"Design of Characterization System For Differential Pressure Flow Meters"

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ABSTRACT

The paper describes the development of a characterization system for differential pressure flow meters (orifice plate), considering the effects associated with the installation, physical-chemical properties, correction of variables such as pressure, temperature and fluid type.

This characterization system, could provide traceability in the measurements of systems with Orifice Plate, Venturi and Cone flow meter, under the particular conditions of the installation, even if the measurement system does not work according to any of the design parameters mentioned in the applicable regulations (ISO 5167, AGA Report no. 3).

The use of mathematical models declared in the national and international standards, implies the fulfillment of the design and installation criteria (mechanical installation), when this is not possible, the alternative is to perform a characterization of the flow measurement system, under specific conditions.

1. INTRODUCTION

1.1. Reference system considerations

- Development of the application for volume and mass quantity calculation (Phase 1, liquid).

- Application development for characterization and flow correction routines:
  - Adjust by polynomial or interpolation.
  - Use of meter adjustment factor (MF).
  - Use of discharge coefficient vs differential pressure as adjustment factor.

- Development of application for associated variables correction factors (secondary instrumentation: temperature, pressure, density).

Reference measurement system.

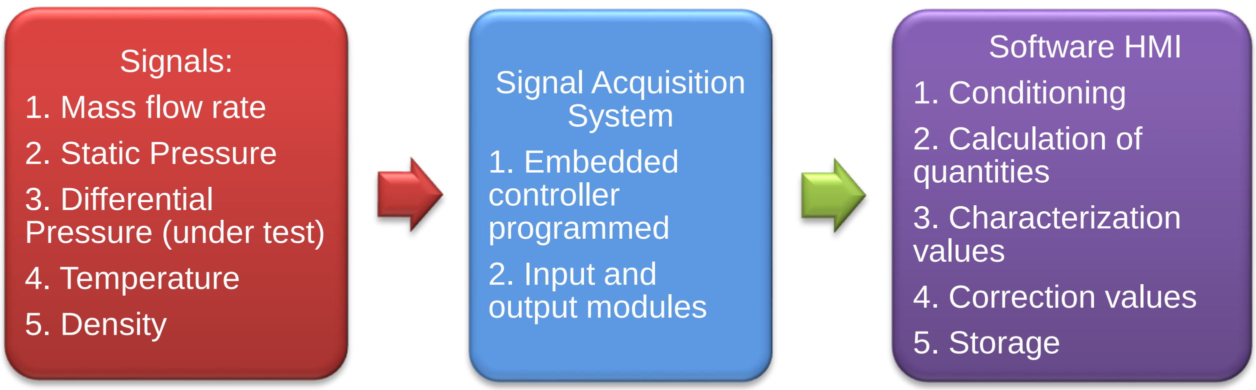

Figure 1. Reference measurement system

1.2. Reference system components (portable)

- Mechanical installation
  Carbon Steel, Schedule 40.

- Mass flow rate measurement (reference)
  Coriolis flow meter, 4 "in. Ø, #300 lb., Endress + Hauser, Promass 83; operating range from 410 to 5519 kg/min, max. Error 0.04 %, traceability to CENAM.

- Temperature and static pressure measurement
  Multivariable indicator transmitter, Rosemount 3095FB.

- Differential Pressure Measurement
  Signal by system under test, electric current loop 4 to 20 mA.

- Signal acquisition system
  National Instruments embedded controller programmed with input / output modules (cRIO).

- Data communication infrastructure
  Radio MODEM Data-Linc with RS-232 / 485 converter Adam.

- Monitoring and control software
  CPU with HMI software for monitoring and quantities calculations.

Image 1. Mass flow meter

Image 2. Multivariable transmitter

Image 3. Data acquisition

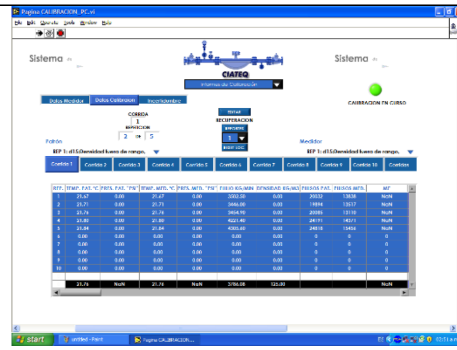

Image 4. Monitoring

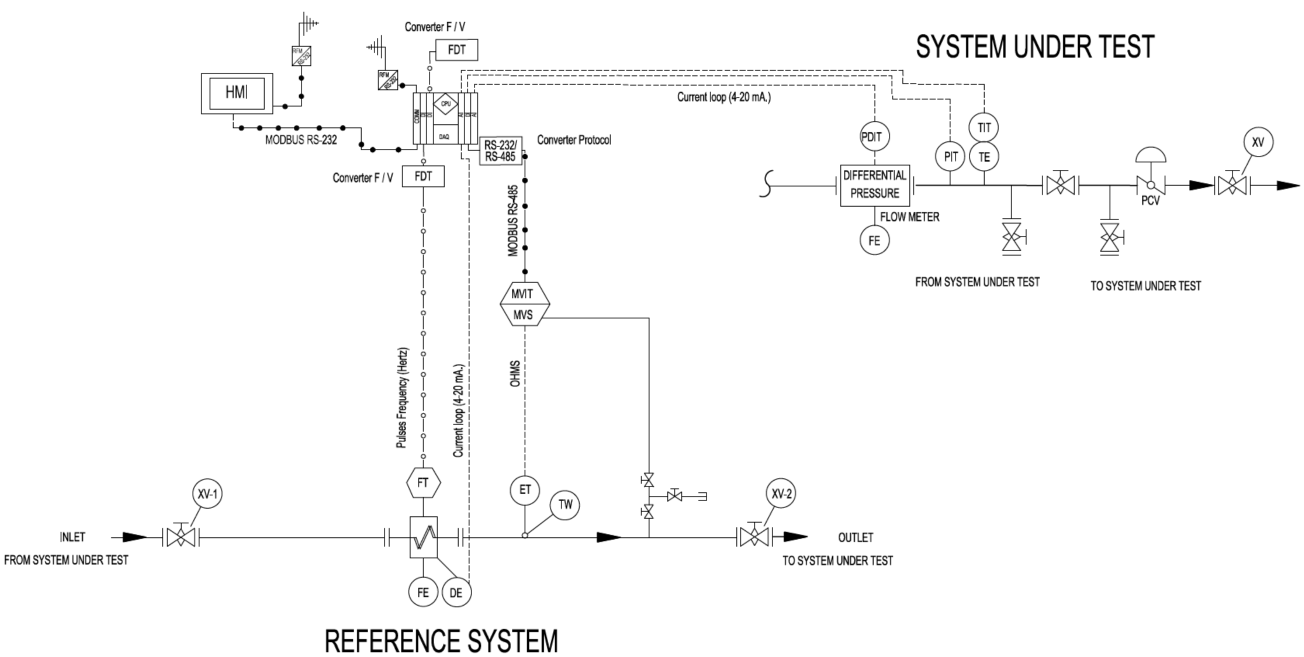

Figure 2. Reference measurement system components (portable).

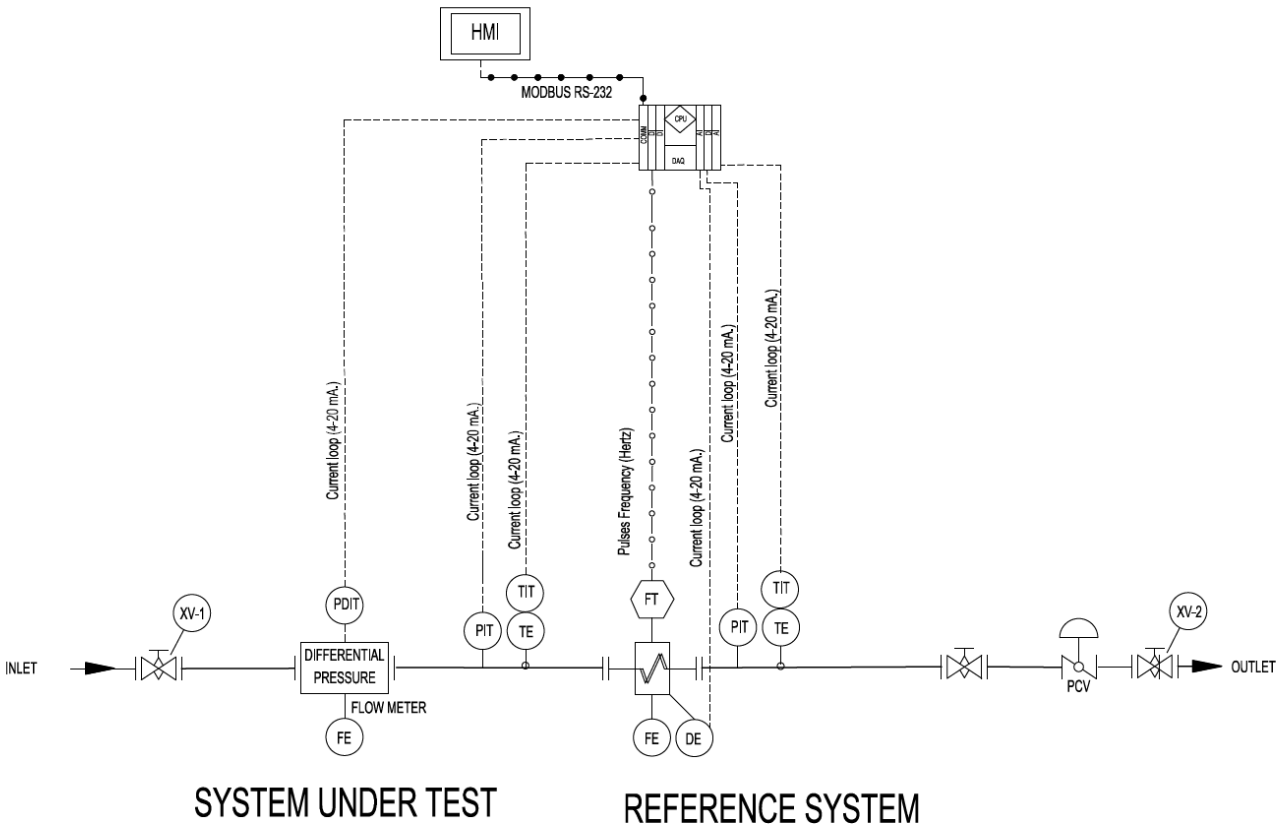

Figure 3. Reference measurement system components (laboratory).

2. LIQUID MASS FLOW RATE TESTING IN FLOW FACILITIES

Characterization tests of differential flow meters were carried out in the flow laboratory of CIATEQ A.C. (accredited to the ema), installing the meter under test in series with the reference meter (Coriolis), with the following operating conditions:

- 9 Test points from 500 to 1740 l/min, at operating conditions (temperature, pressure)
- 5 Repetitions at each point
- Settings
  - Standard installation
  - Outside standard installation

2.1. Operation conditions in flow facilities

Table 1. Operating Conditions

OPERATING CONDITIONS		
Fluid	Non-distilled and non-potable water	
Water Density At Reference Conditions 20°C, 1 kg/cm^2	998.203254784 kg/m^3.	
Pipeline Material	Carbon Steel, Schedule 40	
Size and Class	4 “in. Ø #150 lb.	
Diameter Of The Pipeline	4.026 “in. Ø	
Operating range	400 - 2000	l/min.
Dynamic Viscosity of Water at 20 °C	1.1 x 10^{-6}	m^2/s

Table 2. Differential Pressure Indicator Transmitter (DPIT)

DPIT		
Differential Pressure Transmitter	Endress + Hauser	
Serial No.	F200C21509D	
DPIT Measurement Range	2.5 - 2500	in. of H_2O
Resolution DPIT	0.001	in. of H_2O
Accuracy DPIT	±0.075% of calibrated span.	

2.2. Flow meters under test

- Orifice Plate Flow Meter

Table 3. Orifice Plate Information

Orifice Plate Information		
Orifice Plate Manufacturer	CIATEQ A.C.	
Assembly Fitting, Daniel Brand, Mod. Junior		
Orifice Plate Design Interval	450 - 1800	l/min.
Meter tube material	Carbon Steel	
Orifice Plate Material	Stainless steel	
Nominal Size	4.000” in. Ø	
Meter Tube Diameter “D”	4.026” in. Ø	
Orifice Place Bore Diameter “d”	2.0127” in. Ø	
Beta Ratio	0.5	
Flatness	0.030 mm.	
Orifice Plate Roundness	15.66 µm.	

Orifice Plate Bore Thickness	1.933 mm.
Orifice Plate Thickness	3.3769 mm
Orifice Plate Bevel	44.8°

Image 5. Orifice plate

Image 6. Fitting installation

- Venturi Flow Meter

Table 4. Venturi Information

Venturi Information	
Venturi Manufacturer	CIATEQ A.C.
Assembly in triple "T" installation (8 connections).	
Type Of Manufacture: Machined	
Venturi Material	Stainless steel
Nominal Size	4.000” in. Ø
Meter Tube Diameter “D”	4.026” in. Ø
Diameter "d" Of The Throat	2.013” in. Ø
Beta Ratio	0.5

Image 7. Venturi

Image 8. General installation

- Cone Flow Meter

Table 5. Cone information

Cone Information	
Venturi manufacturer	McCrometer
Body material	Carbon Steel
Cone material	Stainless steel
Nominal size	4.000” in. Ø
Meter diameter “D”	4.026” in. Ø
Cone diameter "d"	2.140” in. Ø
Beta ratio	0.8483

Image 9. Cone

Image 10. General installation

2.3. Differential pressure flow meters installation

- Orifice plate with standard installation

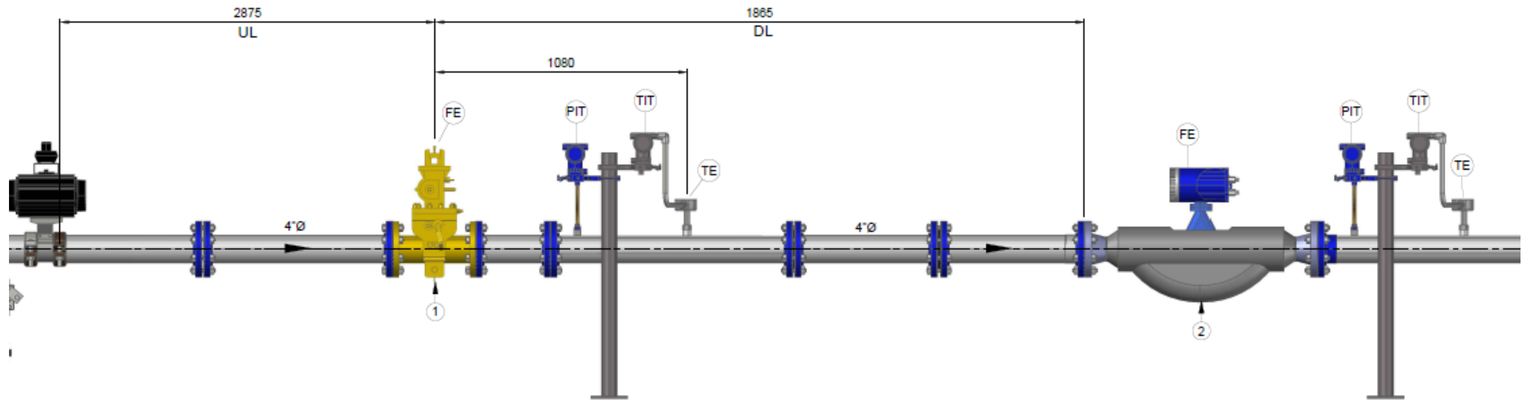

Figure 4. Orifice plate with standard installation

- Orifice plate with outside standard installation

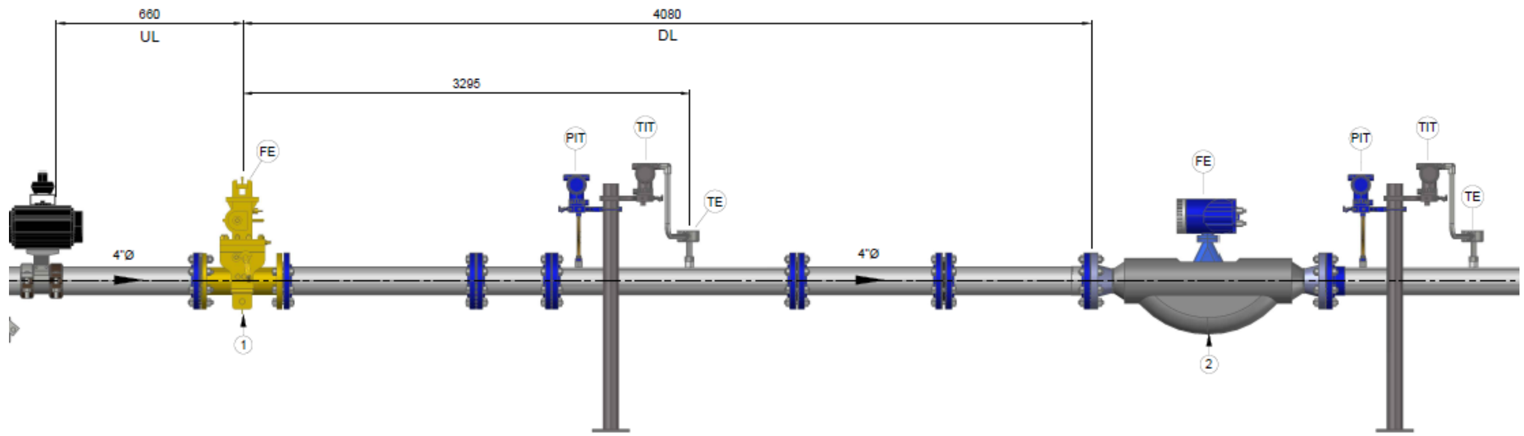

Figure 5. Orifice plate with outside standard installation

- Venturi with standard installation

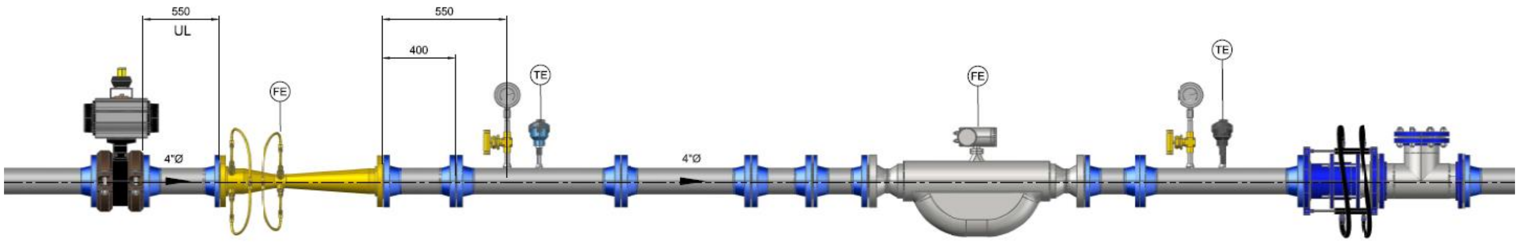

Figure 6. Venturi with standard installation

- Venturi with outside standard installation

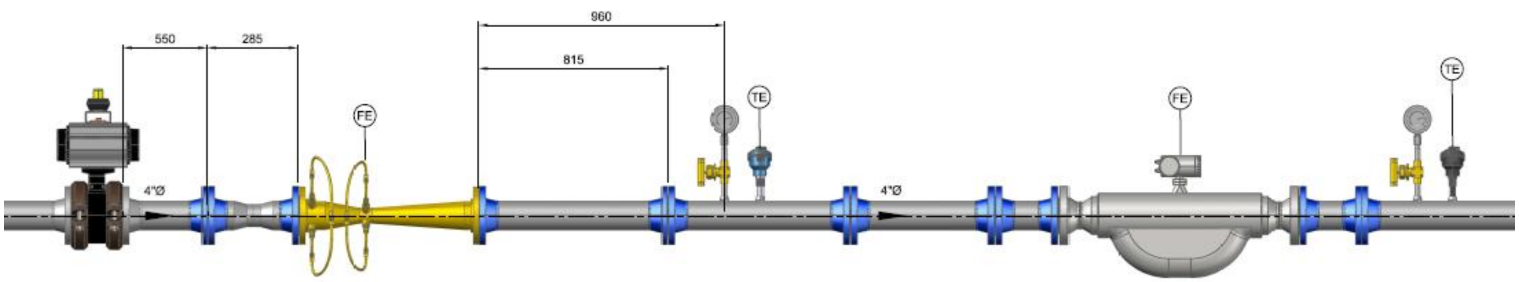

Figure 7. Venturi with outside standard installation

- Cone with standard installation (Manufacturer)

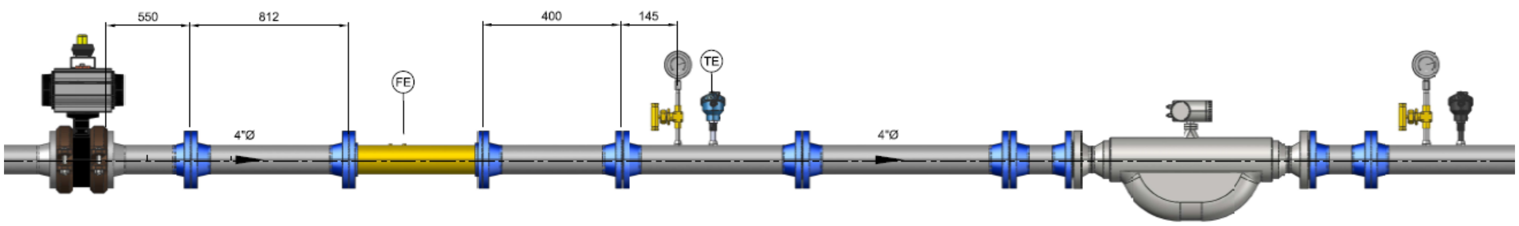

Figure 8. Cone with standard installation (Manufacturer)

- Cone with outside standard installation

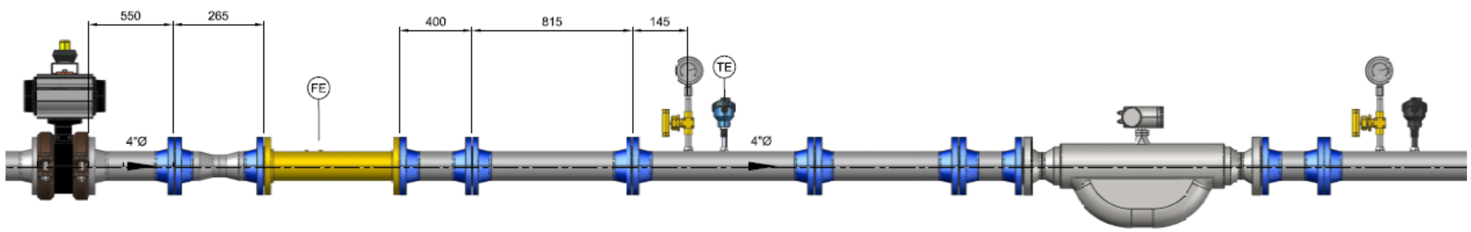

Figure 9. Cone with outside standard installation

3. RESULTS AND ANALYSIS

The comparisons are made, in the determined points, using the infrastructure of the flow laboratory of CIATEQ headquarters Aguascalientes, with the software of acquisition of the laboratory.

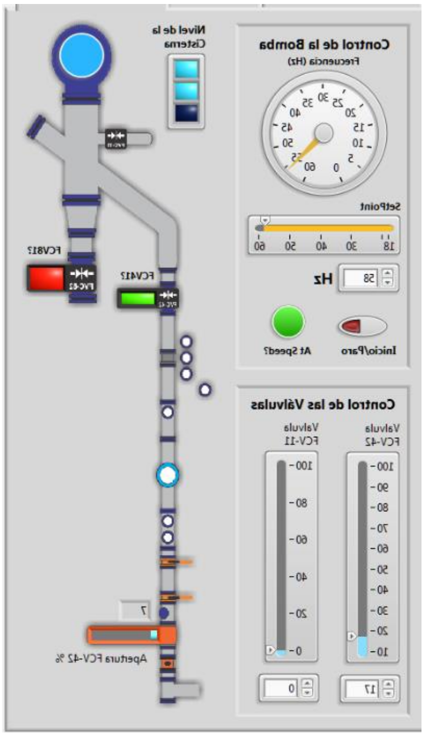

Figure 10. Monitoring system

Table 6. Measurement points (Runs)

Run	Mass Flow Rate (kg/min.)
1	500
2	650
3	800
4	950
5	1100
6	1260
7	1400
8	1550
9	1740

Using the mass flow calculation equation declared in ISO 5167-1 for Plate and Venturi, ISO 5167-5 for Cone, AGA R3 for orifice plate too, and inferring the value of the discharge coefficient (Cd), to determine it in function of the flow of the reference meter (coriolis), the characterization is carried out in each one of the different installations of each meter.

$$C = \frac{Q_m \cdot \sqrt{1-\beta^4}}{\varepsilon \frac{\pi}{4} d^2 \sqrt{2\Delta_p \rho}} \ldots \text{(De ISO 5167)}$$

………Eq. 1

The density value calculated by the acquisition software is used from the pressure and temperature measured during the test.

Derived from the consecutive comparison of the three flow meters by differential pressure (orifice plate, Venturi and Cone) against the reference meter (Coriolis) the following results are obtained:

3.1. Orifice Plate Flow meter

- Orifice Plate according to ISO-5167-1 (Standard)

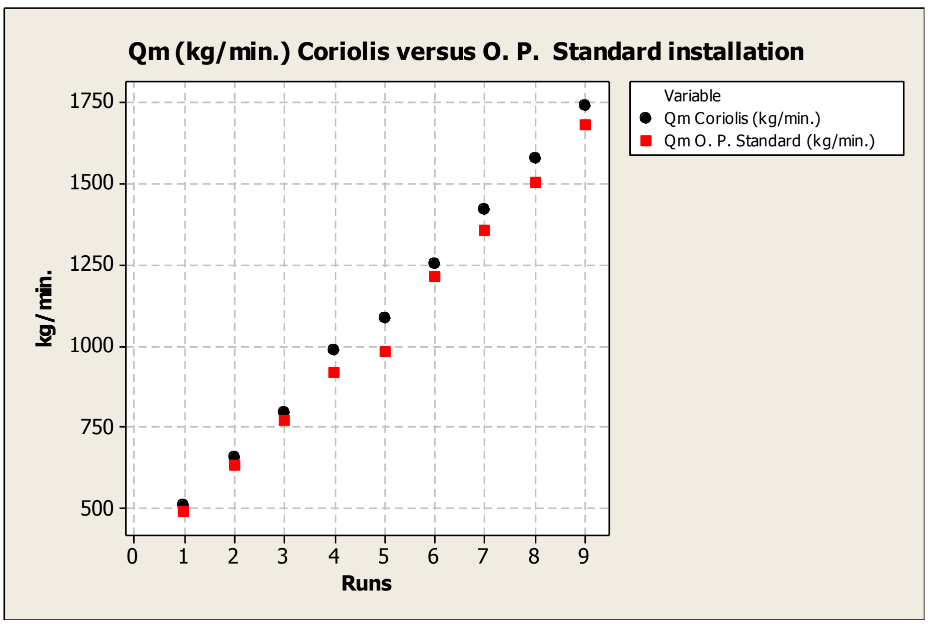

Figure 11. O.P. Standard Qm (ISO)

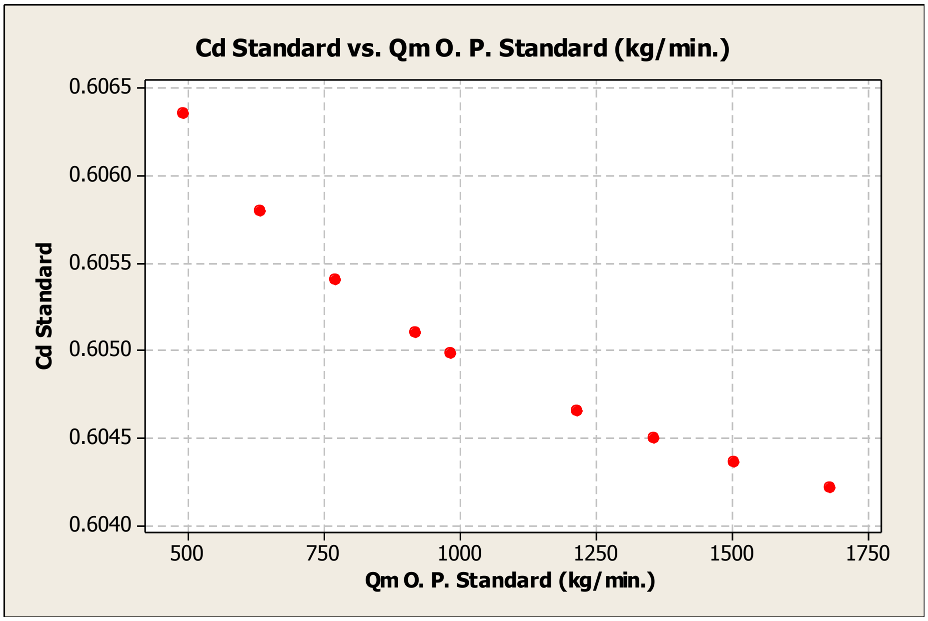

Figure 12. O. P. Standard Cd vs. Cd by standard (ISO)

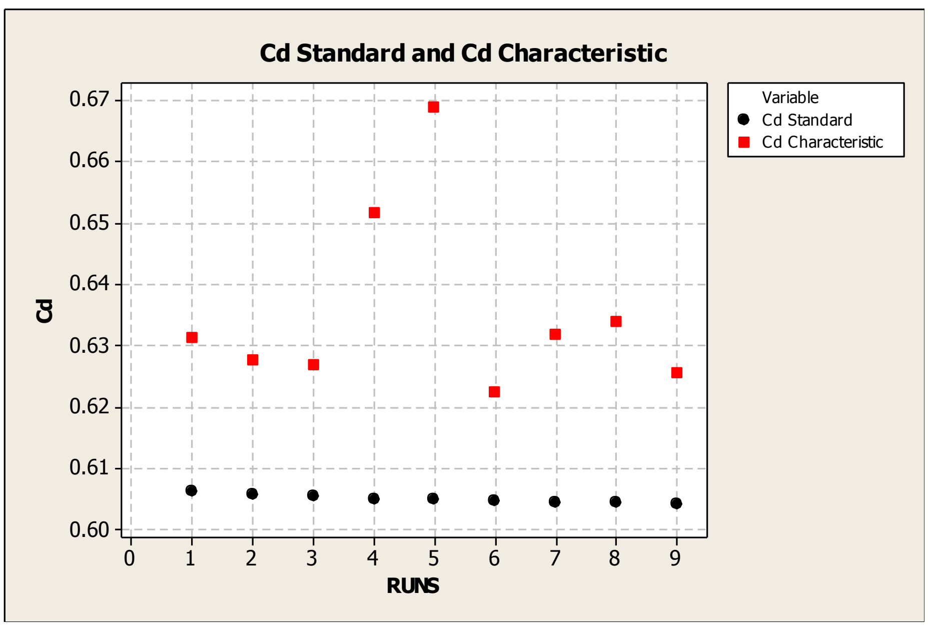

Figure 13. O.P. Cd by standard vs. Cd Characteristic (ISO)

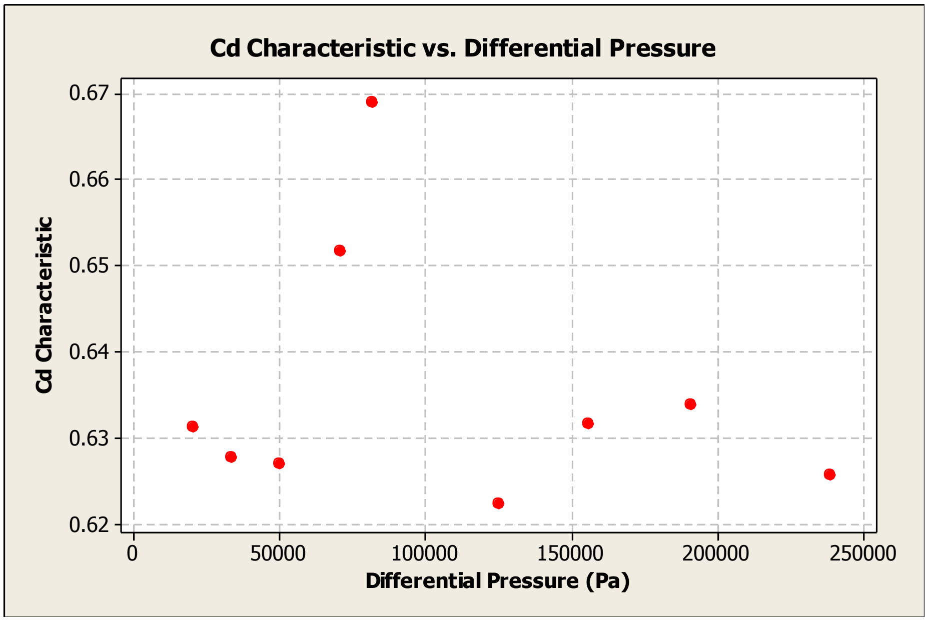

Figure 14. O.P. Cd Characteristic vs. Differential pressure (ISO)

- Orifice Plate outside of ISO-5167-1 (Outside standard)

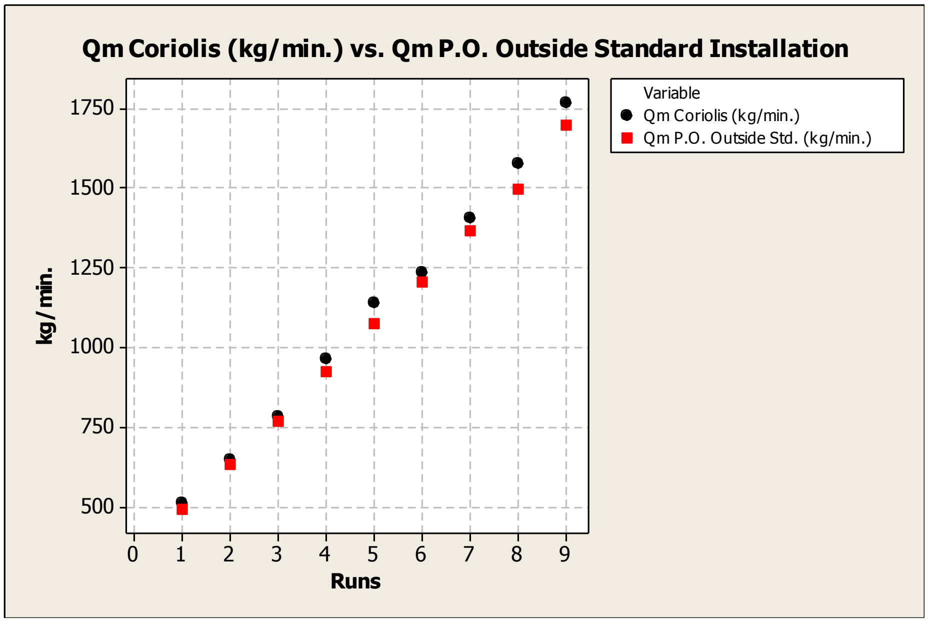

Figure 15. O.P. Standard Qm (Outside ISO)

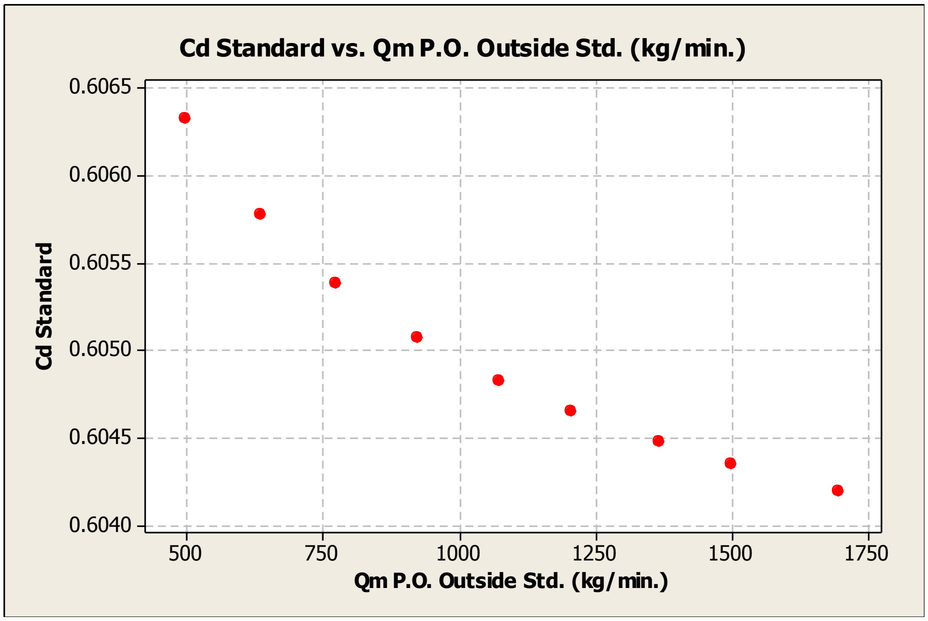

Figure 16. O. P. Standard Cd vs. Cd by standard (Outside ISO)

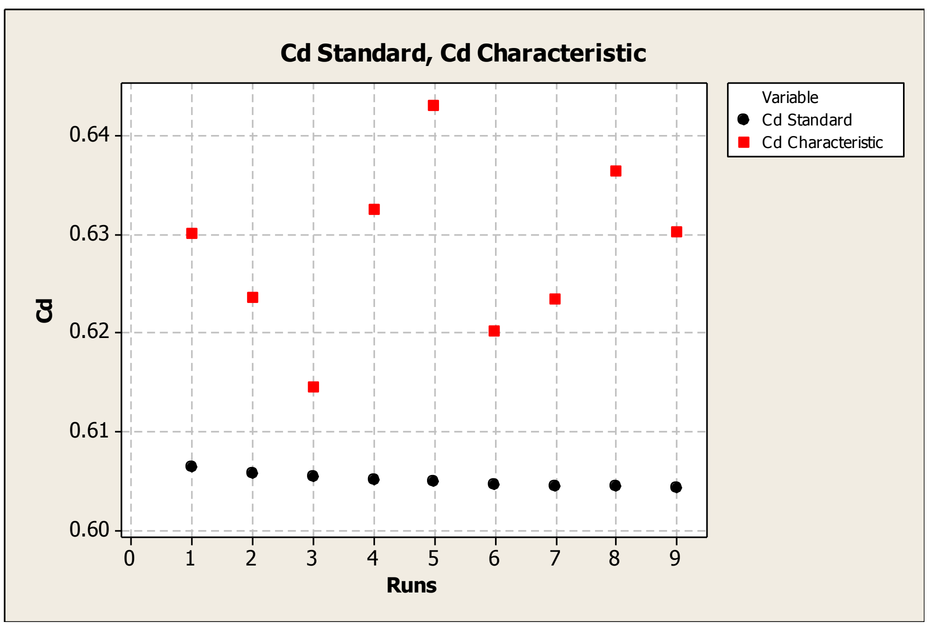

Figure 17. O.P. Cd by standard vs. Cd Characteristic (Outside ISO)

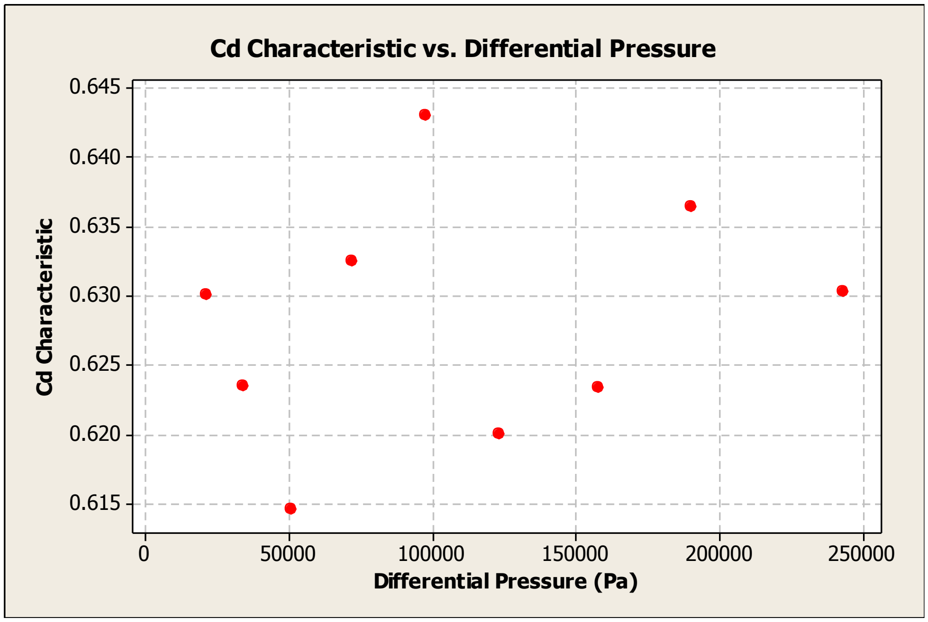

Figure 18. O.P. Cd Characteristic vs. Differential pressure (Outside ISO)

- Orifice Plate according to AGA Report no. 3 (Standard AGA)

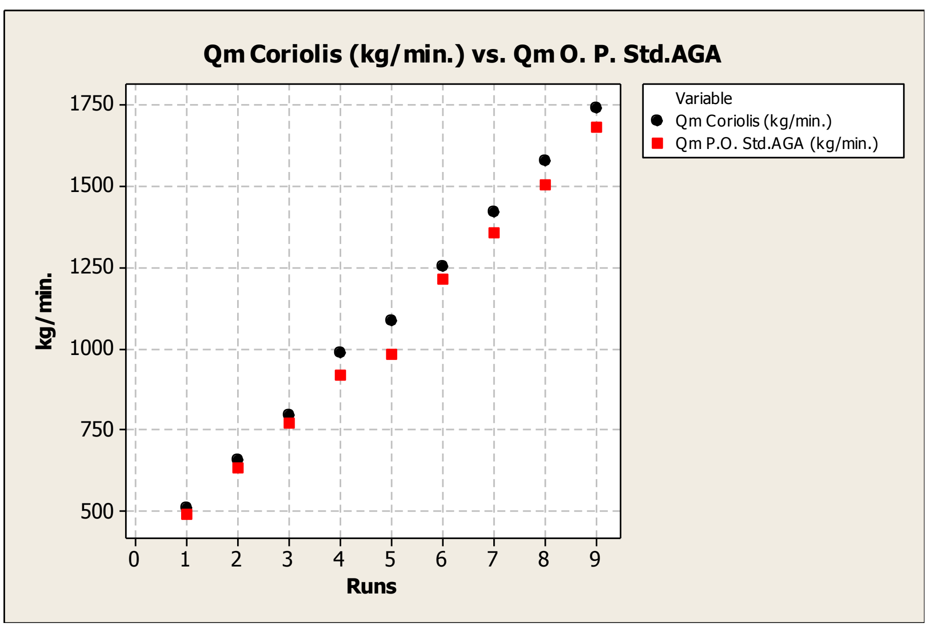

Figure 19. O.P. standard Qm (AGA)

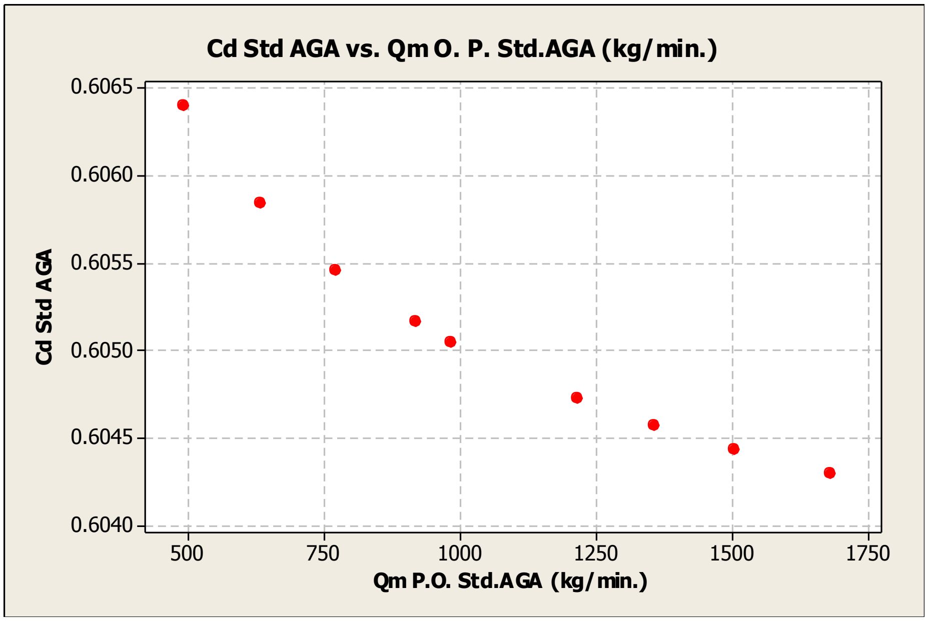

Figure 20. O. P. standard Cd vs. Cd by standard (AGA)

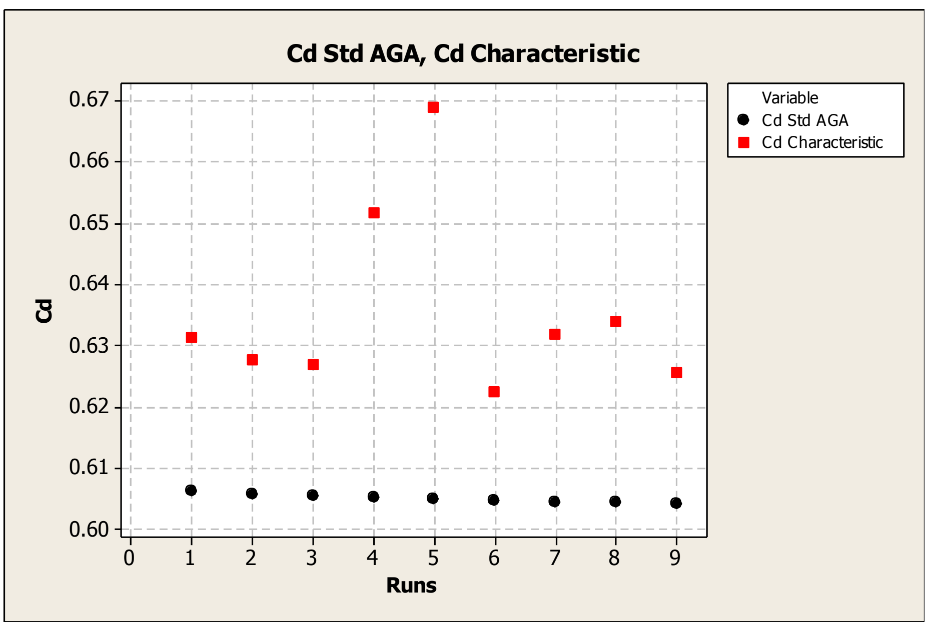

Figure 21. O.P. Cd by standard vs. Cd Characteristic (AGA)

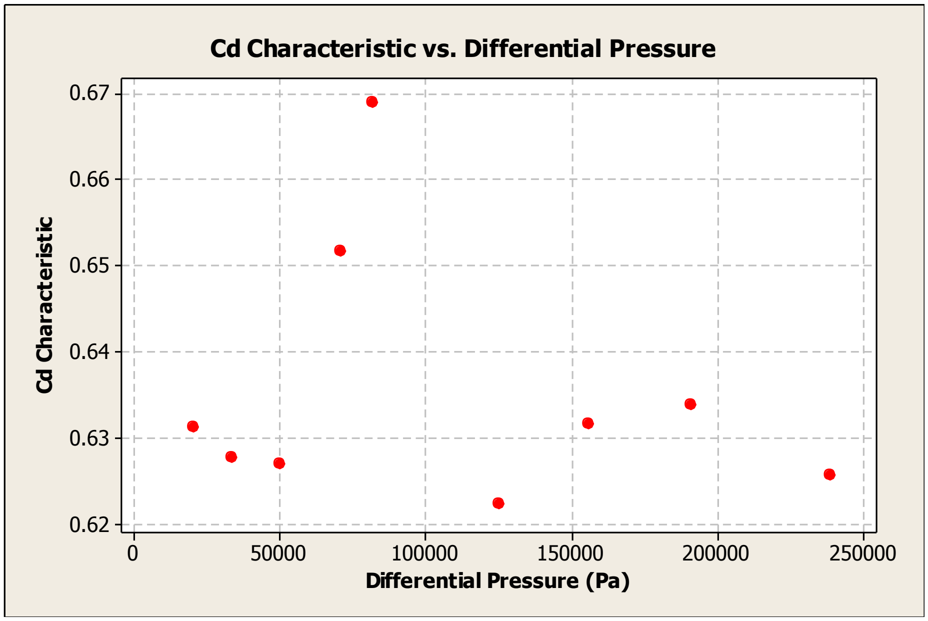

Figure 22. O.P. Cd Characteristic vs. Differential pressure (AGA)

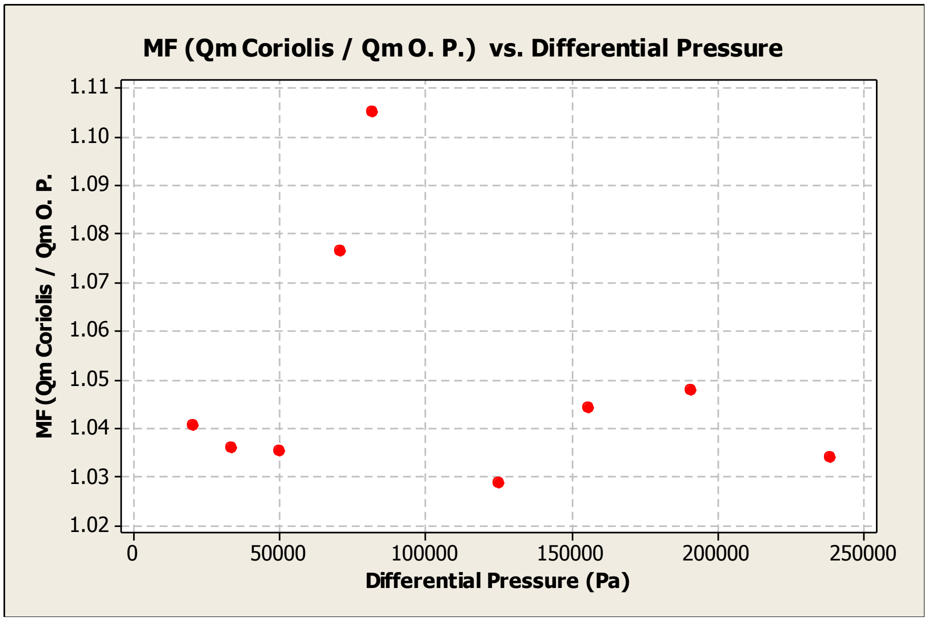

Figure 23. Meter Factor vs. Differential pressure (AGA)

- Orifice Plate outside of AGA Report no. 3 (Outside standard AGA)

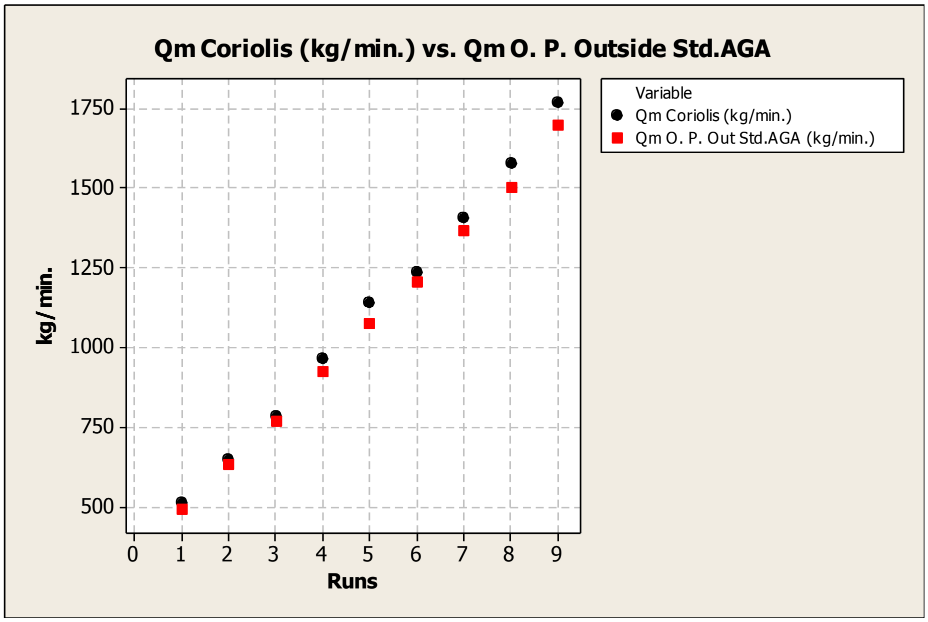

Figure 24. O.P. standard Qm (Outside AGA)

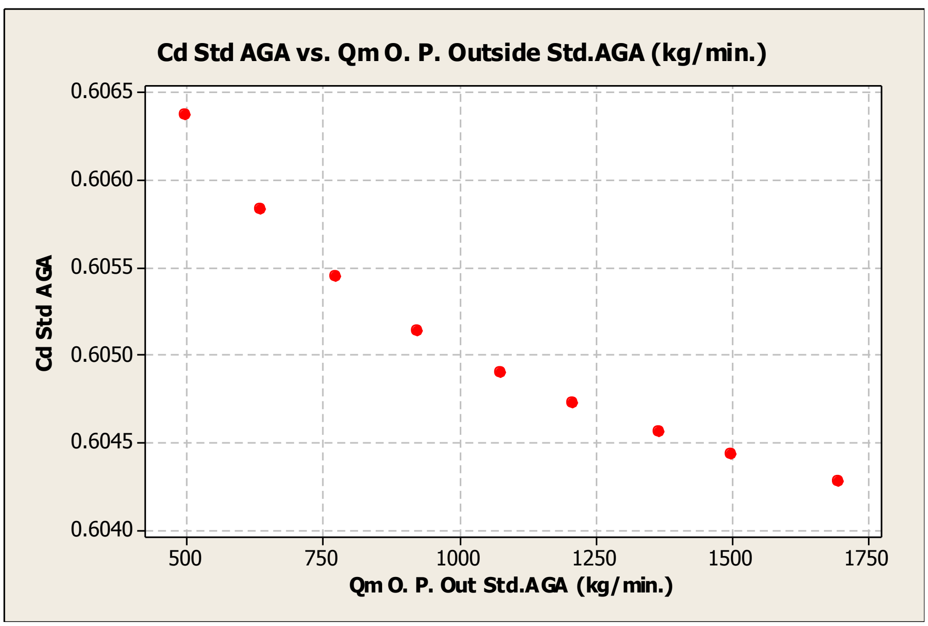

Figure 25. O.P. standard Qm (Outside AGA)

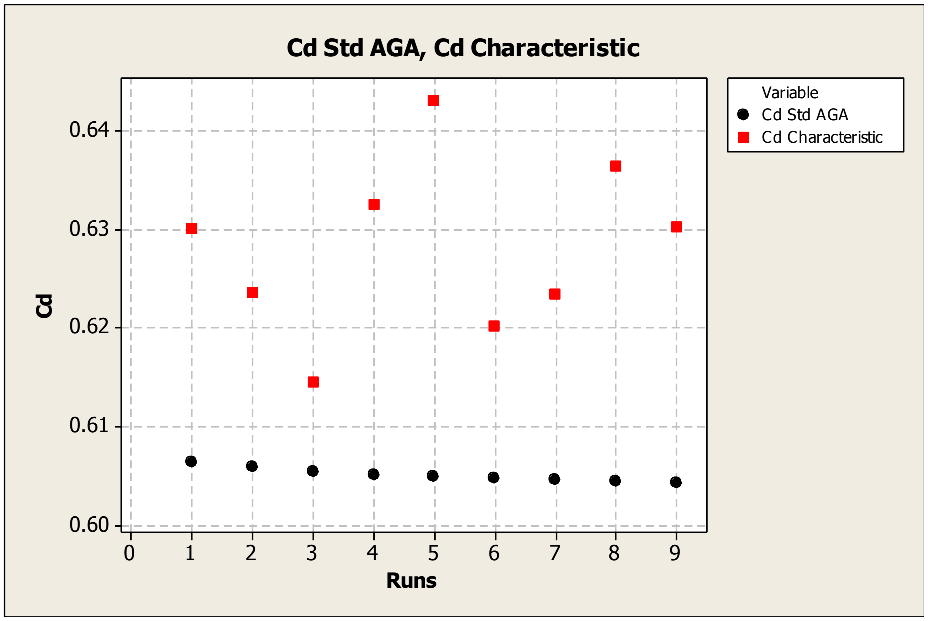

Figure 26. O.P. standard Cd vs. Cd by standard (Outside AGA)

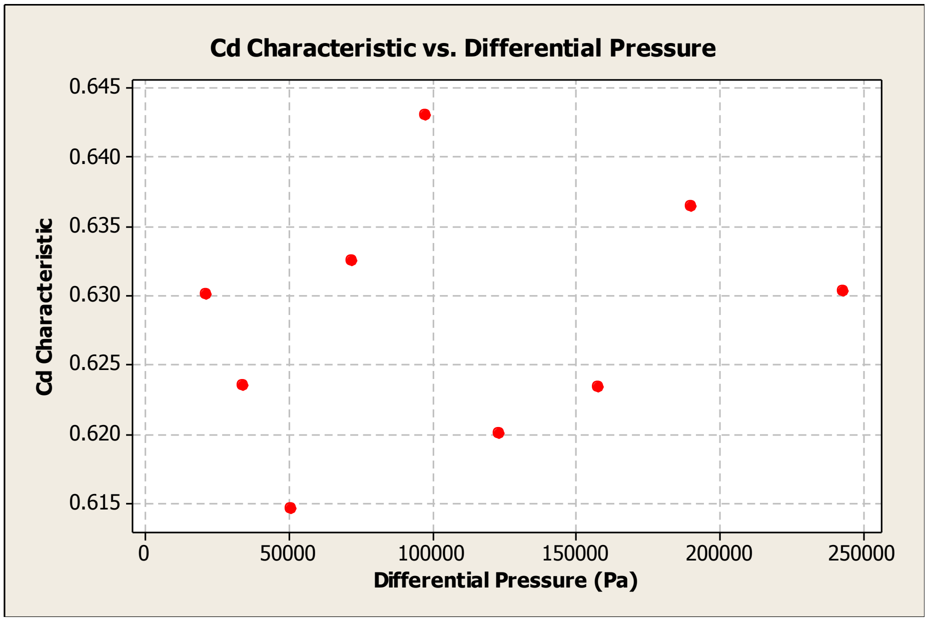

Figure 27. O.P. Cd Characteristic vs. Differential pressure (Outside AGA)

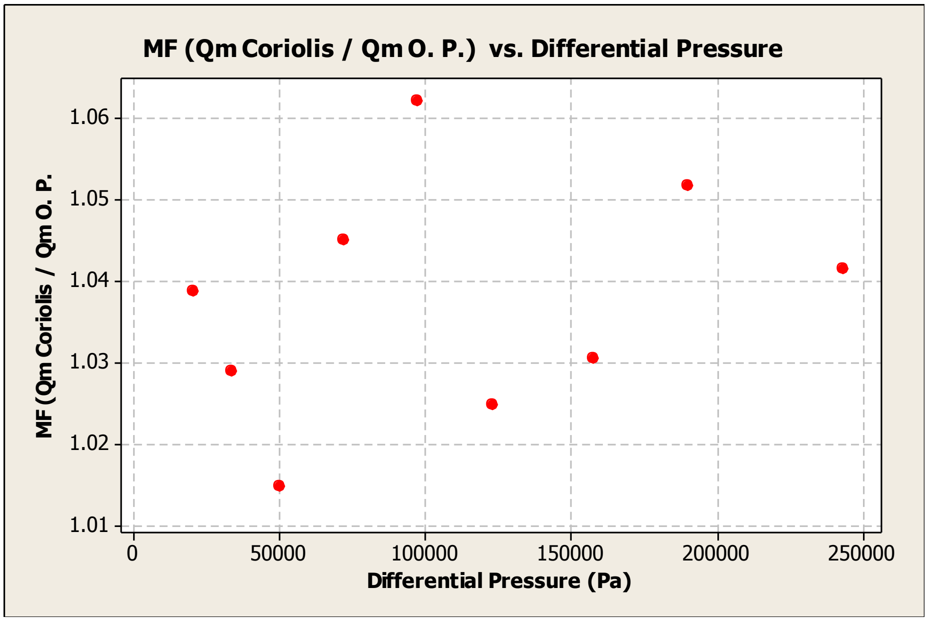

Figure 28. Meter Factor vs. Differential pressure (Outside AGA)

3.2. Venturi flow meter

- Venturi according to ISO-5167-4 (Standard)

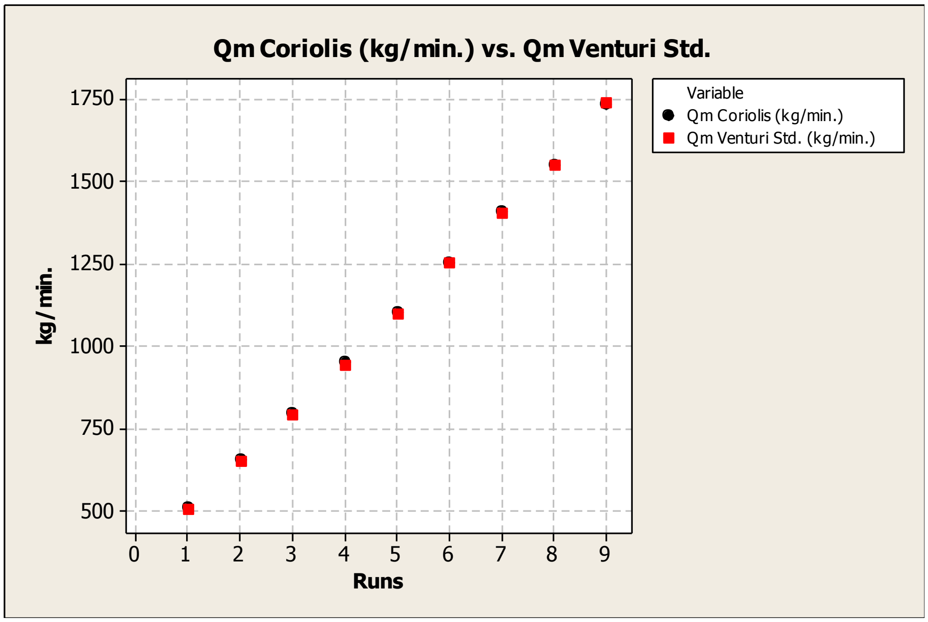

Figure 29. Venturi Qm (Standard ISO)

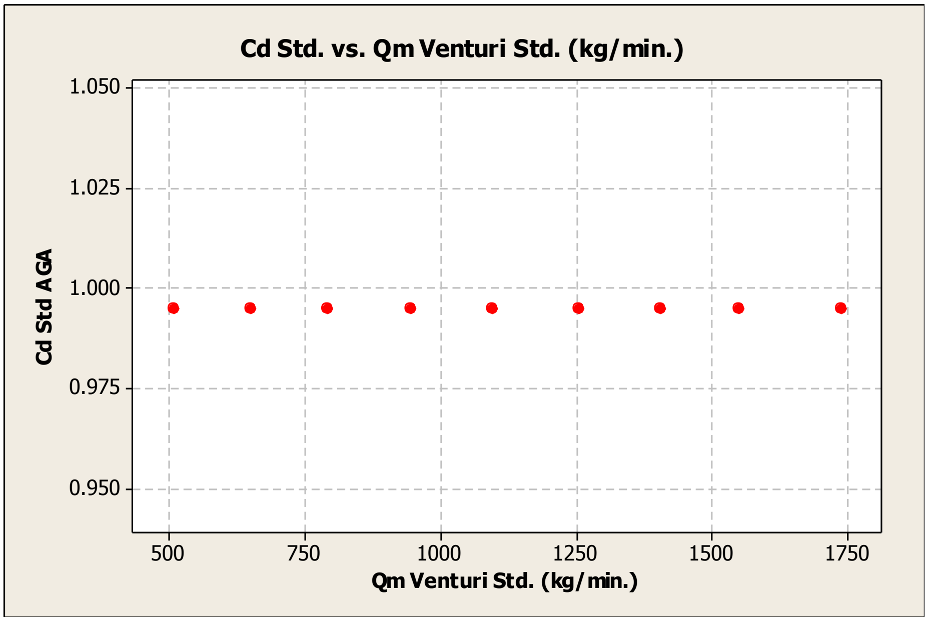

Figure 30. Venturi Cd by Standard vs. Qm (Standard ISO)

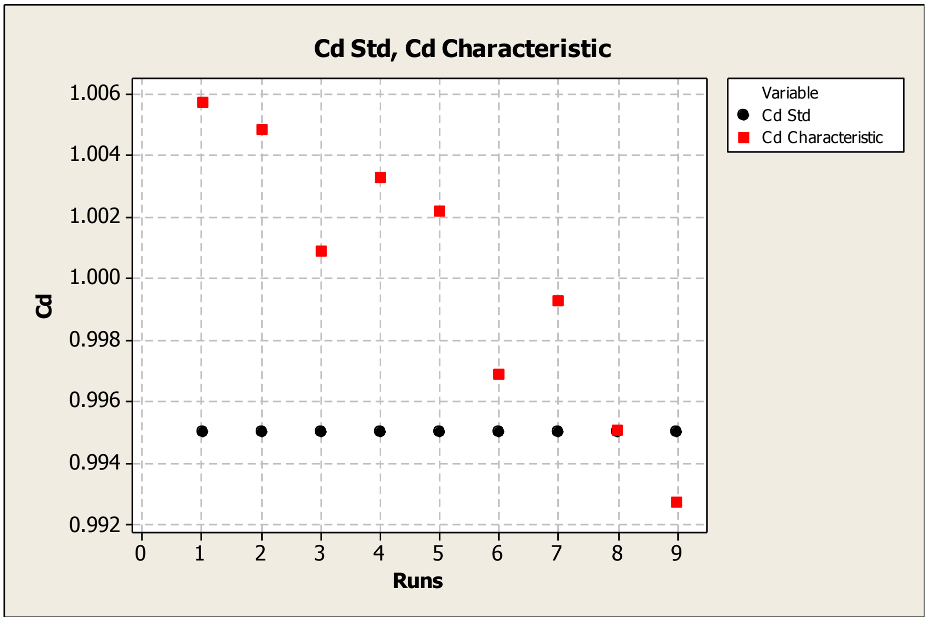

Figure 31. Venturi Cd by Standard vs. Cd Characteristic (Standard ISO)

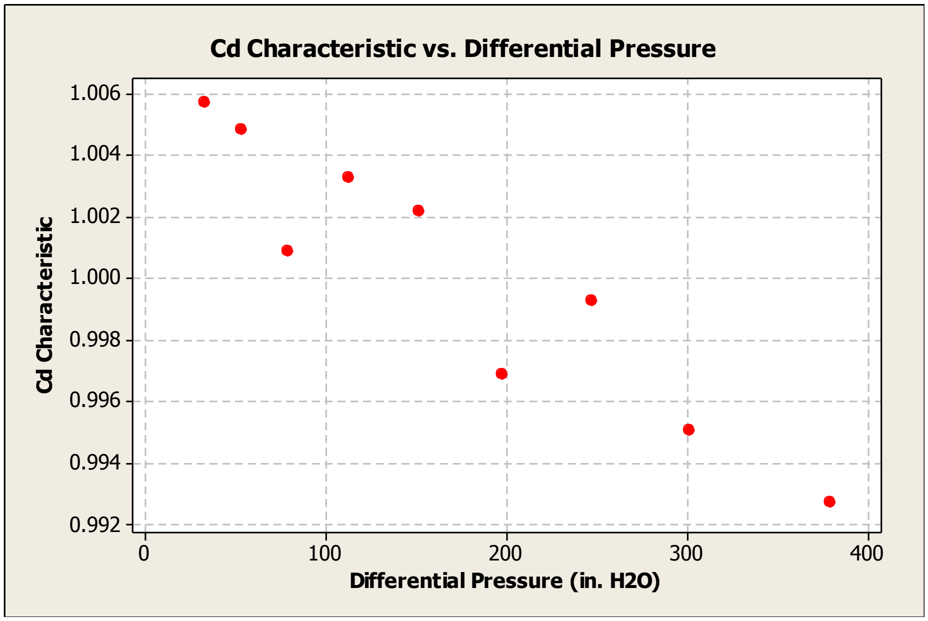

Figure 32. Venturi Cd Characteristic vs. Differential pressure (Standard ISO)

- Venturi outside of ISO-5167-4 (Outside standard)

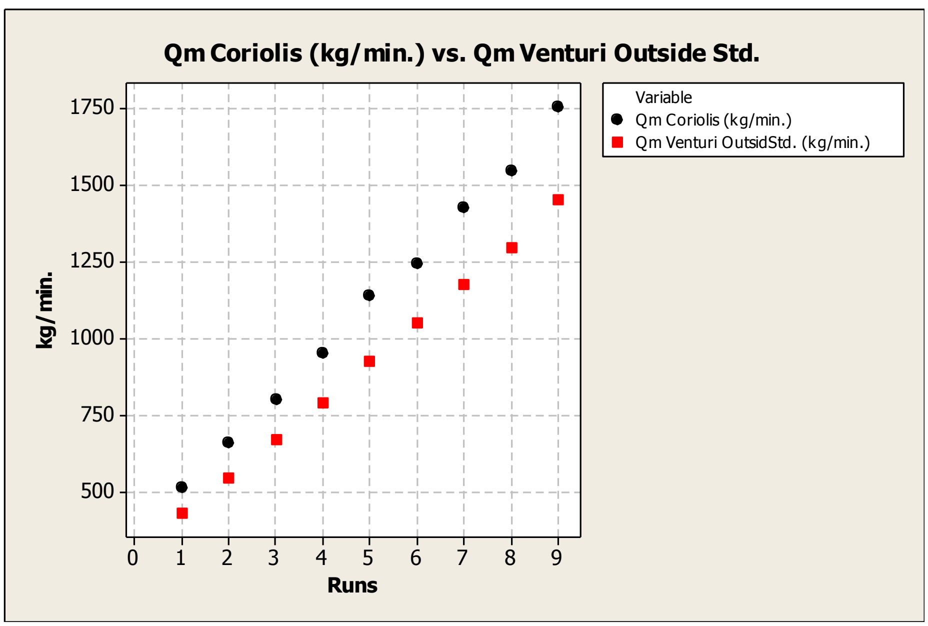

Figure 33. Venturi Qm (Outside Standard ISO)

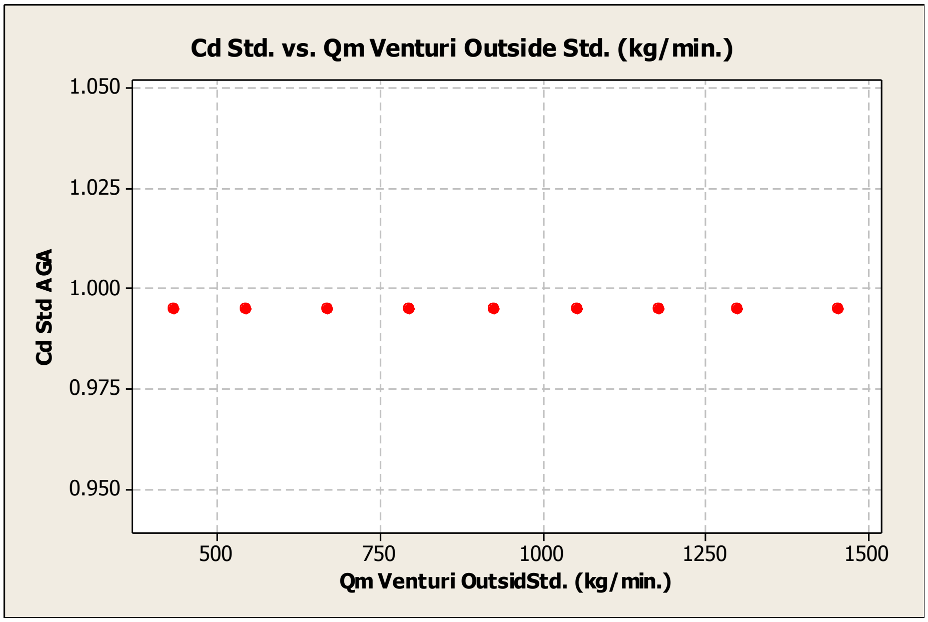

Figure 34. Venturi Cd by Standard vs. Qm (Outside Standard ISO)

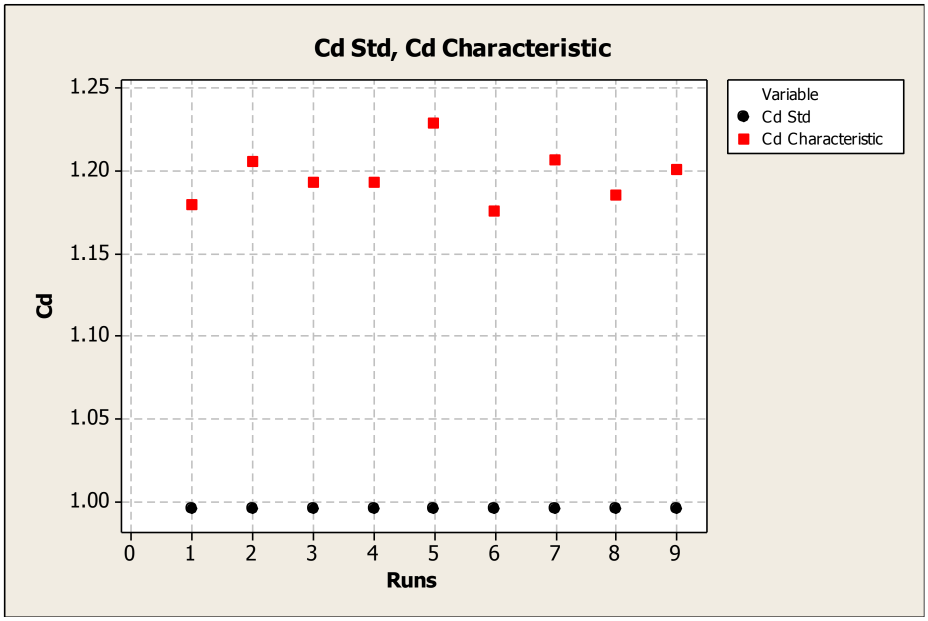

Figure 35. Venturi Cd by Standard vs. Cd Characteristic (Outside Standard ISO)

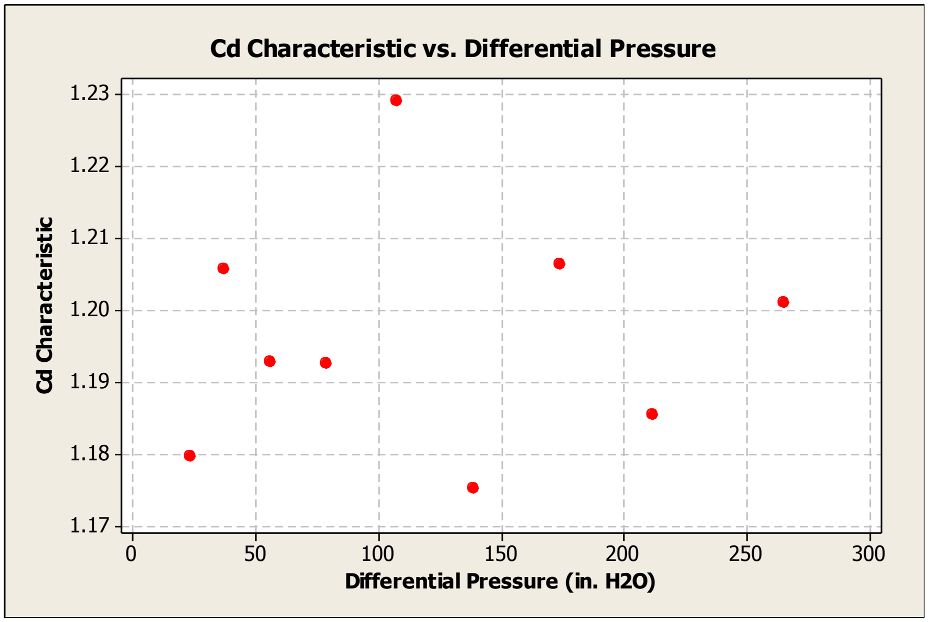

Figure 36. Venturi Cd Characteristic vs. Differential pressure (Outside Standard ISO)

3.3. Cone flow meter

- Cone according to ISO-5167-5 (Standard)

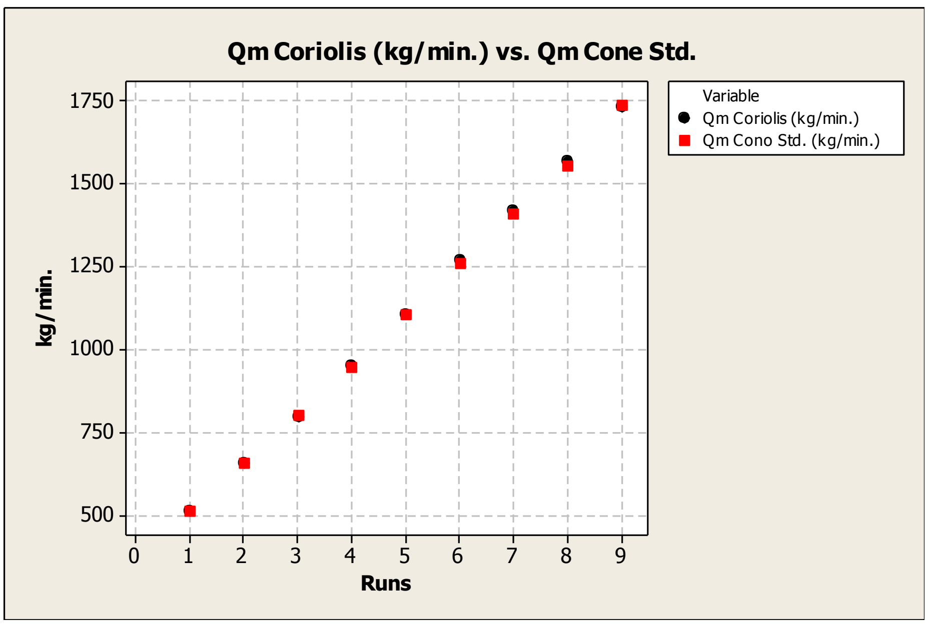

Figure 37. Cone Qm (Standard ISO)

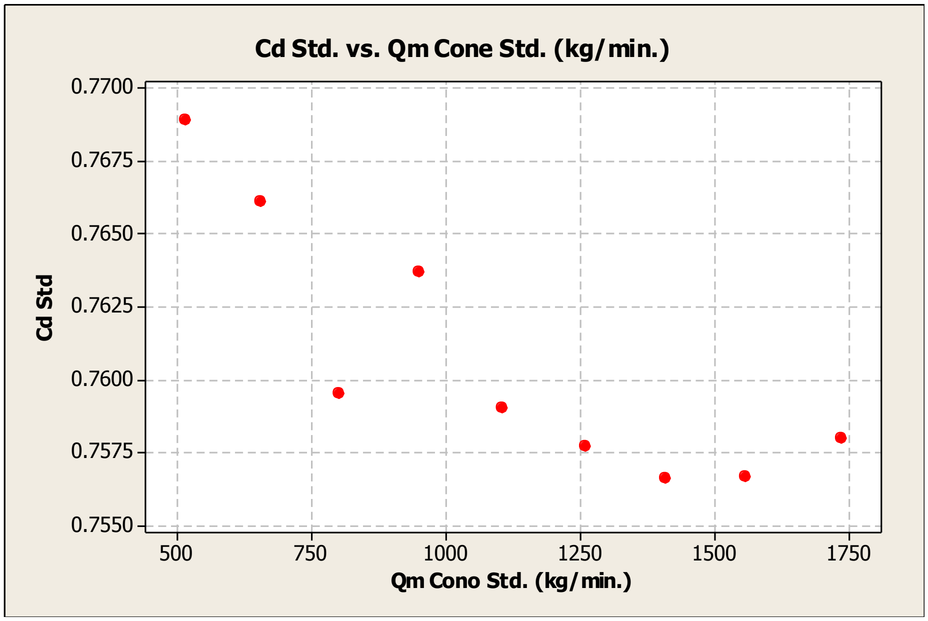

Figure 38. Cone Cd by Standard vs. Qm (Standard ISO)

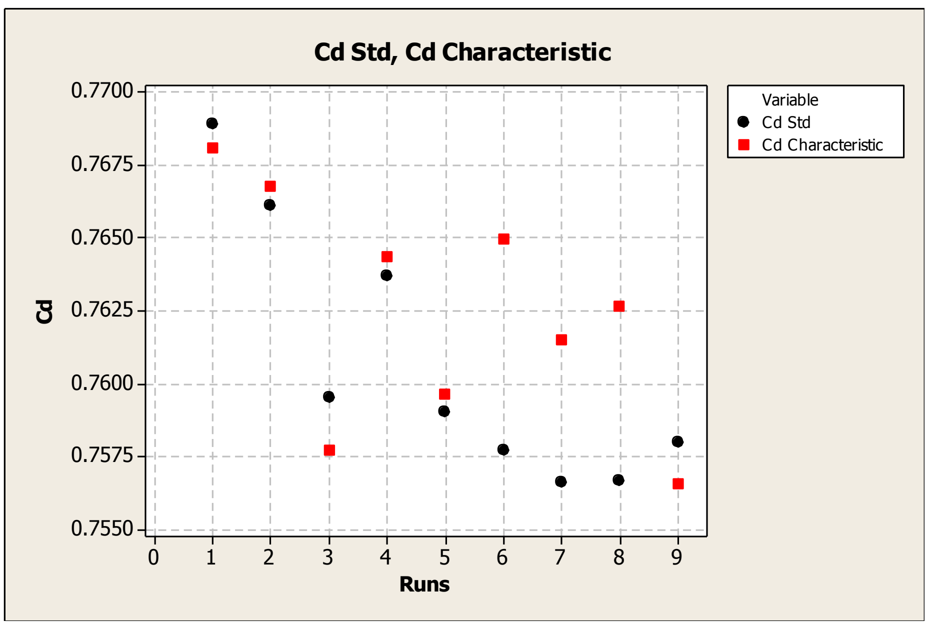

Figure 39. Cone Cd by Standard vs. Cd Characteristic (Standard ISO)

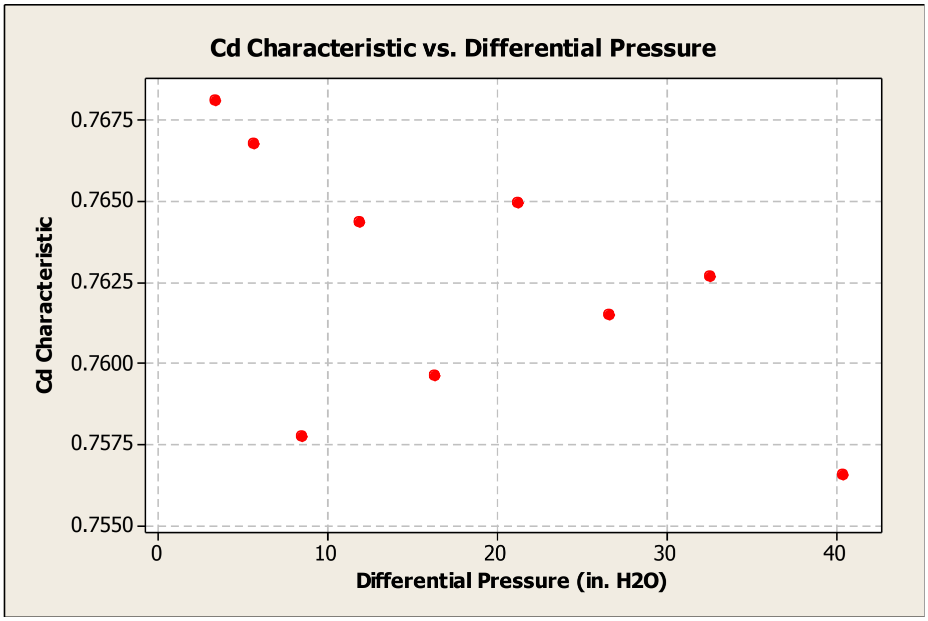

Figure 40. Cone Cd Characteristic vs. Differential pressure (Standard ISO)

- Cone outside of ISO-5167-5 (Outside standard)

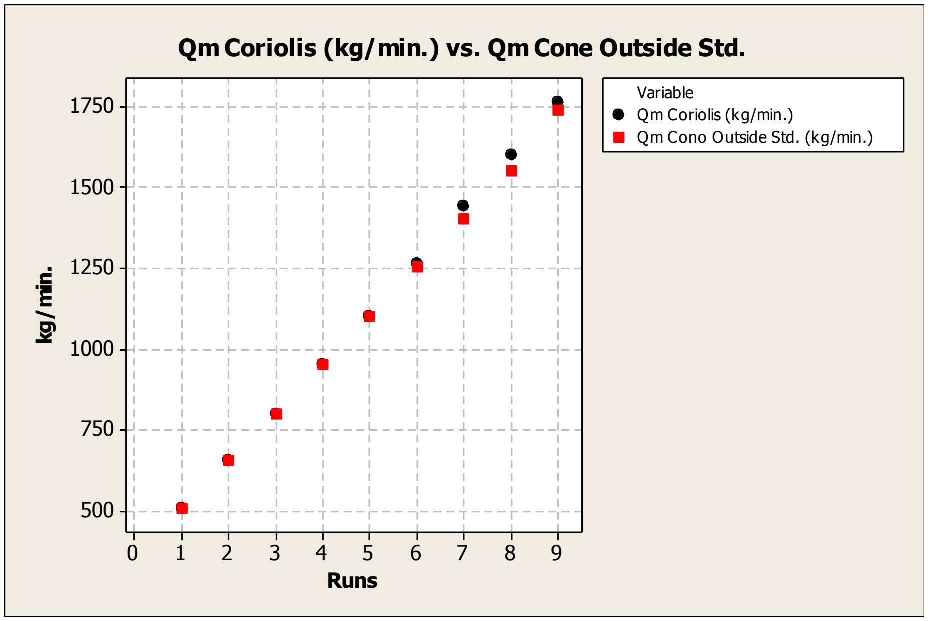

Figure 41. Cone Qm (Outside Standard ISO)

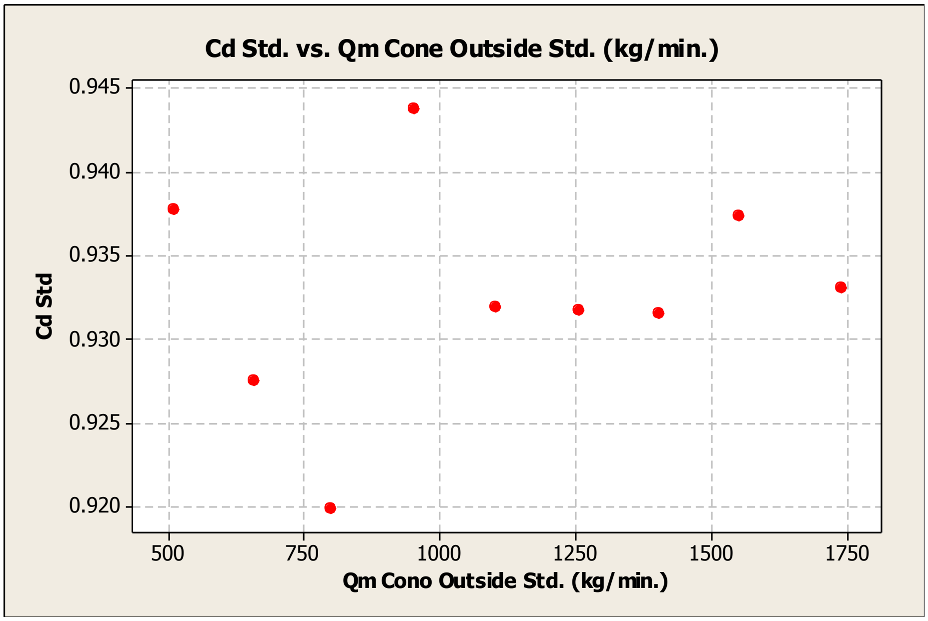

Figure 42. Cone Cd by Standard vs. Qm (Outside Standard ISO)

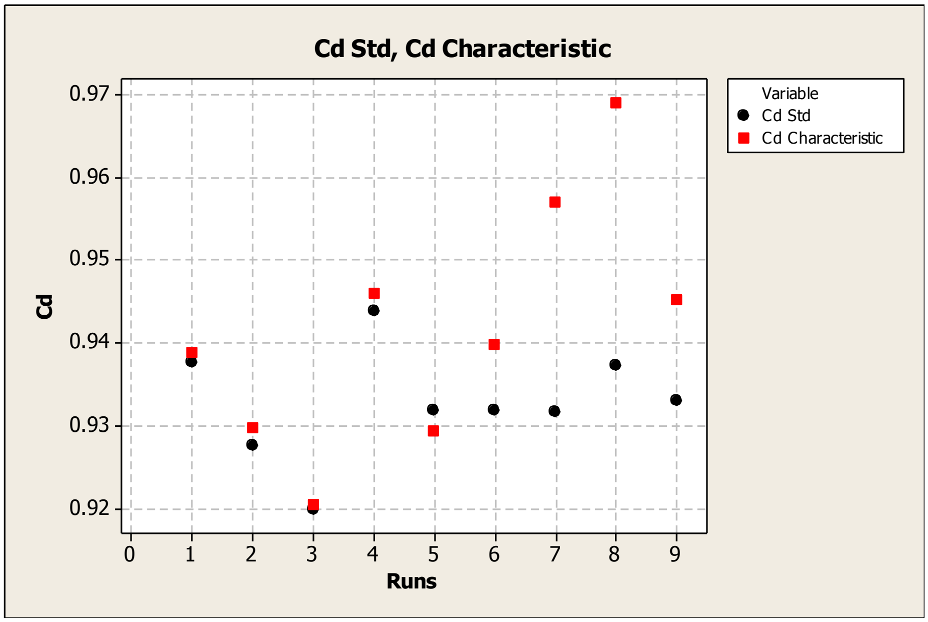

Figure 43. Cone Cd by Standard vs. Cd Characteristic (Outside Standard ISO)

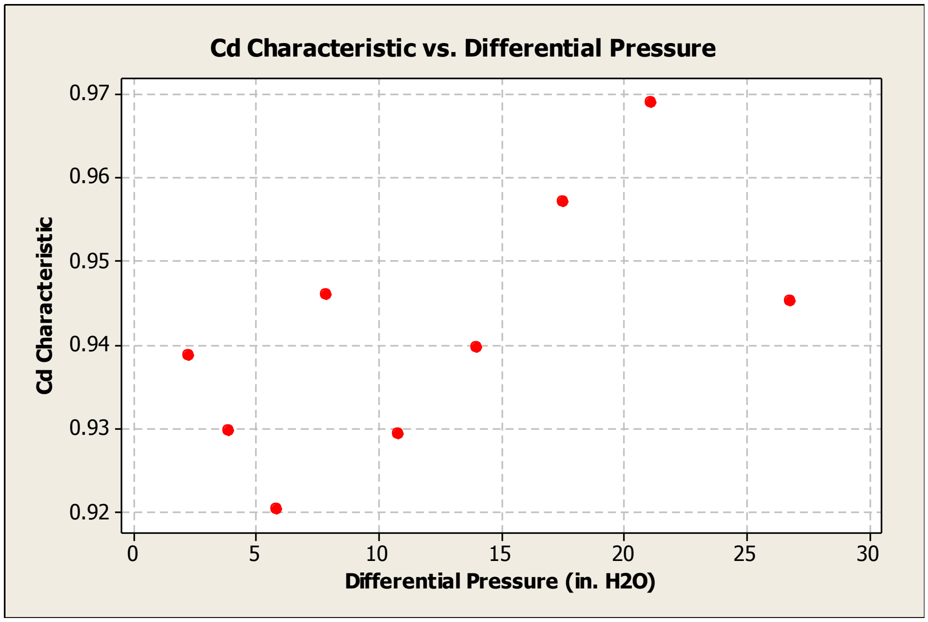

Figure 44. Cone Cd Characteristic vs. Differential pressure (Outside Standard ISO)

4. Conclusions

CIATEQ performs the design and manufacture of pressure differential type meters (orifice plate, Venturi and Cone) under the recommendations of the ISO 5167 standard.

The performance of this type of tests is intended to characterize the performance of each of the meters, under the operating conditions (flow, pressure and temperature) in which they will be normally operating.

The particular characteristics of the installation of the flow laboratory of CIATEQ, such as distances of straight pipe, types of valves, pumping system, repeatability of the measurements, process conditions, physical state of the pipeline, type of fluid, effects environmental and the specifications of the instruments used for the measurement, together generate a direct impact on the value of the discharge coefficient obtained empirically.

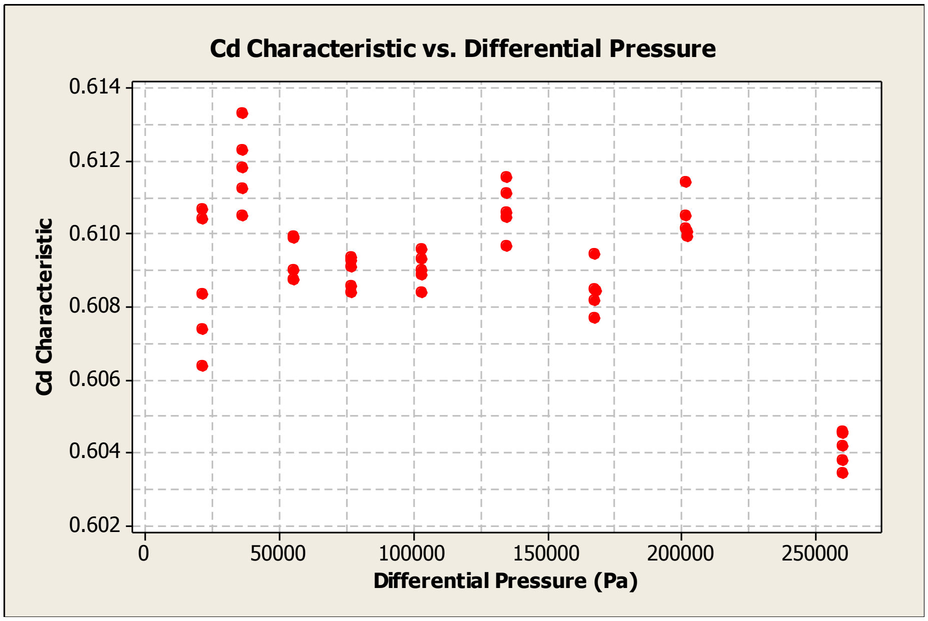

Figure 45. Interpolation data O.P.

A tool is developed to characterize the flow meters for each particular installation, by means of a "baseline" that allows to establish the own and particular values of the installation, generating an adjustment table (Differential pressure against discharge coefficient, or MF vs. ΔP) as an option to correct the value of the measurements made, by means of polynomial adjustment or interpolation of points.

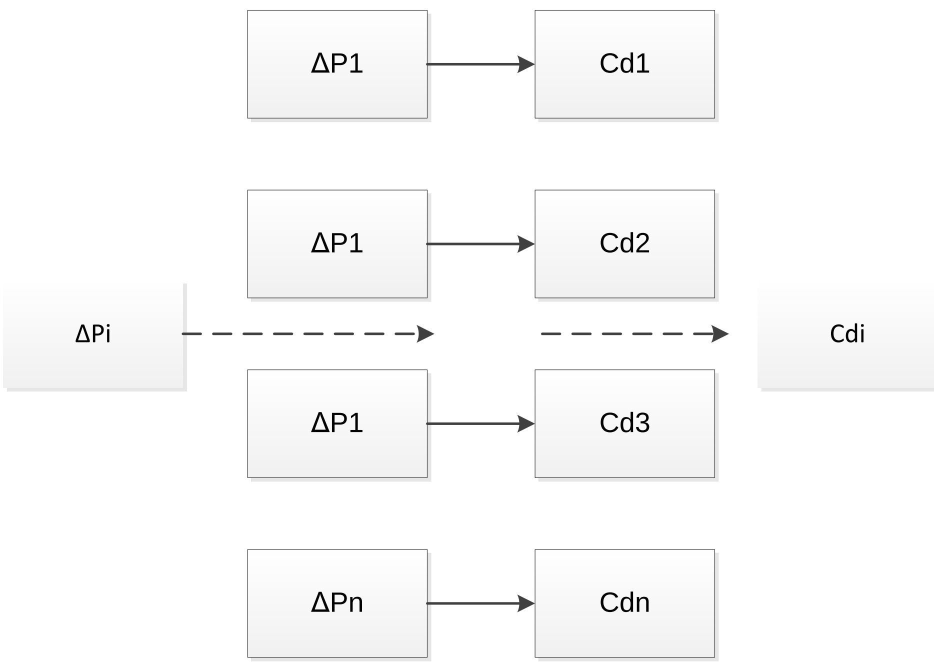

Figure 46. Interpolation routine

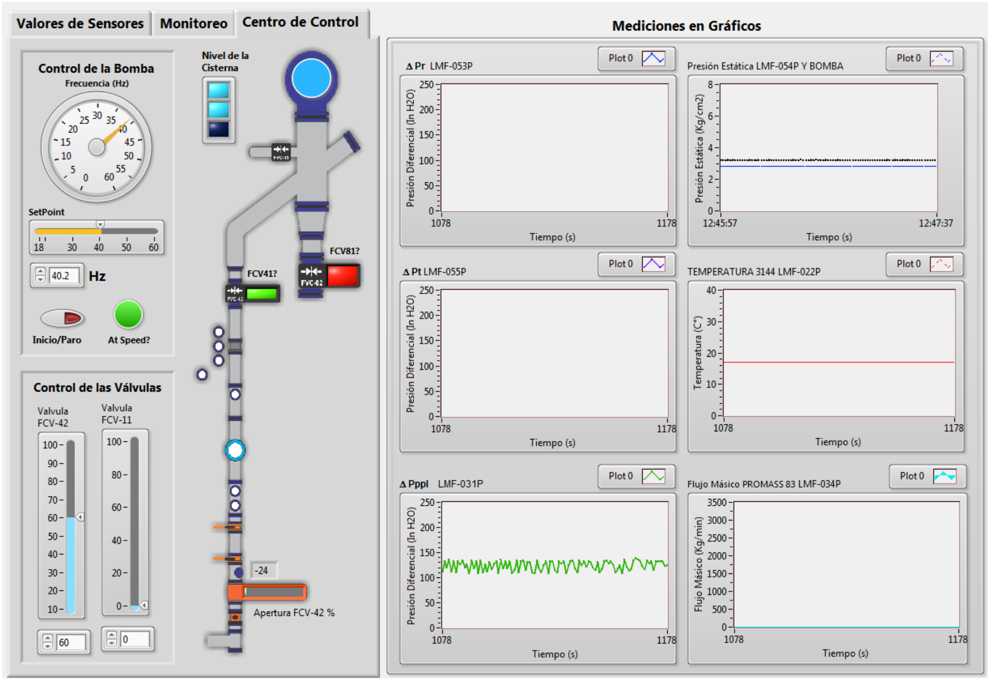

Figure 47. Monitoring system

The next step is to extend the study to natural gas flow systems, incorporating into the Characterization System, the considerations of the joint effects of the isentropic exponent value and the Joule - Thompson effect.

5. References

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