April 26, 2006

Report on Nebraska Retail Fuel Dispenser Data
Submitted by Henry Oppermann

Introduction

The Nebraska Weights and Measures Bureau (W&M) tested retail fuel dispensers over a period of more than one year (November 2004 through February 2006. This effort provides unique and valuable data on the performance of retail fuel dispensers. The objectives included examining the variability of test results for different test drafts and to examine how these results varied over a period of more than one year.

Nebraska W&M tested five different dispensers in three different stations using the different products listed below.

Location; Dispenser Number	Product	Dispenser Manufacturer
Omaha, NE; Unit 1	Diesel fuel	Gilbarco
Norfolk, NE, Unit 2	Unleaded gas with ethanol	Gilbarco
Norfolk, NE; Unit 3	Unleaded gas	Gilbarco
Aurora, NE; Unit 3	Unleaded gas with ethanol	Tokheim
Aurora, NE; Unit 4	Unleaded gas	Tokheim

Each dispenser was tested approximately once per week over a period of approximately one year using bottom-drain 5-gallon test measures. The time and date of each test were recorded along with the totalizer reading for the meter, the temperature of the air, and the barometric pressure as reported at the local airport. The pressure in the pumping system was also recorded.

- Three 5-gallon wet-down tests were conducted to equalize the temperature of the product throughout the dispensing system. The meter errors for each wet-down test were recorded. The temperature of the fuel in the dispenser was measured and recorded for the first wet-down test.
- Three fast-flow tests were conducted and the meter errors recorded. The temperature of the fuel in the test measure was measured and recorded for the third fast-flow test.
- Three slow-flow tests were conducted and the meter errors recorded.

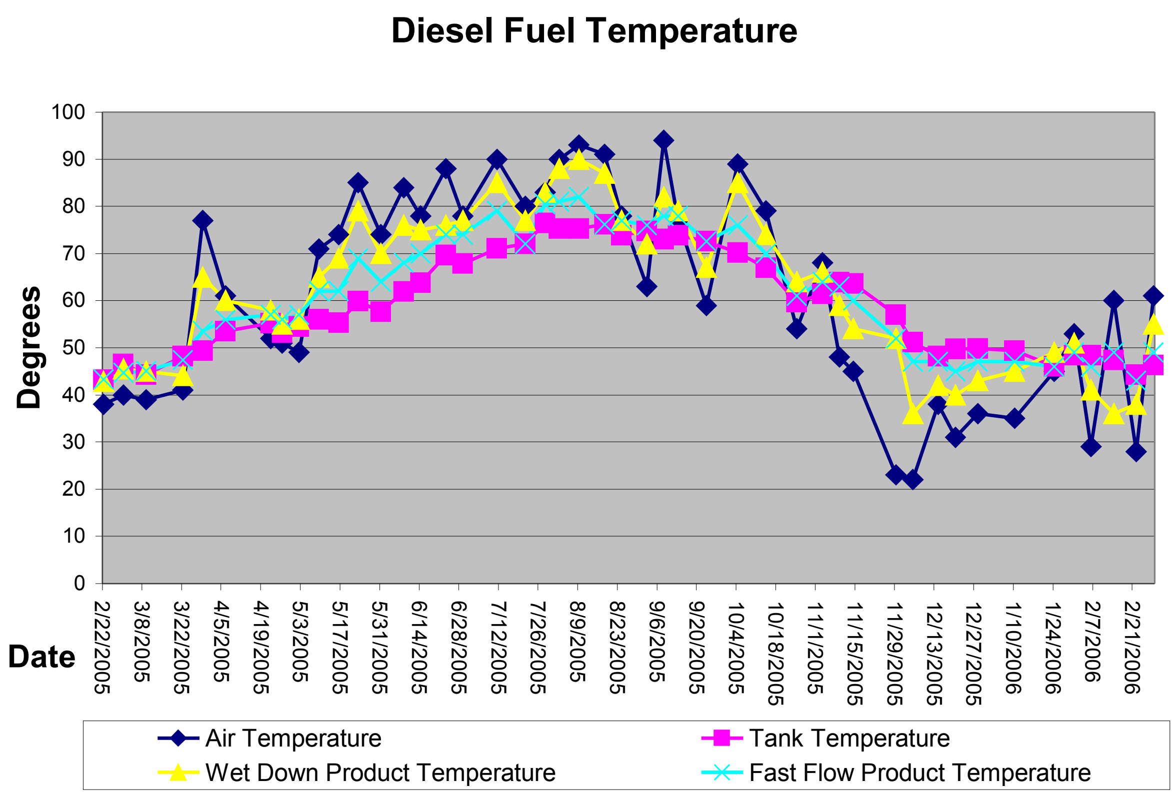
The following subjects will be addressed in this report.

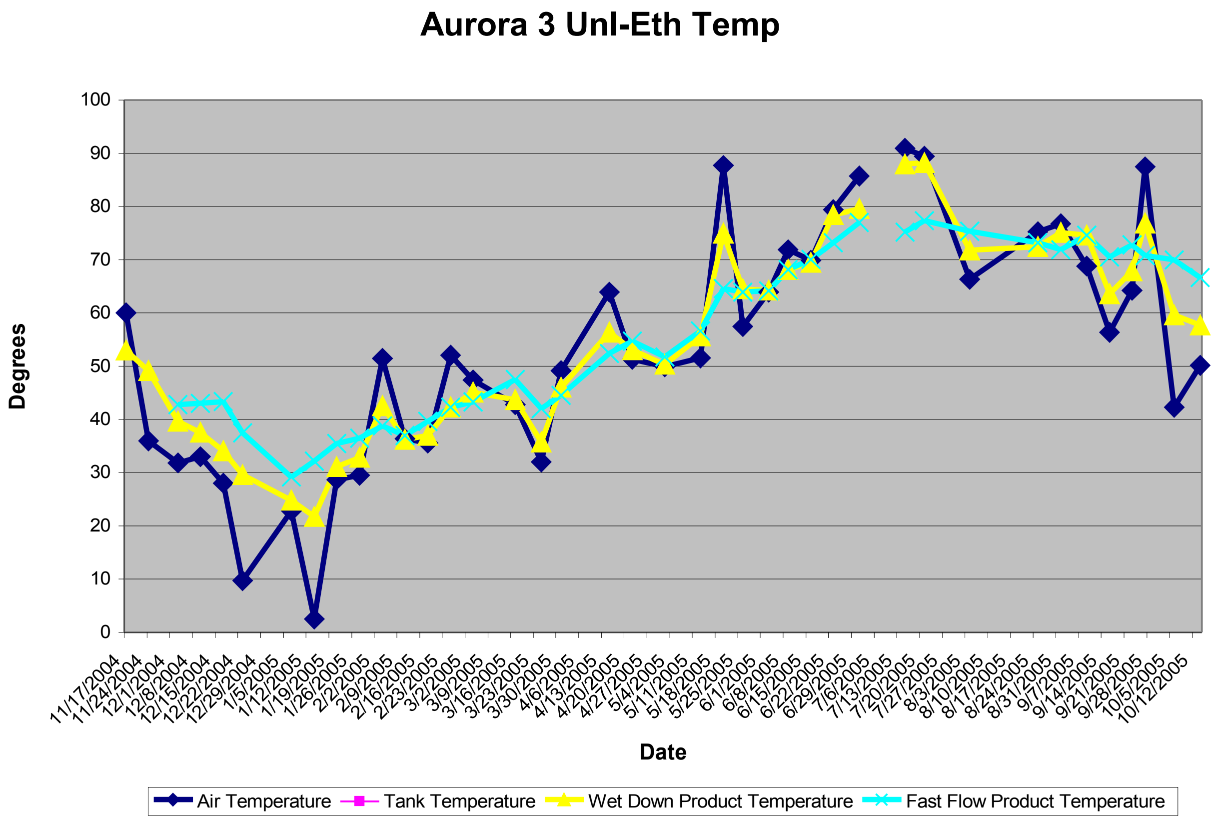
1. The test results for a fuel dispenser can vary significantly if the temperature of the dispenser delivery system is not equalized before conducting the accuracy test.
2. The accuracy of the dispenser meters varied slightly with the changes in the temperature of the product being measured.
3. There was no detectable change in the accuracy of the meters at the same temperature during the period of data collection.

1. Temperature Differences in the Delivery System

The test data show significant variations in test results in the three wet down tests compared to the three fast-flow tests and three slow-flow tests conducted immediately after the three wet-down tests. The three wet-down tests passed 15 gallons of fuel through the dispenser before the three fast-flow tests were conducted, which effectively equalized the temperature of the product in the feed lines to the dispenser, in the dispenser meter and piping inside the dispenser, in the hose of the dispenser, and in the test measure. The unequal temperatures in the dispenser delivery system often caused the test results for the wet-down tests to vary by up to several cubic inches from the fast-flow results that were conducted when the temperature of the product and meter were equalized. Variations in test results in consecutive test runs are frequently observed by weights and measures inspectors when they test dispensers. The Nebraska test data indicate the frequency and magnitude of changes in test results due to the lack of thermal equilibrium throughout the delivery system.

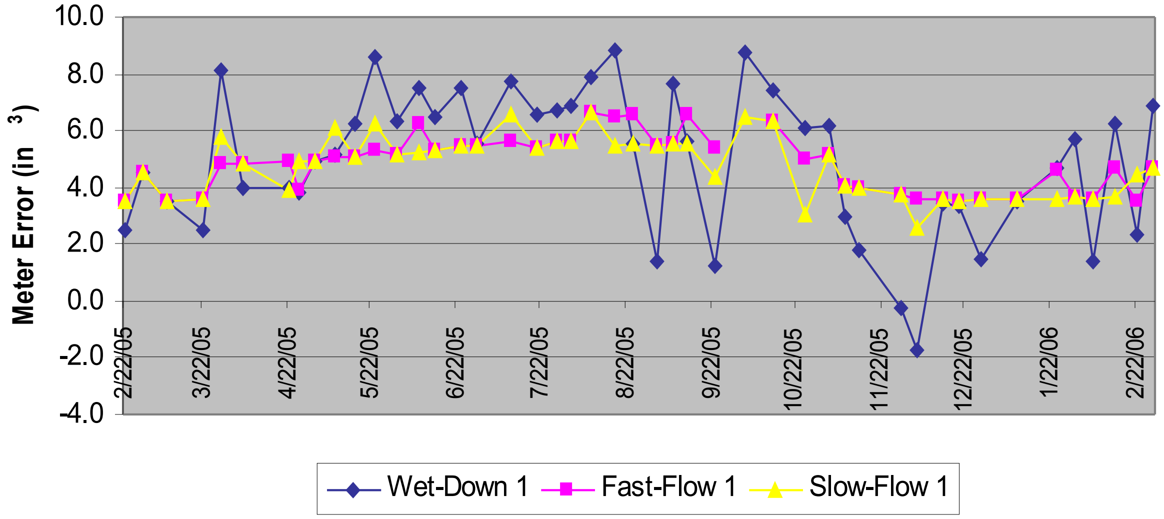
Nebraska W&M graphed the air temperature, the temperature of the product for the wet-down tests, and the temperature of the product for the fast-flow test for each meter tested. The air and and product temperatures reflect the changing of the seasons. Two graphs of the temperature data are included below to indicate the nature of the temperature cycle.



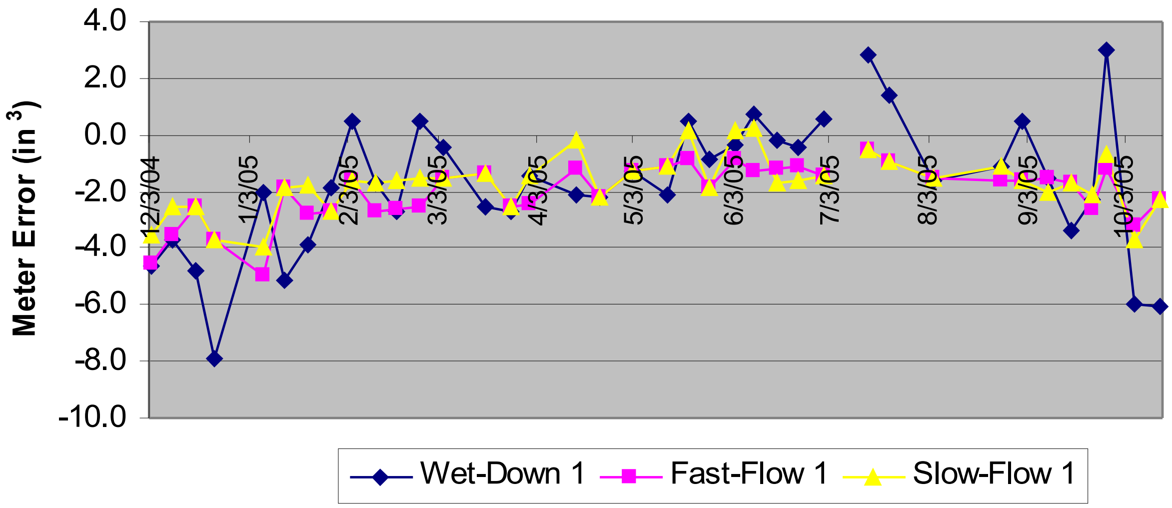


For each meter the observed meter errors for the first run of each set of tests were graphed, that is, the observed errors for the first wet-down test, the first fast-flow test, and the first slow-flow test. Temperature corrections were made for the capacity of the test measures for these graphs. The graphs indicate significantly greater variation in results for the wet-down tests than for either the fast-flow or slow-flow tests. The data raise a concern about the validity of test results on a meter when the product temperature in the system under test is not equalized before testing the performance of a meter. The observed meter errors when temperatures are not equalized are indicative of errors that exist in actual transactions, but the test results may not be best basis on which to evaluate the performance of the meter in the dispenser. The graphs for two dispensers are used to illustrate the results.

Omaha 1 Diesel Fuel

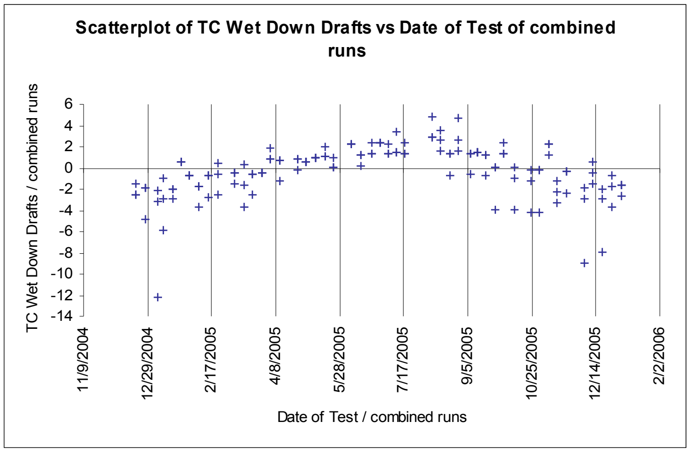


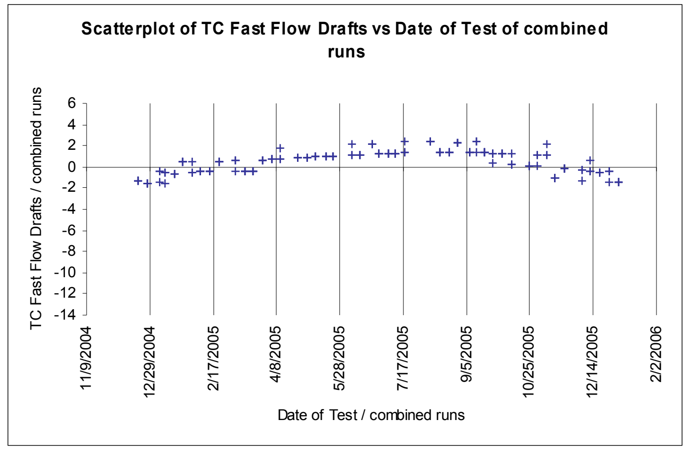
Aurora 3 Unleaded with Ethanol



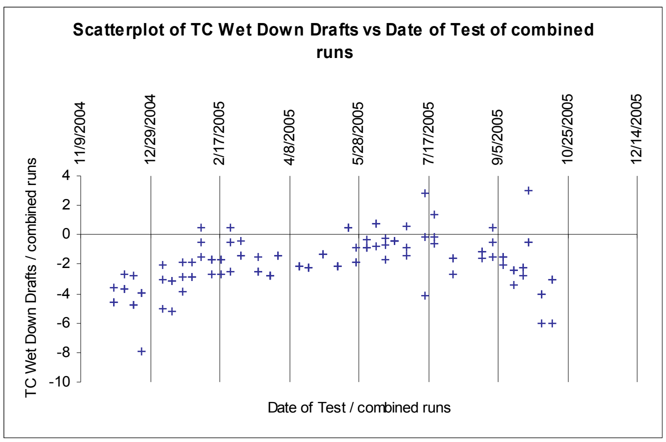
The graphs of the results for all of the wet-down and fast-flow tests provide another view of the variation in the test results and are shown below for two dispensers. The slow-flow results are not shown, because they are very similar to the fast-flow results for each dispenser. Temperature corrections were made to the capacity of the test measures for all of the following graphs.

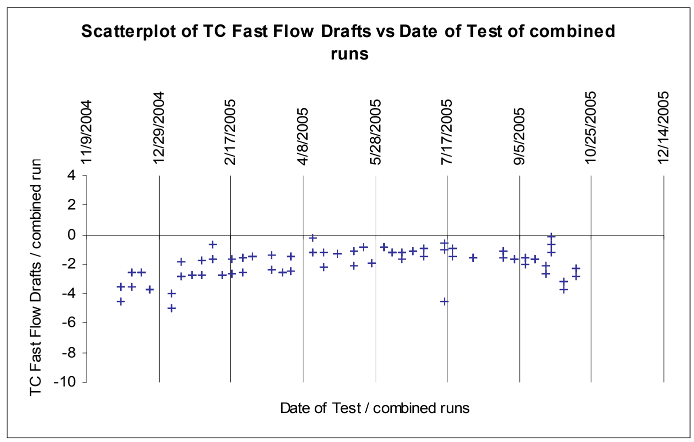
Below are graphs indicating the test results in cubic inches for the **Norfolk 2 Gilbarco meter** over the time period of the tests. The fast-flow results are shown to the same scale on the Y-axis as for the wet-down tests to more clearly indicate the variation in test results a the temperature is stabilized within the delivery system.





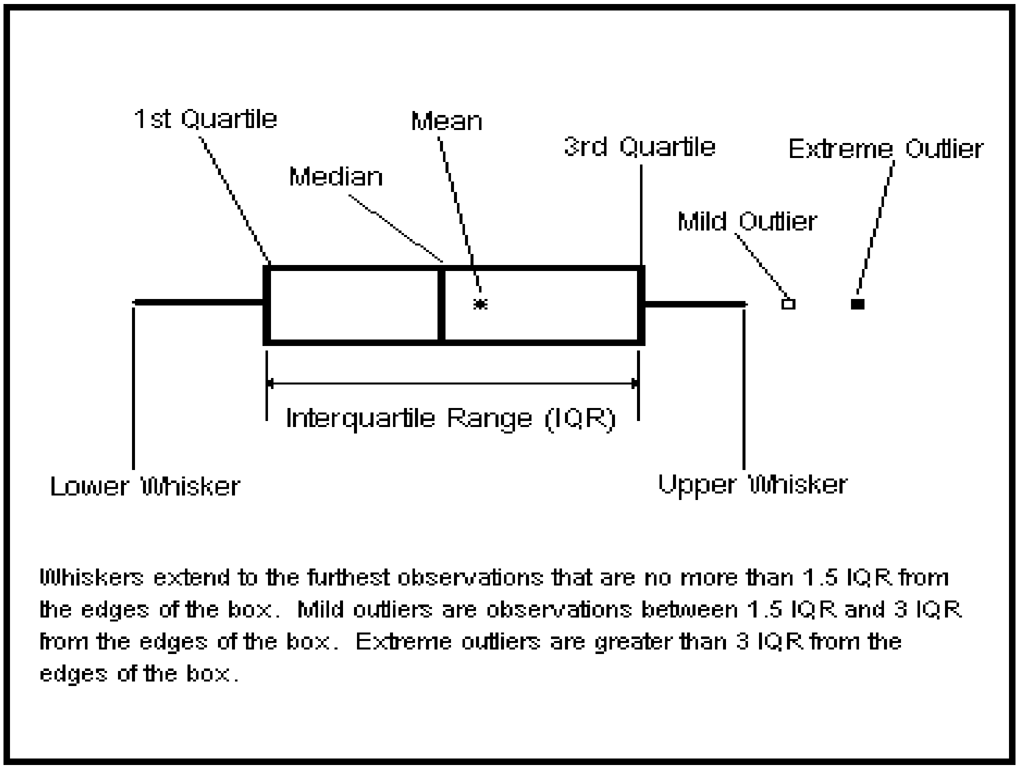
Below are similar graphs for the results (in cubic inches) for the **Aurora 3 Tokheim meter.**



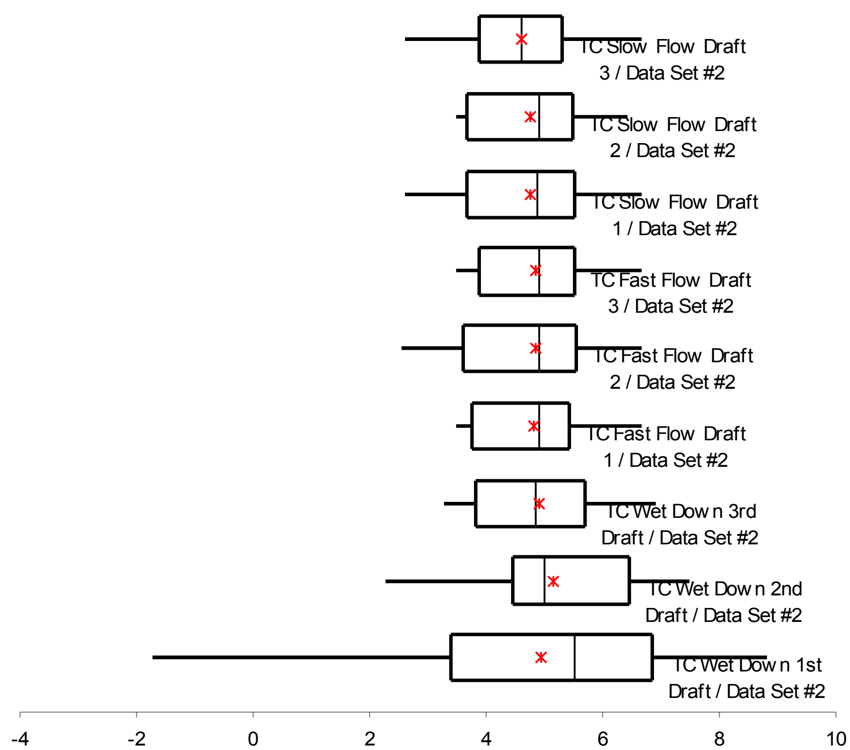


Another way to examine the variation in the results for the wet-down tests, the fast-flow tests, and the slow-flow tests is to examine box and whisker graphs to indicate the range of results for each type of test. These are indicated below with an explanation of the graph structure that is provided in the software package used to perform the regression analyses. The horizontal axes in the box and whisker graphs are meter errors in cubic inches.

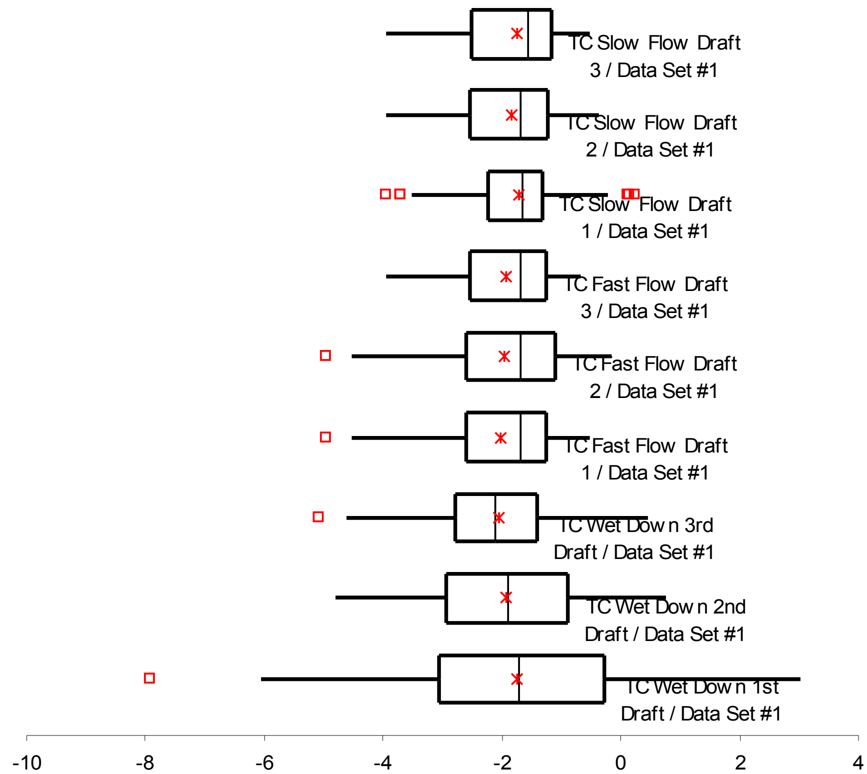
That graphs show that the variation in test results is quite large for the wet-down tests, but that the width of the distributions for the fast-flow and slow flow tests converge to a fairly constant width for each dispenser once the temperatures within the delivery system have equalized. The graphs below also indicate that the 15 gallons of fuel passed through the dispensers was about the minimum needed to stabilize the temperature in the delivery systems for these dispensers.



Box Plot Comparison for Omaha Unit 1 Diesel Fuel



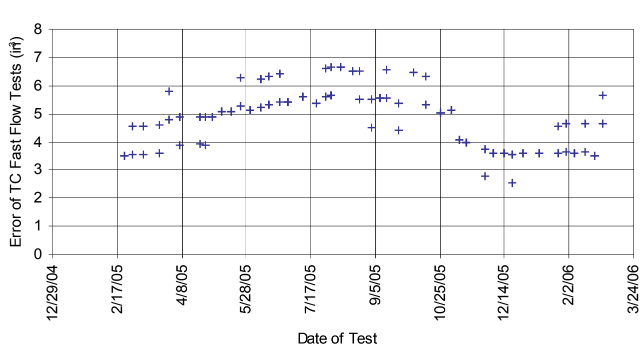
Box Plot Comparison for Aurora Unit 3 Gasoline



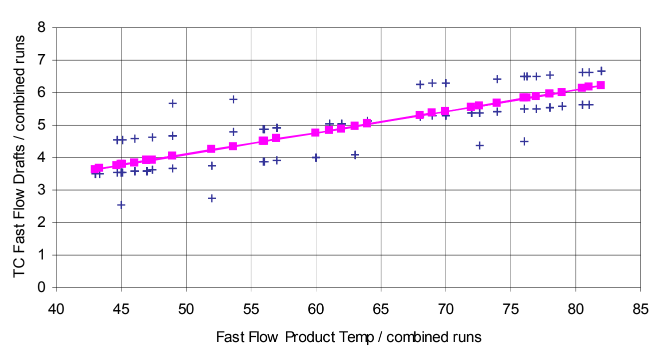
2. Meter Accuracy Changed with Product Temperature

Three dispensers with Gilbarco meters and two dispensers with Tokheim meters were used to collect the data over a period of more than one year. Both the Gilbarco and Tokheim meters were positive displacement piston meters. Both the Gilbarco and Tokheim meters changed accuracy as the temperature of the product changed; however, the accuracy of the Tokheim meters changed less than half the amount of the Gilbarco meters. Below are graphs showing the meter errors for the fast-flow tests over time and to the right are the meter errors graphed against the temperature of the product. The best-fit lines for the data versus the product temperature are shown as the line and boxes on the graphs below on the right.

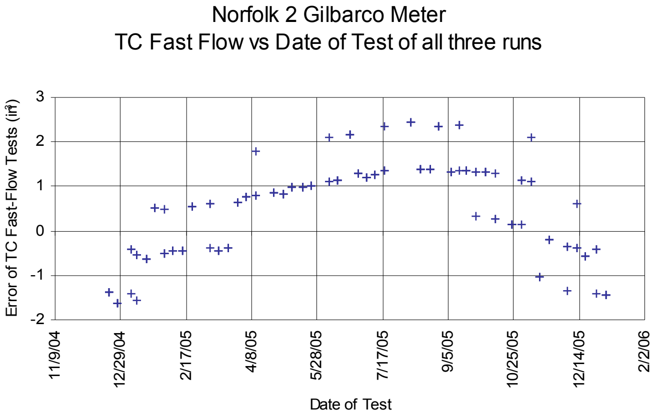
Omaha Diesel Fuel; Gilbarco Meter
TC Fast Flow vs Date of Test of all three runs

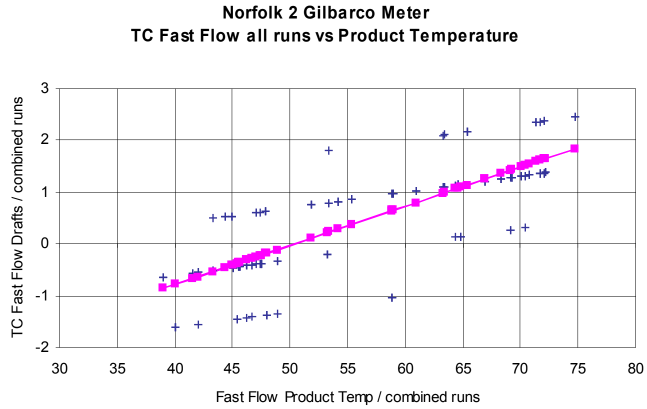


Omaha Diesel Fuel; Gilbarco Meter
Fast Flow all runs vs Product Temperature

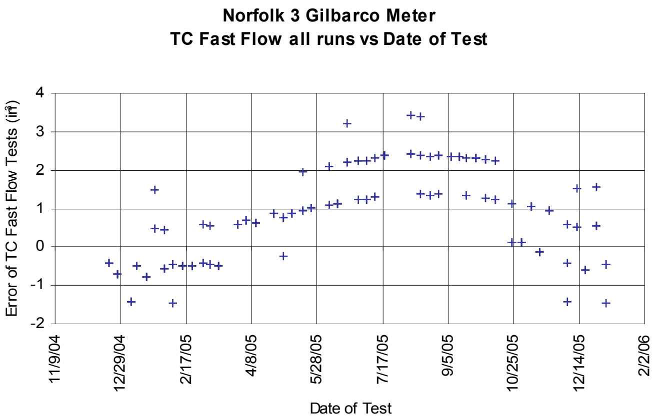


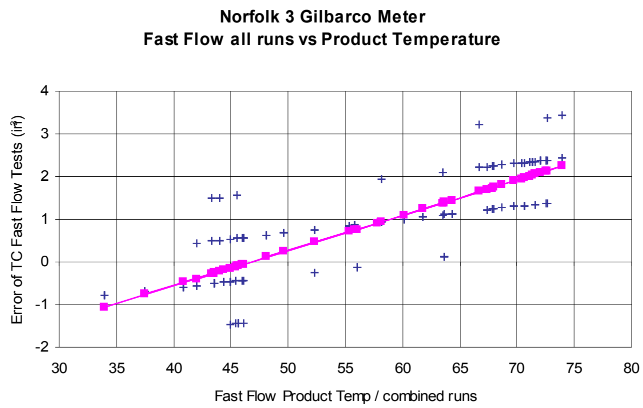
Correlation Coefficient = 0.8393



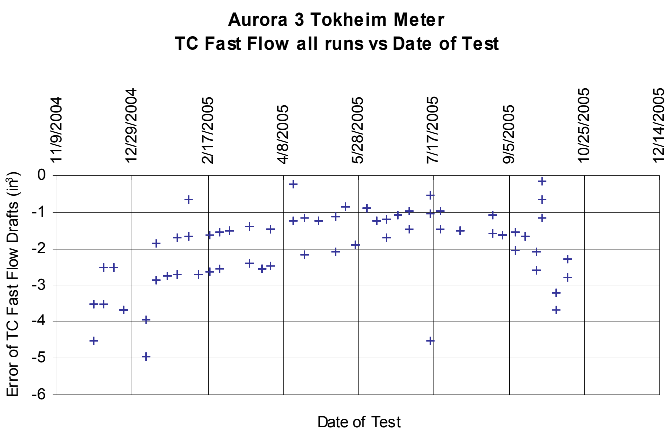


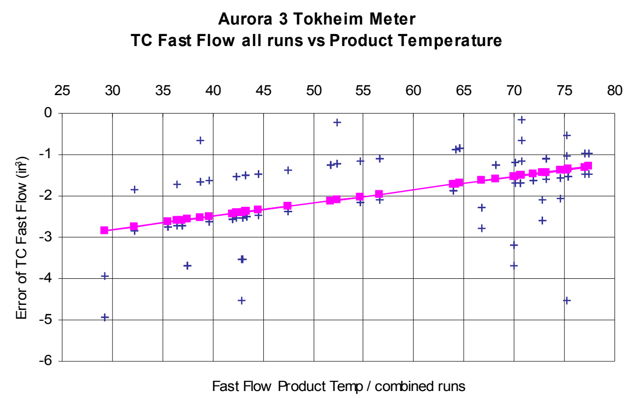
Correlation Coefficient = 0.7952



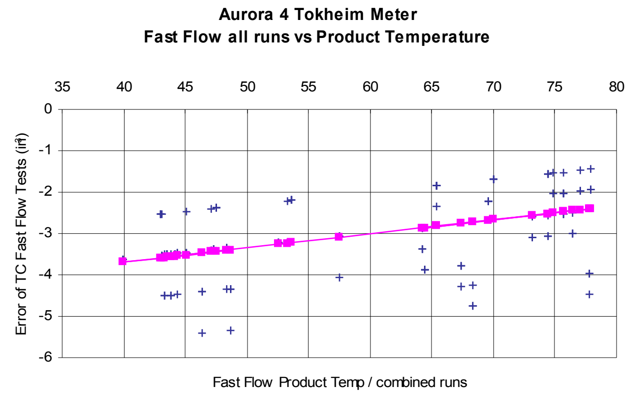


Correlation Coefficient = 0.8361

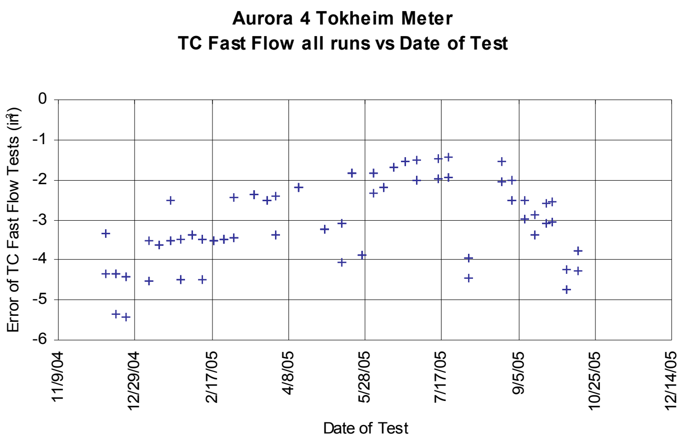




Correlation Coefficient = 0.5068



Correlation Coefficient = 0.4744



The correlation coefficients for the graphs to the right above are a measure of the strength of the relationship between changes in the meter accuracy as the temperature of the product changes. The results for the Gilbarco meters show high correlations, but the Tokheim meters have much smaller correlations, which are indicated by the data for the Tokheim data appearing more horizontal in the graphs on the above right. The excellent repeatability of the Gilbarco meters coupled with the greater change in accuracy with changes in product temperature result in the higher correlation coefficient for the Gilbarco meters when the data are examined for the change in accuracy with respect to changes in the product temperature.

The Tokheim meters exhibited less change in meter accuracy with the change in the temperature of the product. The data for the Tokheim meters show slightly more random error (that is, a wider range of values for the same product temperature) than do the Gilbarco meters. The Gilbarco meter measuring diesel fuel showed less change with product temperature than the Gilbarco meters that measured gasoline. Perhaps this is a result of the viscosity of gasoline versus the viscosity of diesel fuel as the product temperature changed.

Over a 40º F temperature range, the meter accuracies changed as indicated below for the different dispensers. The regression coefficients for the best-fit lines were used for these calculations.

Change in Meter Accuracy over a 40º F Temperature Change

Temperature	Omaha diesel;	Norfolk 2;	Norfolk 3;	Aurora 3;	Aurora 4;

range	Gilbarco	Gilbarco	Gilbarco	Tokheim	Tokheim
40º F	2.64 in^3	3.03 in^3	3.30 in^3	1.29 in^3	1.37 in^3

A statistical software package was used to calculate regression analyses of the data. As stated earlier, temperature corrections were made to the test measures and the meter errors were corrected for the changes in the capacity of the test measures. In one set of data, one meter error was omitted from the analysis because it was a statistical outlier and was not consistent with the data before or after the reading. In one other case, one meter error value was missing a minus sign, which was put in and the corrected data value was used in the analysis.

Regression analyses were run for multiple variables for the test results for each dispenser for the fast-flow and slow-flow tests. The regressions were run using the average of the three test results for the fast-flow and slow-flow test results to reduce the influence of random errors on the test results. The regression analyses were run for:

1. The air temperature;
2. The product temperature for the fast-flow test (which was also used for the slow-flow data);
3. The barometric pressure; and
4. The time of day (morning or afternoon) for when the tests were conducted.

It is important to note that the air temperature and the product temperature are not independent variables. After studying the different regressions, it was concluded that the multiple regressions using both the air temperature and the product temperature do not give valid results because the air and product temperatures are related. Hence, the most appropriate regressions are based on the meter performance with respect to product temperature. This means that the regressions for meter performance and product temperature are one-variable linear regressions. The multiple variable regressions that included barometric pressure and time of day analysis did not indicate that these variables had a significant effect on the test results.

Below are the regression analysis results for the different dispensers.

Regression Results for Meter Error and Product Temperature

Meter	**Correlation Coefficient R**	**R-Square**	**Standard Error of Estimate*** (in^3)	Coefficient for the fast-flow product temperature (in^3/º F)	Probability that the coefficient may actually be zero
Omaha diesel; Gilbarco	0.8393	0.7045	0.5457	0.0659	<0.0001 (<0.01%)
Norfolk 2; Gilbarco	0.7952	0.6324	0.6467	0.0757	<0.0001
Norfolk 3; Gilbarco	0.8361	0.6991	0.6419	0.0824	<0.0001
Aurora 3; Tokheim	0.5068	0.2569	0.8520	0.0322	<0.0001
Aurora 4; Tokheim	0.4744	0.2250	0.8458	0.0342	<0.0001

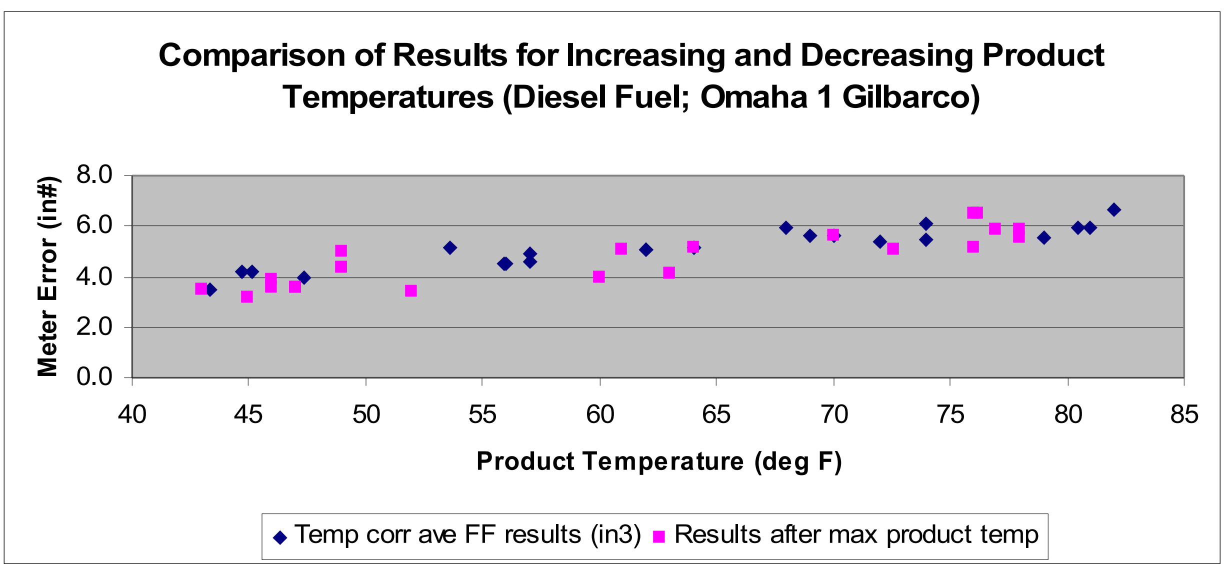
*This is essentially the standard deviation of the residuals. It indicates the typical error that is likely to be made when using the fitted value to predict outcomes. The standard error of estimate is often used to judge which of several potential regression equations is the most useful. If the regression equation is used to predict the test results, then approximately 2/3 of the predictions will be within one standard error (standard deviation) of the actual meter error.

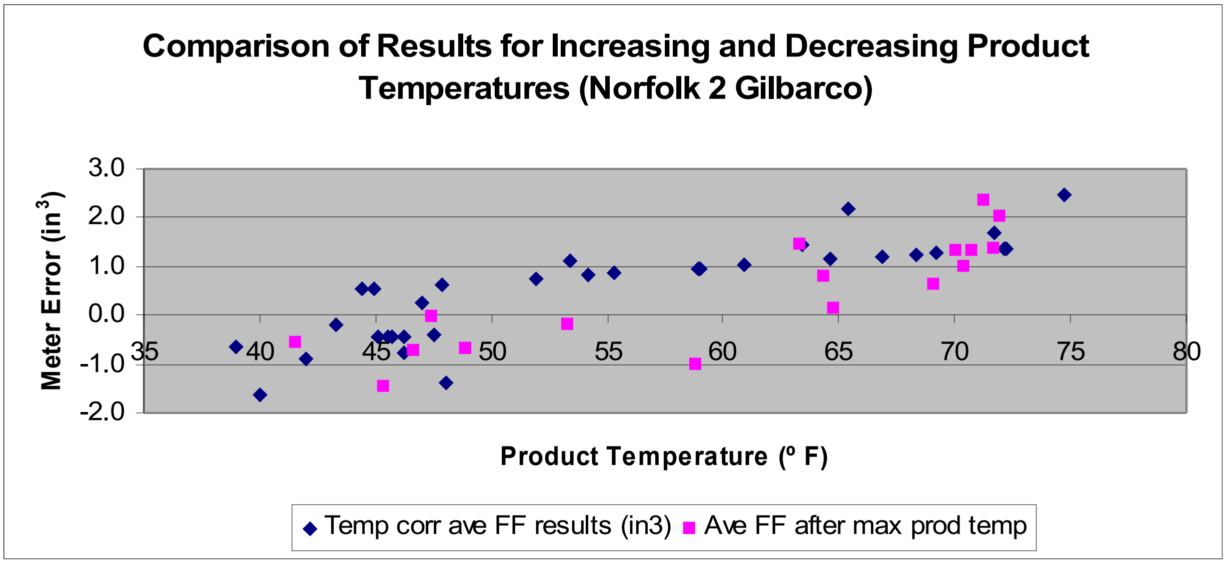
Because of the large amount of test data, it is possible to conclude that the Tokheim meters change accuracy with the temperature of the product, although the magnitude of the change is relatively small. The values in the column titled "R-Square" is the amount (percentage) of the variability in the data that is explained by the regression. For example, for the Omaha diesel dispenser, just over 70% of the variation in the data can be explained by the relationship of meter error with product temperature. In the case of the Aurora 4 dispenser, only 22% of the variability in the data can be explained by the regression. In the case of the Tokheim meters, random errors and/or other unidentified variables represent the bulk of the variability in the test data for these dispensers.

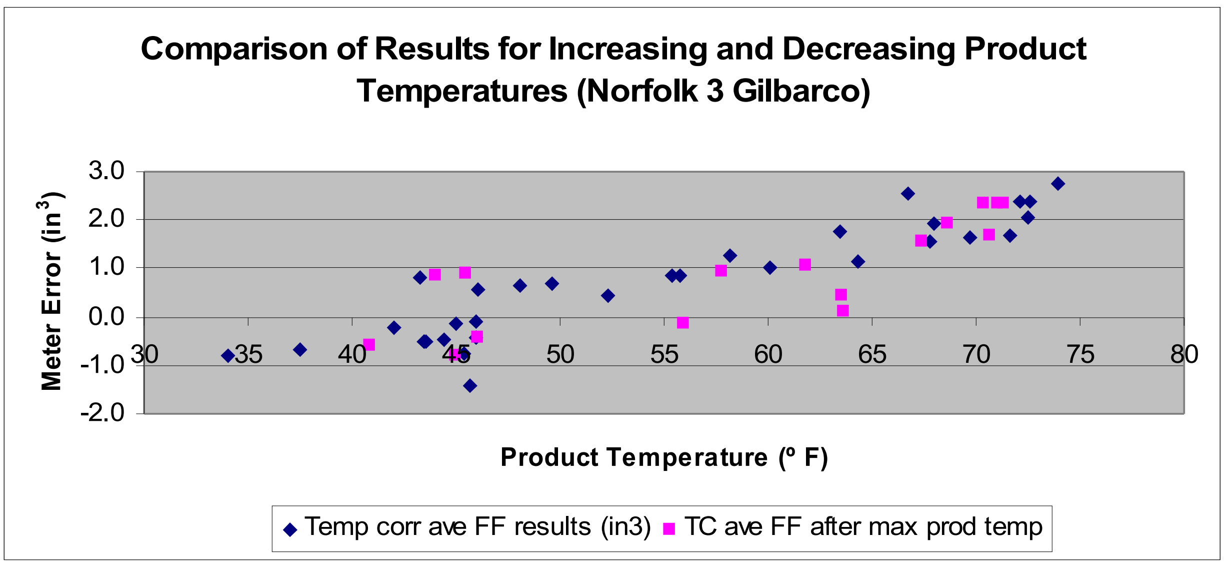
The last column in the table above indicates the probability for the null hypothesis, that is, the probability that there is no relationship between the meter accuracy and the product temperature. The null hypothesis is rejected because the probability of it being true for the data evaluated is less than 0.01%. Hence, the converse is true, that is, that the accuracy of the meter changes as the temperature of the product changes.

3. Meter Accuracy over Time at the Same Product Temperature

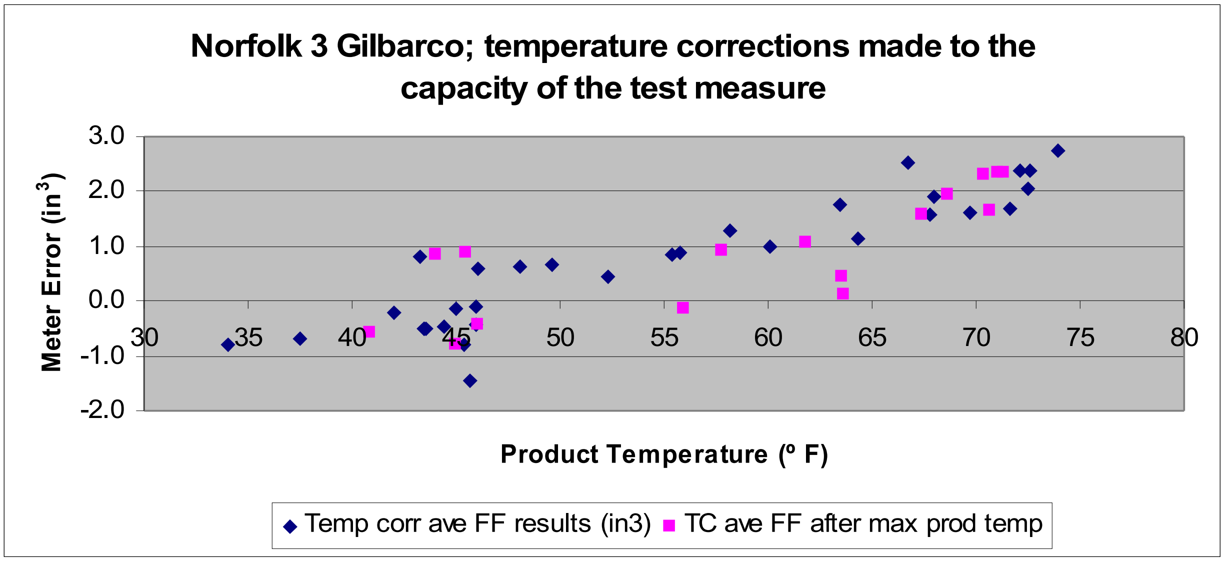
To evaluate if the accuracy of the meters changed over the time of testing, the test results for all dispensers were graphed to show the test results as the product temperature increased and then as the temperature of the product decreased after the maximum product temperature. Three dispensers (with the Gilbarco meters) had a significant number of tests after the maximum product temperature was reached. These three graphs are shown below for the diesel fuel Omaha 1 dispenser, and the Norfolk 2 and 3 dispensers. The graphs do not indicate any detectable change in meter performance over the time of data collection. Remember that temperature corrections were made to the capacity of the test measures for the different product temperatures.

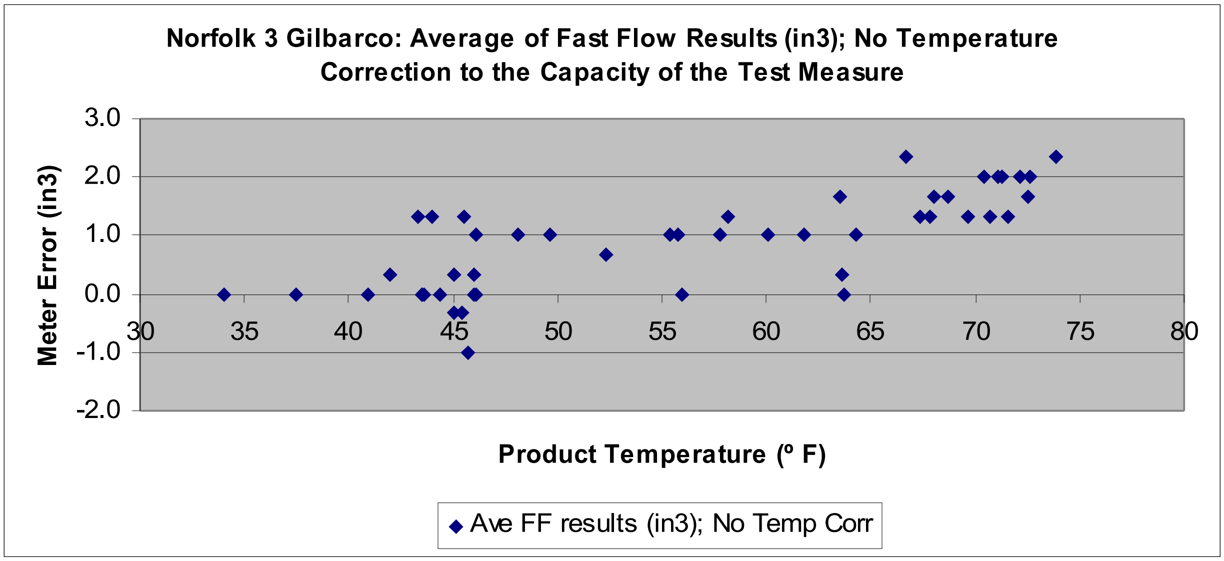






To illustrate the importance of making temperature corrections to the capacity of the test measures in the analysis of these test results, the graphs below for the Norfolk 3 Gilbarco dispenser are shown for the data with temperature corrections to the test measure capacity (the graph shown above in the section for observation 10 is repeated below for ease of comparison) and for the data without temperature corrections to the test measure. The temperature corrections to the test measure becomes more significant for the product temperatures at the extremes of the temperature range, that is, for temperatures most distant from the test measure reference temperature of 60 ºF. The magnitude of the effect is approximately 0.9 cubic inch if the product temperature is 30 ºF from the reference temperature of 60 ºF for a stainless steel test measure.





Conclusions

As stated in the introduction, the following conclusions can be drawn.

1. The test results for a fuel dispenser can vary significantly if the temperature of the dispenser delivery system is not equalized before conducting the accuracy test.
2. The accuracy of the dispenser meters varied slightly with the changes in the temperature of the product being measured.
3. There was no detectable change in the accuracy of the meters at the same temperature during the period of data collection.