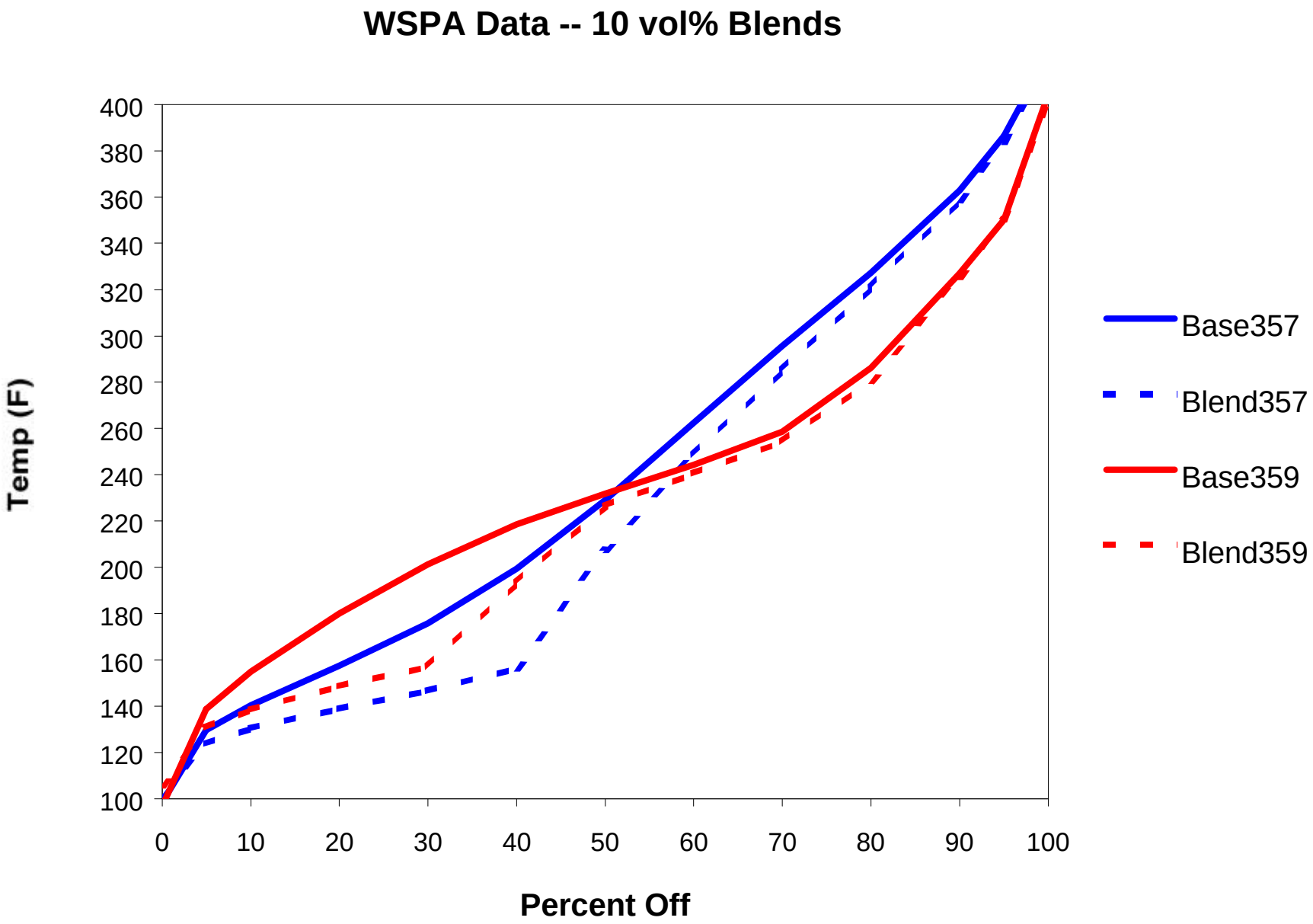
T_{50} Model

- Data Observed To Behave Differently At High And Low Ethanol Contents
- Two Model Ranges:
  - $4\% \leq EtOH < 9\%$
  - $9\% \leq EtOH \leq 10\%$


Gasoline/Ethanol Blends
Base T50=196
Temp (F)
360
340
320
300
280
260
240
220
200
180
160
140
120
100
0
10
20
30
40
50
60
70
80
90
100
Percent Off
Base 7
2 vol%
4 vol%
6 vol%
10 vol%


Gasoline/Ethanol Blends
Base T50=212
Temp (F)
340
320
300
280
260
240
220
200
180
160
140
120
100
0
10
20
30
40
50
60
70
80
90
100
Percent Off
Base 8
2 vol%
4 vol%
6 vol%
10 vol%


Gasoline/Ethanol Blends
Base T50=224
Temp (F)
340
320
300
280
260
240
220
200
180
160
140
120
100
0
10
20
30
40
50
60
70
80
90
100
Percent Off
Base 9
2 vol%
4 vol%
6 vol%
10 vol%


WSPA Data -- 10 vol% Blends
Temp (F)
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
0
10
20
30
40
50
60
70
80
90
100
Percent Off
Base357
Blend357
Base359
Blend359

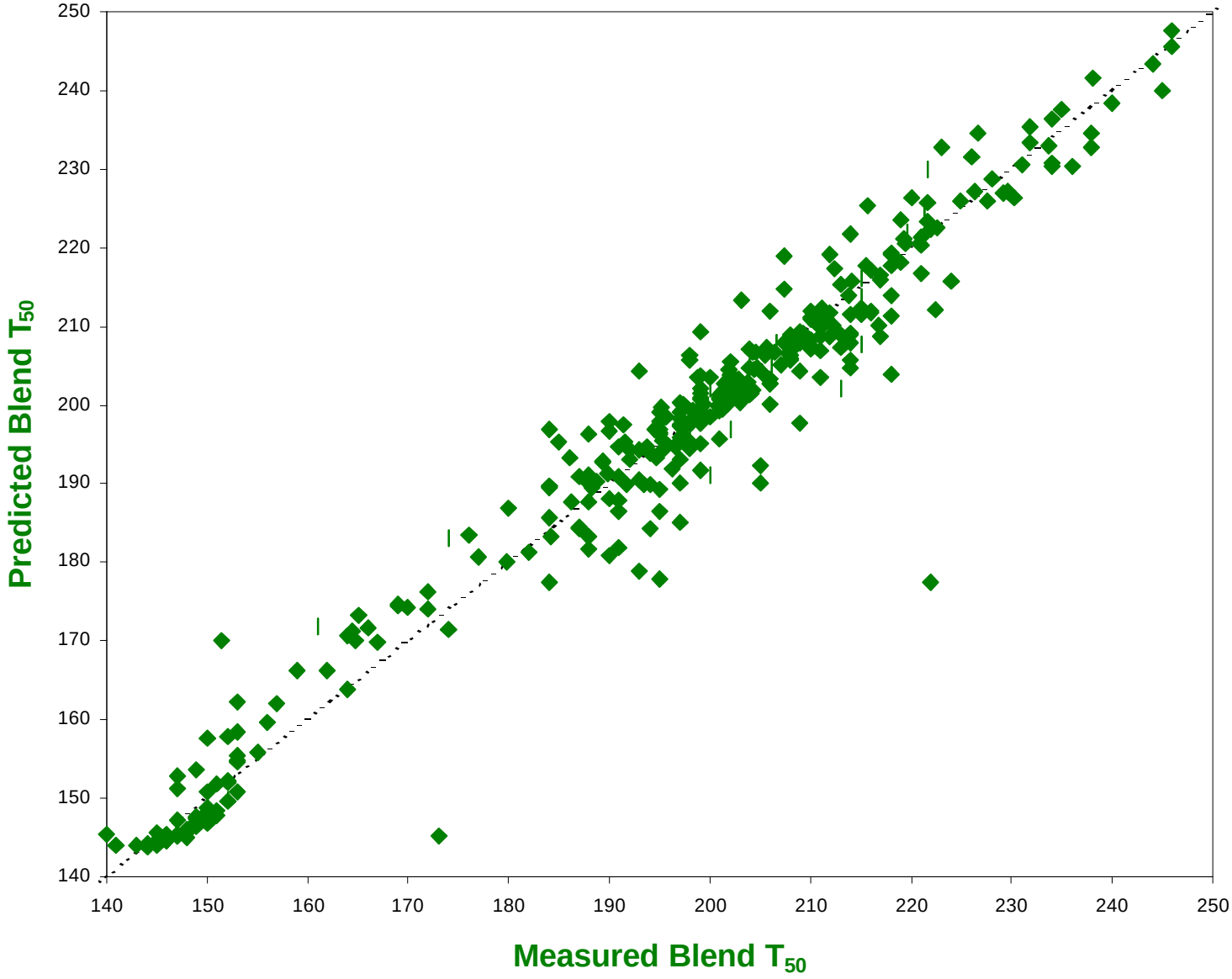
T_{50} Model - 4% ≤ EtOH < 9%

- Data Basis:
  - 242 Observations
- $T_{50\ Blend} = 21.930 + 14.875*EtOH - 10.238*RVP_{Base} + 0.6720*T_{50\ Base} + 0.02579*T_{90\ Base} - 0.8313*EtOH^2 - 0.3103*RVP_{Base}*EtOH + 0.06623*T_{50\ Base}*EtOH - 0.05519*T_{90\ Base}*EtOH + 0.03607*RVP_{Base}*T_{90\ Base}$
- RMSE = 3.18
- $R^2 = 0.945$

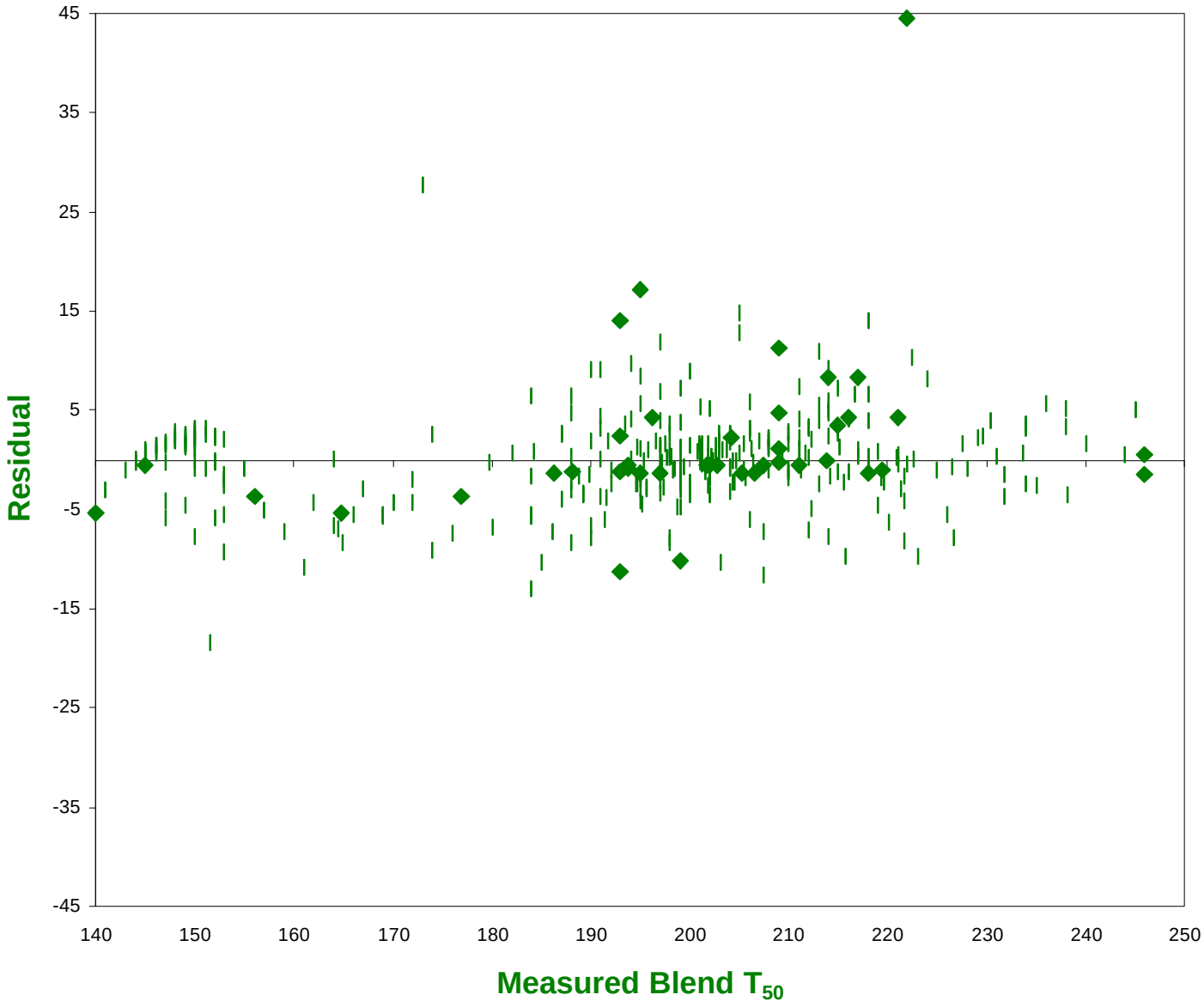
T_{50} Model - 9% ≤ EtOH ≤ 10%

- Data Basis:
  - 188 Observations
  - 2 Outliers Removed
  - EtOH Content Excluded From Terms
- $T_{50\ Blend} = 559.276 - 0.5431*RVP_{Base} - 4.1884*T_{50\ Base} - 0.3957*T_{90\ Base} + 0.01482*T50^2 - 0.05309*T_{50}*RVP_{Base} + 0.02884*T90*RVP_{Base}$
- RMSE = 5.82
- $R^2 = 0.954$

Blend T_{50}: Predicted vs. Actual



Blend T_{50}: Residuals



Summary

- Have Developed Workable Models
- Work Will Continue To Improve Models