Tatsuno Coriolis Flow Meter Development Testing in High Pressure Hydrogen

Cooperative Research and Development Final Report

CRADA Number: CRD-18-726

NREL Technical Contact: Matthew Post

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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Contract No. DE-AC36-08GO28308

CRADA Report
NREL/TP-5400-73475
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Suggested Citation
Post, Matthew. 2019. *Tatsuno Coriolis Flow Meter Development Testing in High Pressure Hydrogen: Cooperative Research and Development Final Report, CRADA Number CRD-18-726*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-73475. https://www.nrel.gov/docs/fy19osti/73475.pdf.

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NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, Vehicle Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

Cooperative Research and Development Final Report

Report Date: January 3, 2019

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of subject inventions, to be forwarded to the DOE Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Tatsuno North America, Inc

CRADA number: CRD-18-726

CRADA Title: Tatsuno Coriolis Flow Meter Development Testing in High Pressure Hydrogen

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$ 30,000.00
TOTALS	$30,000.00

Abstract of CRADA Work:

This project will provide test data on the new Tatsuno coriolis flow meter. This flow meter has been developed by Tatsuno for the purpose of achieving improved flow meter performance for 70 mega pascal (MPA) hydrogen dispensing. Testing will be conducted at the National Renewable Laboratory (NREL) Hydrogen Infrastructure Testing and Research Facility (HITRF) facility utilizing the hydrogen flow meter benchmark testing apparatus. The benchmarking apparatus utilizes a gravimetric method for measuring flow for direct comparison with flow meter output. Using the NREL meter benchmarking apparatus will allow direct comparison with data taken on previous versions of the Tatsuno coriolis flow meter product. Flow meter accuracy at 70 MPA hydrogen dispensers is an issue that has generated a lot of effort by both standards organizations and the station providers.

Summary of Research Results:

NREL tested the Tatsuno BA 1025, S/N H0255 Flow Meter from 1/31/18 – 2/16/18. During the testing, the flow meter was subjected to three different flow rates/pressure ramp rates and three different pressure fill ranges. Table 1 shows the different flow rate/pressure ramp rate labels for the testing and Table 2 shows the pressure ranges. The flow meter was placed in the system so that it experienced a constant inlet pressure. By having the meter held at a constant pressure, the intent is to simulate the flow meter being installed before the pressure control valve in a dispenser. Note with Table 2 that the meter only sees a constant inlet pressure and the fill pressure is the pressure observed in the cylinders. The low pressure was run with two different inlet pressures which would simulate a cascade fill or a full pressure supply fill. Each combination of flow rate and fill pressure was run in triplicate.

Table 1 - Flow rate/ramp rate labels

Label	Description
HR	High Rate – 3.0 kg/min or 50 g/sec or 12,000 psi/min
MR	Medium Rage – 1.5 kg/min or 25 g/sec or 6,000 psi/min
LR	Low Rate – 0.75 kg/min or 12.5 g/sec or 3,000 psi/min

Table 2 - Fill pressure ranges

Label	Description
HP	High Pressure – 6,000 10 10,000 psi (11,000 psi inlet)
MP	Medium Pressure – 4,000 to 8,000 psi (10,000 psi inlet)
LP	Low Pressure – 500 to 4,000 psi (10,000 psi inlet)
LP	Low Pressure – 500 to 4,000 psi (6,000 psi inlet)

Figure 1 below shows a single fill from a test. The MATLAB analysis determines a steady-state zone for both the beginning and end of the fill and averages the three methods over that period to determine the total mass that went through the meter for a given test. For the differential pressure calculation, an average differential pressure in the fill zone is reported in this document. In addition, each test file contains pressure in and pressure out reading for the entirety of the fill.

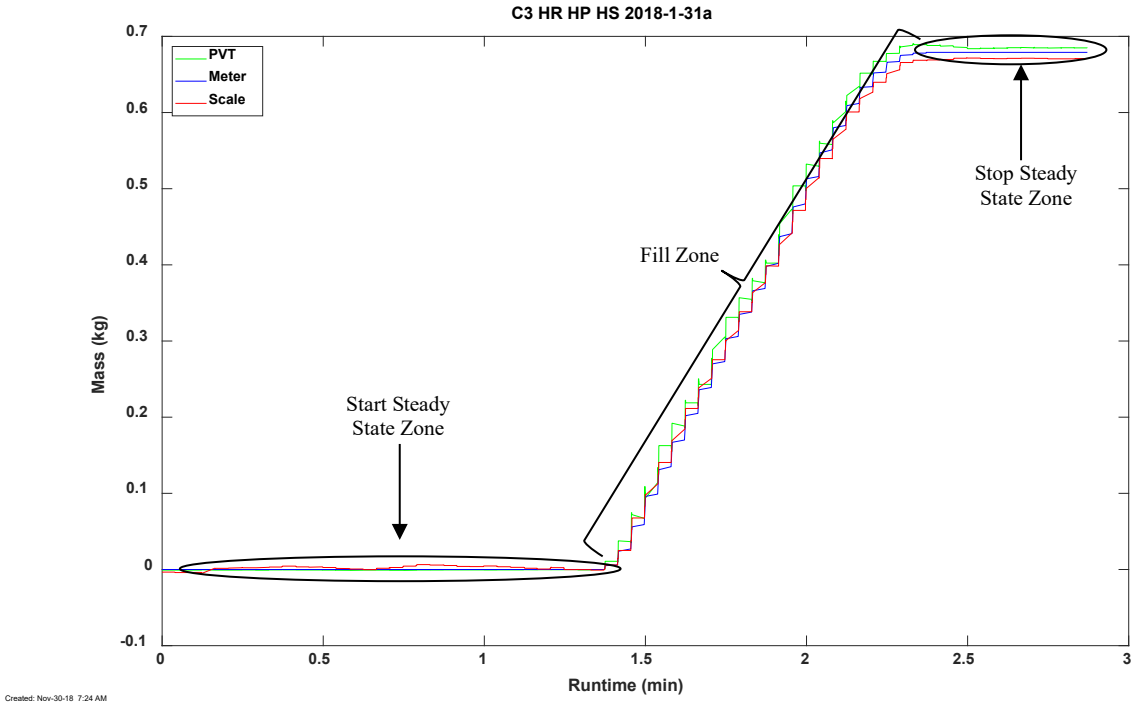


Figure 1 - Mass Over Time for a Fill

Table 3 below shows all the flow tests that were completed on the flow meter. The PVT method was determined to be the standard for this round of testing.

Table 3 - All Tests Compiled

Flow Rate [kg/min]	Meter Final Readout [kg]	PVT Final Readout [kg]	Percent Error [%]	Average Differential Pressure [psig]
3	0.68	0.69	-1.05%	230
3	0.68	0.68	0.16%	110
3	0.66	0.67	-1.39%	-3
3	0.68	0.68	-0.23%	138
3	1.10	1.12	-2.45%	337
3	0.99	1.01	-2.53%	48
3	1.01	1.05	-3.66%	104
3	1.00	1.02	-2.34%	351
3	1.02	1.05	-2.73%	845
3	1.02	1.04	-1.59%	973
3	0.82	0.83	-1.51%	163
3	0.86	0.87	-1.68%	70
3	0.82	0.83	-1.46%	323
1.5	0.82	0.83	-1.20%	48
1.5	0.69	0.69	-0.01%	35
1.5	0.68	0.68	-0.79%	42
1.5	0.85	0.86	-1.33%	106
1.5	0.99	1.01	-2.02%	118
1.5	0.99	1.01	-2.25%	89
1.5	0.99	1.01	-1.39%	197
1.5	1.03	1.05	-1.71%	200
1.5	1.01	1.03	-1.52%	230
1.5	1.00	1.02	-1.39%	312
1.5	0.88	0.89	-1.33%	84
1.5	0.91	0.92	-1.44%	75
1.5	0.89	0.90	-1.15%	87
0.75	0.68	0.68	0.00%	-13
0.75	0.67	0.67	-0.28%	14
0.75	0.77	0.78	-0.94%	13
0.75	0.70	0.70	-0.92%	15
0.75	0.98	0.99	-1.81%	36
0.75	0.98	0.99	-1.76%	35
0.75	1.00	1.01	-1.16%	34

Flow Rate [kg/min]	Meter Final Readout [kg]	PVT Final Readout [kg]	Percent Error [%]	Average Differential Pressure [psig]
0.75	0.98	1.00	-1.75%	56
0.75	1.02	1.03	-1.26%	57
0.75	1.00	1.02	-1.99%	57
0.75	0.89	0.90	-1.01%	24
0.75	0.92	0.93	-0.81%	23
0.75	0.90	0.91	-0.59%	21

Statistical Summaries:

The statistical summaries section begins to dive into the statistical analysis of the tests performed by looking at the **percent error when compared to the PVT method**. The statistical analysis can lead to general conclusions based on breaking the flow meter into categories, however, the further the categories are broken down into the less test samples, N, the data has. It is up to the customer to determine if the data has significance to them. For instance, Figure 2 shows a summary of all the flow tests. The data has a mean percent error of -1.39% (**negative error means meter is reading high**) with a standard deviation of 0.79% and there are 39 data points.

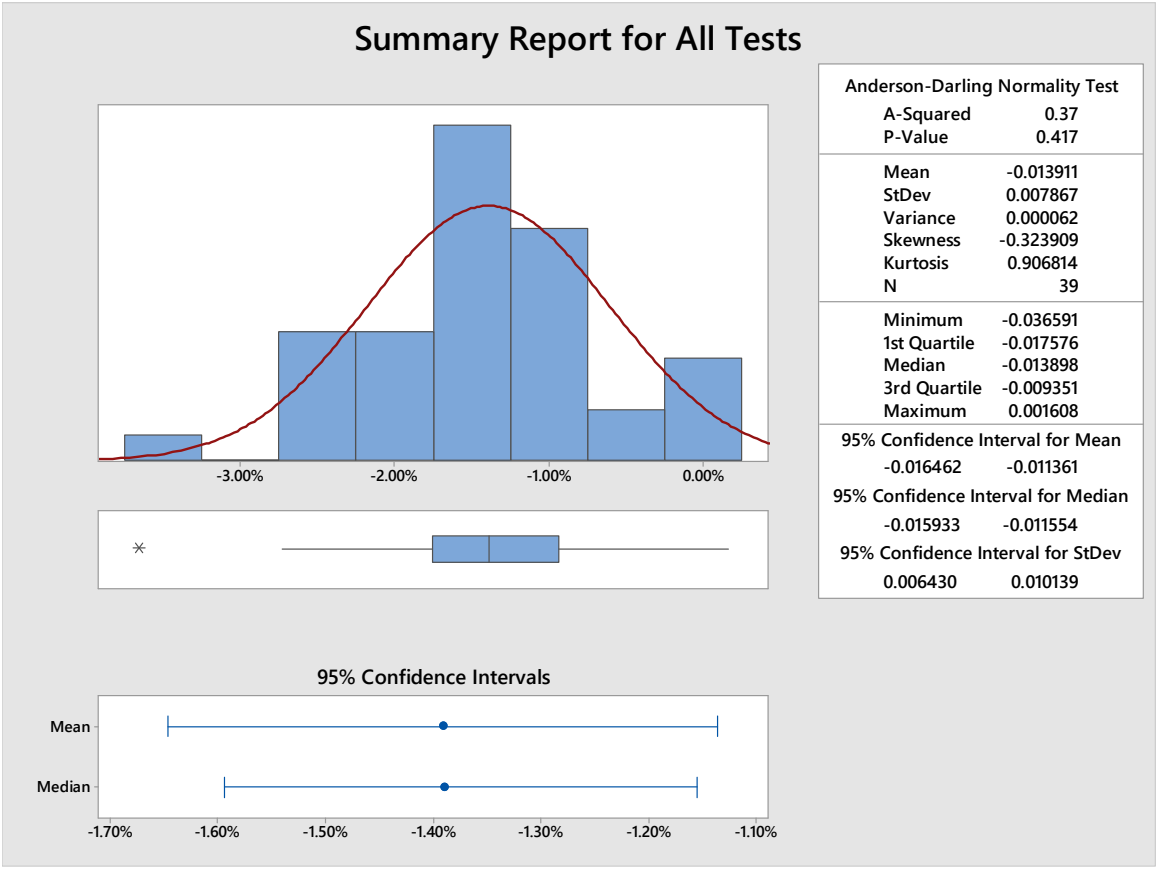
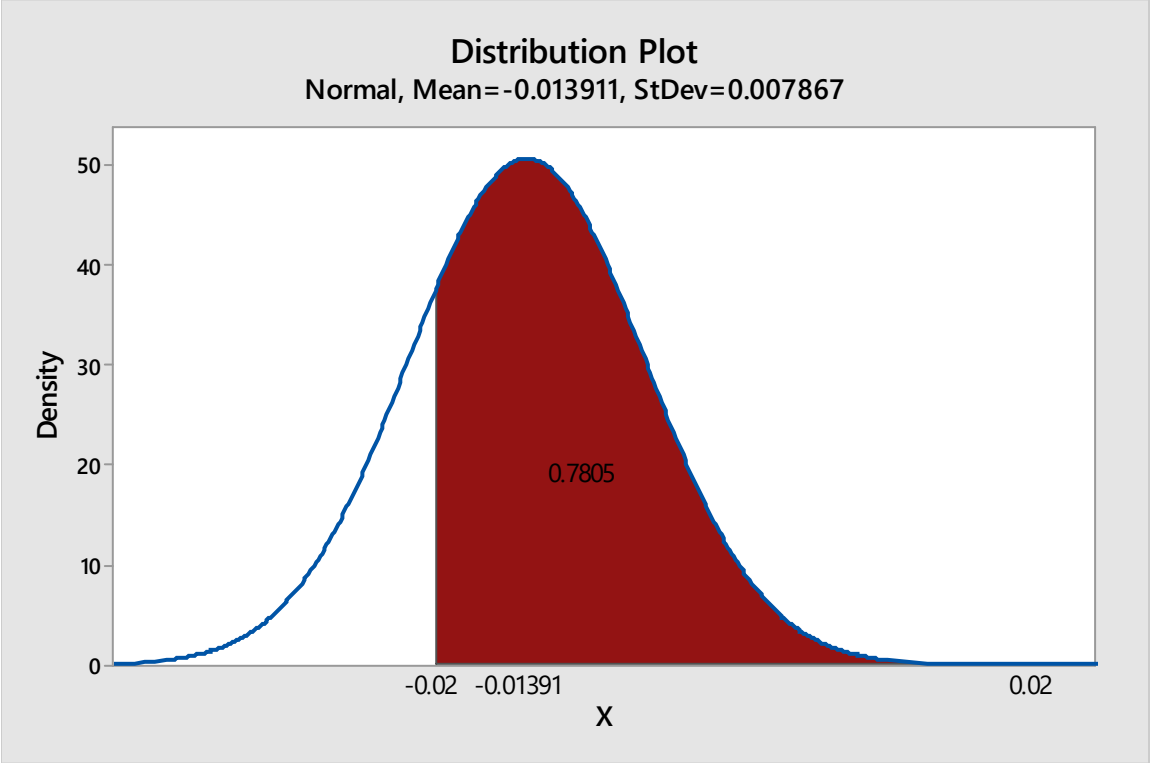


Figure 2 - Summary Report for All Tests

Single plot probability

The probability a single fill would be within a specified error range is the ultimate way that a meter would be tested by weights and measures agencies. We calculated this probability by using the mean, standard deviation, and confirming the normality of the data analyzed with Minitab. We checked the normality of the data using the Anderson-Darling test. When we confirmed normality, we input the mean and standard deviation into a distribution plot to obtain the single fill probability. We compared the data against a 2% accuracy requirement that will most likely be the final NIST maintenance standard. Key findings from the single fill probability plot:

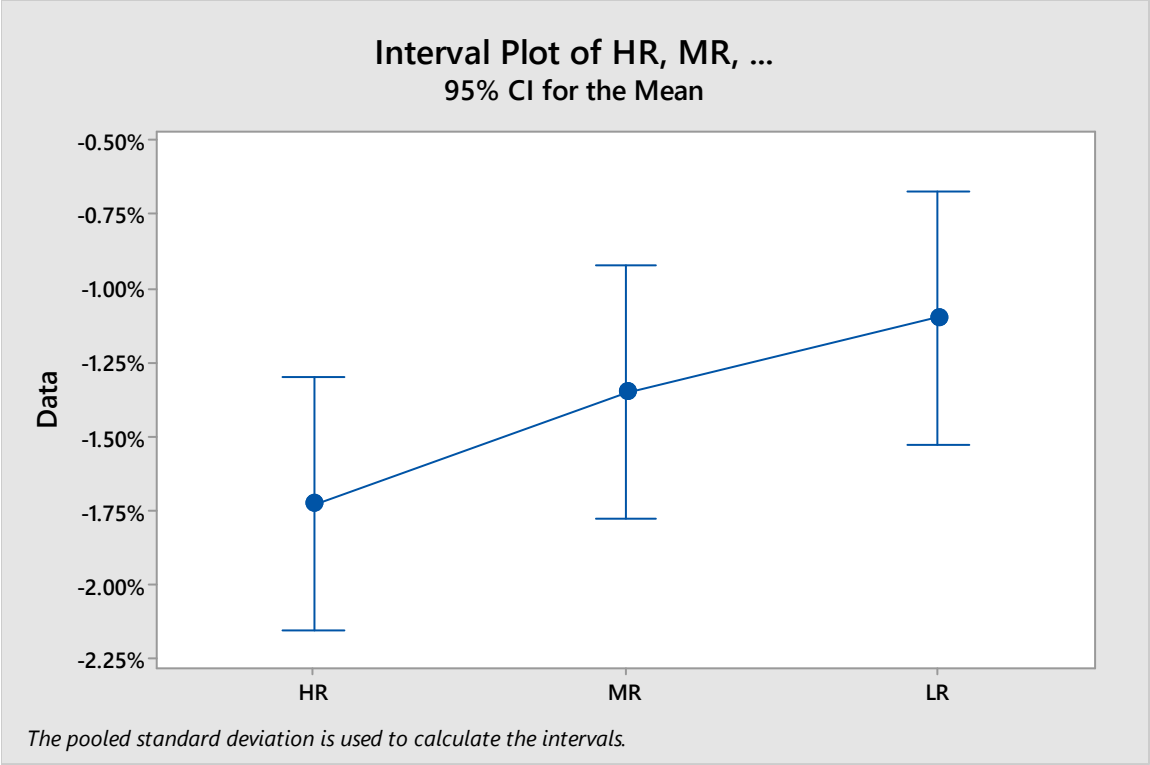
- For all the tests there is a single fill probability of 78% that a fill will fall within ±2%



ANOVA

An ANOVA is an analysis that identifies differences among group means. The null hypothesis for this data is that there is no difference in meter performance based on the categories. We determined that a significance level of 0.05 was appropriate for this analysis and compared that to the calculated P-value. If the P-value was less than 0.05, the null hypothesis is rejected and there may be a significant difference in meter performance based on the categories. Key findings from the ANOVA analysis:

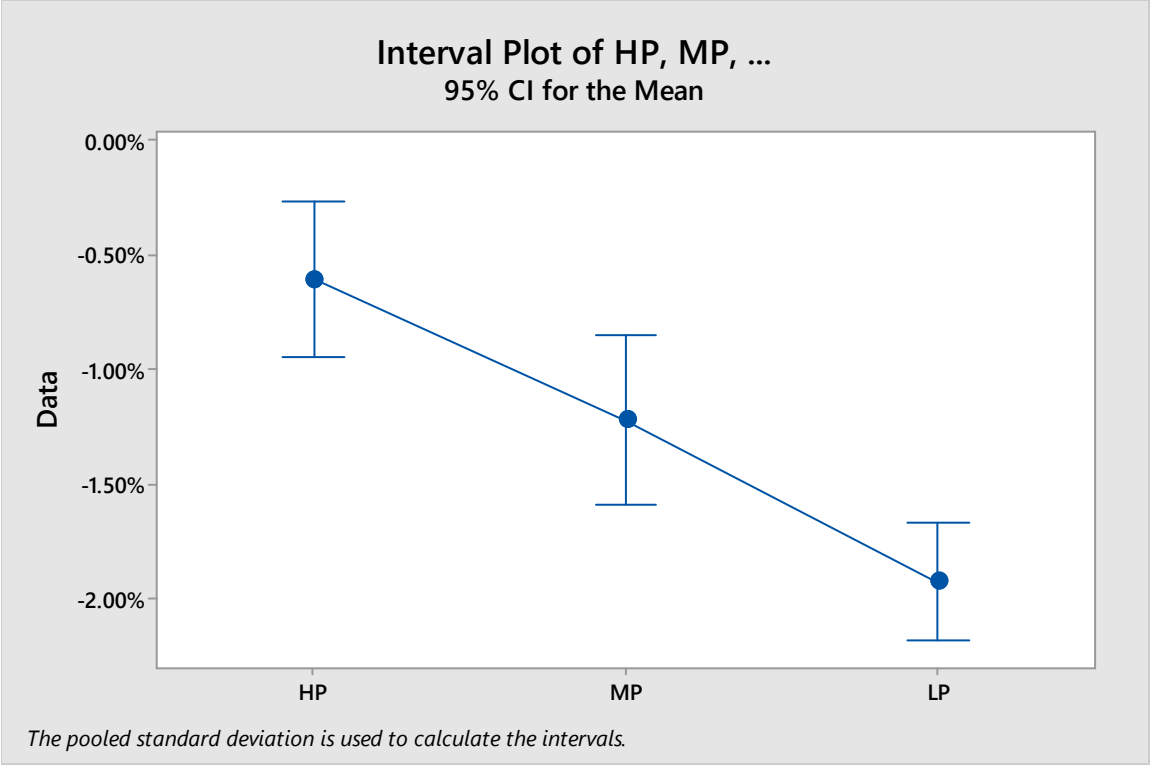
- When separated out by expected flow, there was no significant difference between meter performance
- When separated out by pressure ranges, the data suggested that the null hypothesis should be rejected and the meter performance could depend on pressure



One-way ANOVA: HR, MR, LR

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	$\alpha = 0.05$

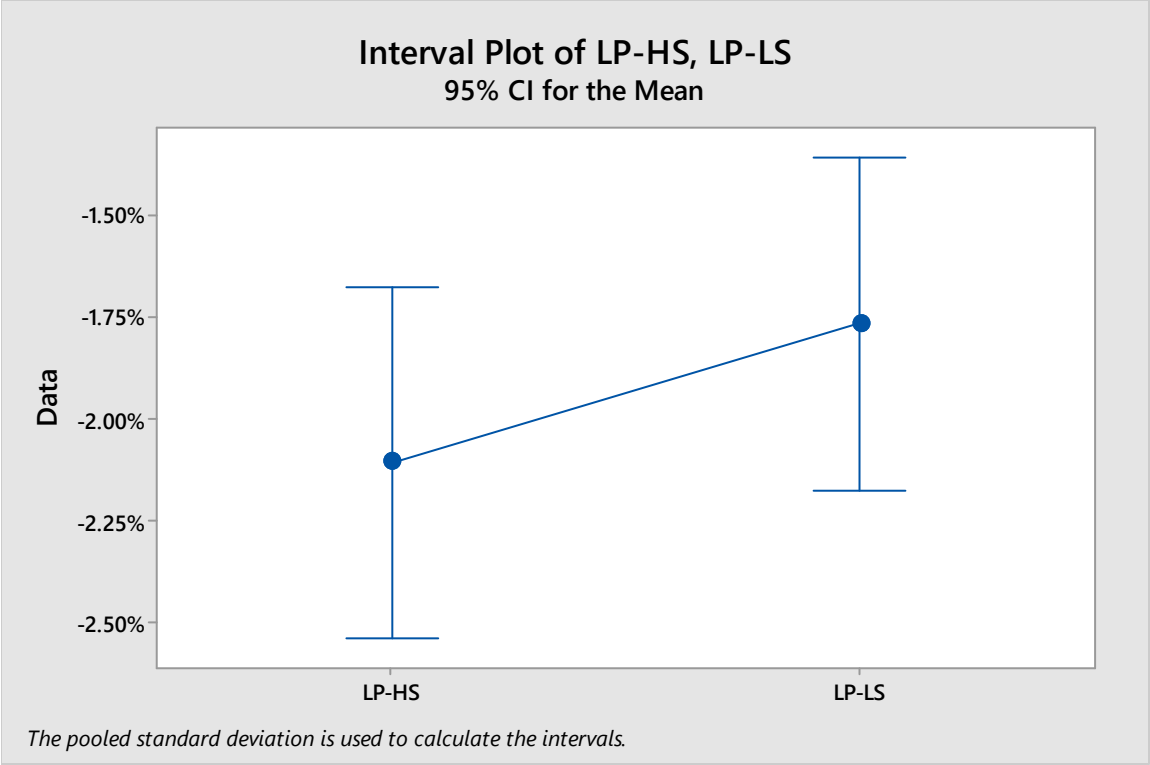
Equal variances were assumed for the analysis.
P-Value 0.119
Conclusion: Cannot reject the null hypothesis



One-way ANOVA: HP, MP, LP

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	$\alpha = 0.05$

Equal variances were assumed for the analysis.
P-Value 0.000
Conclusion: Reject the null hypothesis, it is possible one mean is different.



One-way ANOVA: LP-HS, LP-LS

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	$\alpha = 0.05$

Equal variances were assumed for the analysis.
P-Value 0.244
Conclusion: Cannot reject the null hypothesis

Subject Inventions Listing:

None

ROI #:

None

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DOE Program Office:

Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office