Volume Metrology in Mexico and the USA

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NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

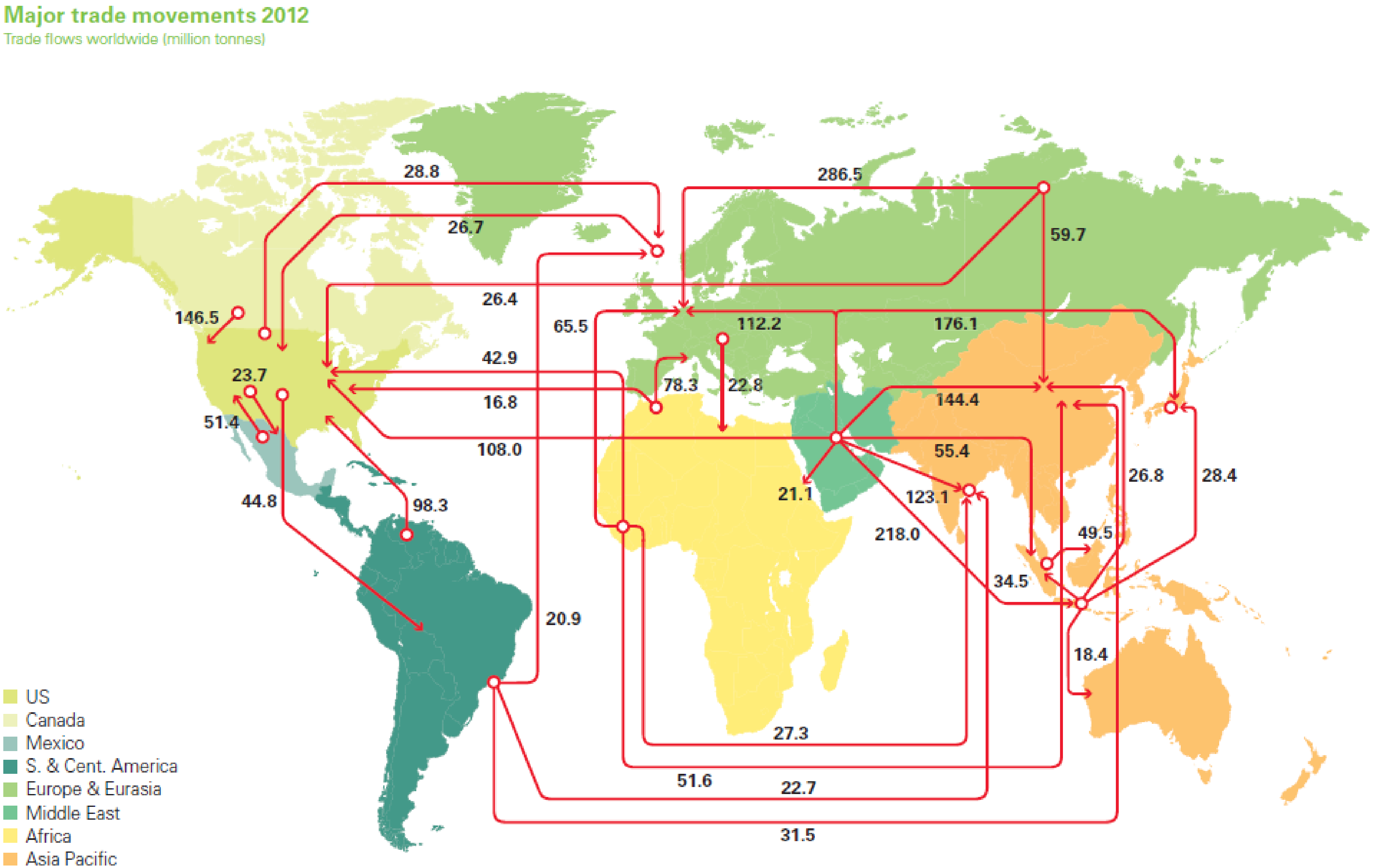
CENAM
CENTRO NACIONAL DE METROLOGÍA

Outline

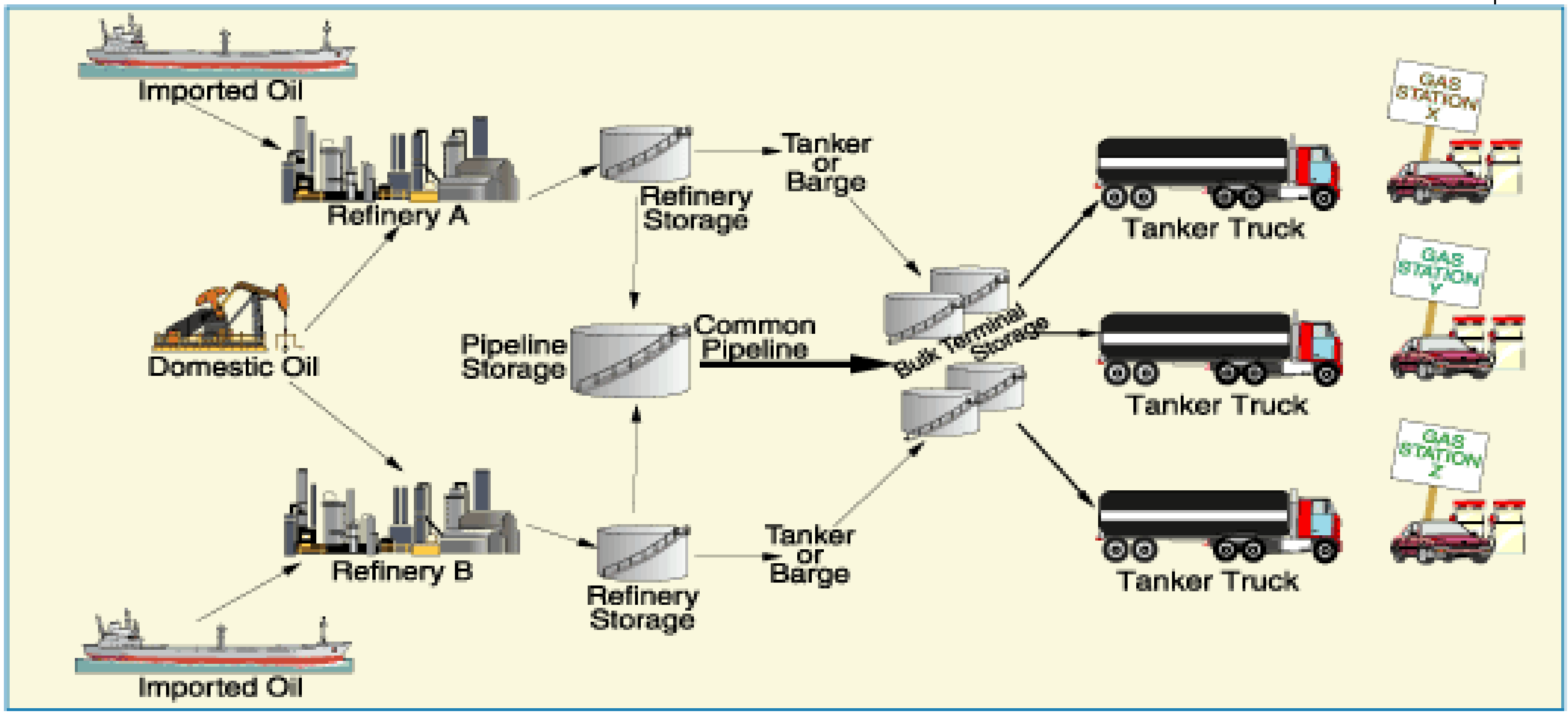
1. Consumption and Distribution
2. Calibration and Traceability Chain
3. Volume Calibrations at NIST
4. Volume Calibrations at CENAM
5. CCM.FF-K4
6. Questions and comments

1 Impact of volume measurements

Major Oil Trade Movements

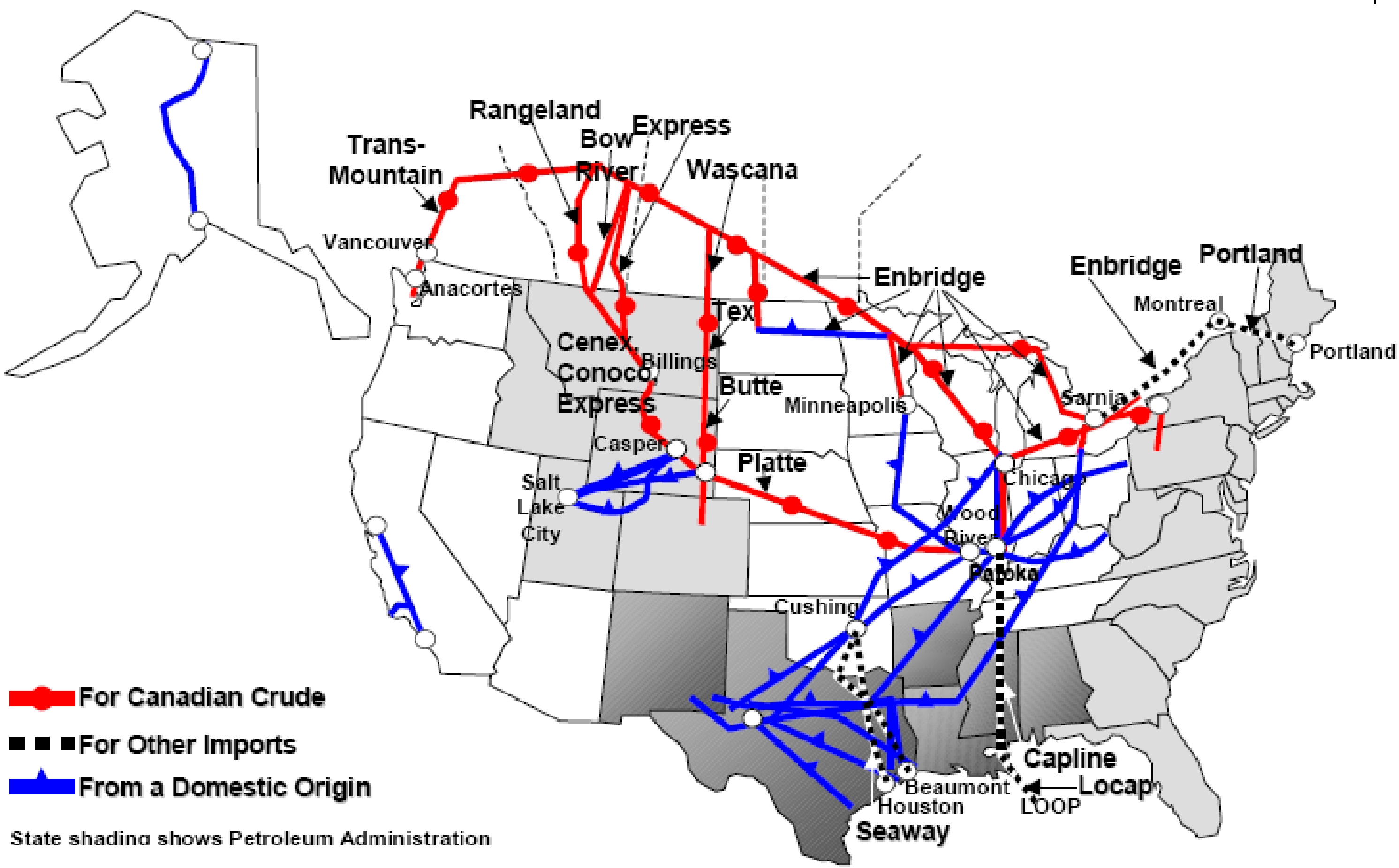


Distribution



Petroleum is metered > 11 times between the well head and the consumer!

Selected Crude Oil Trunkline Systems



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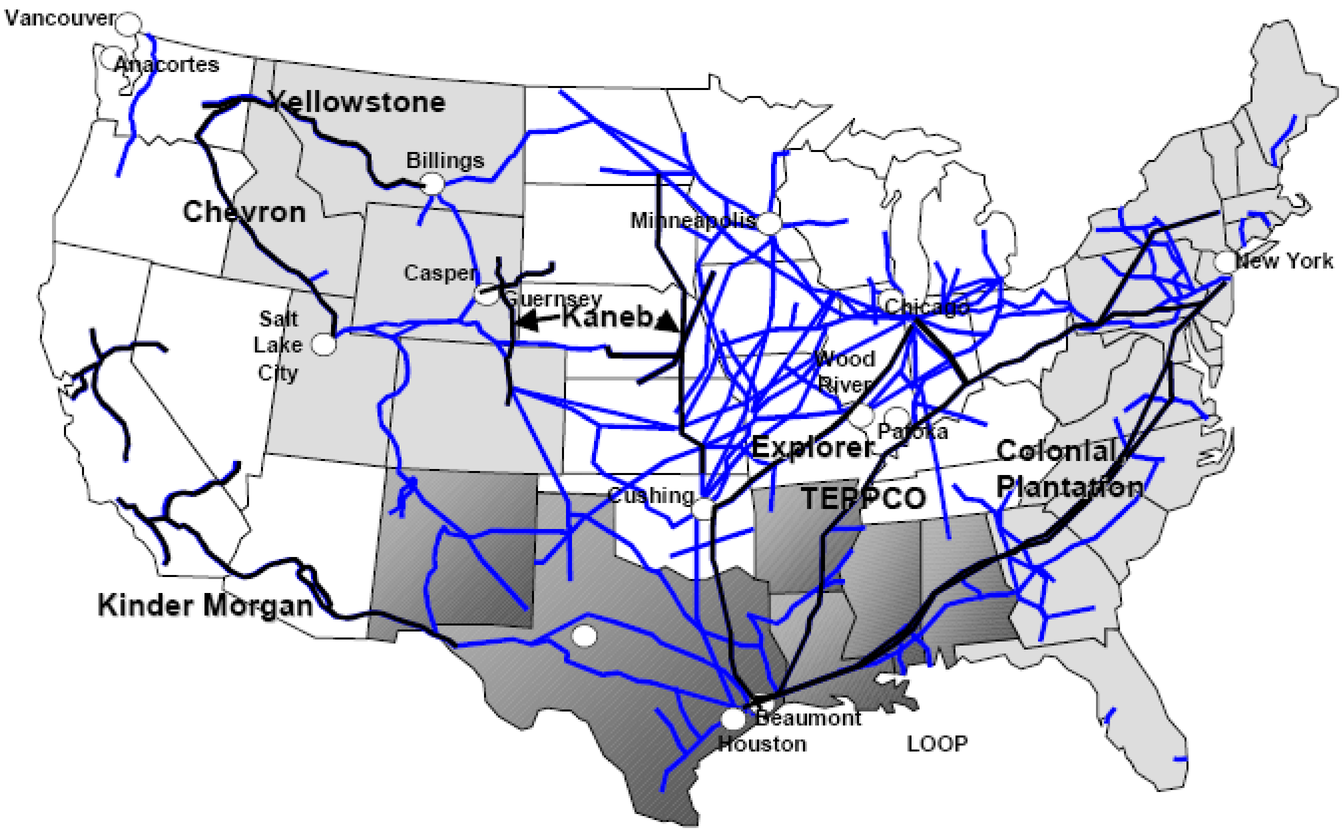
Major Refined Product Pipelines

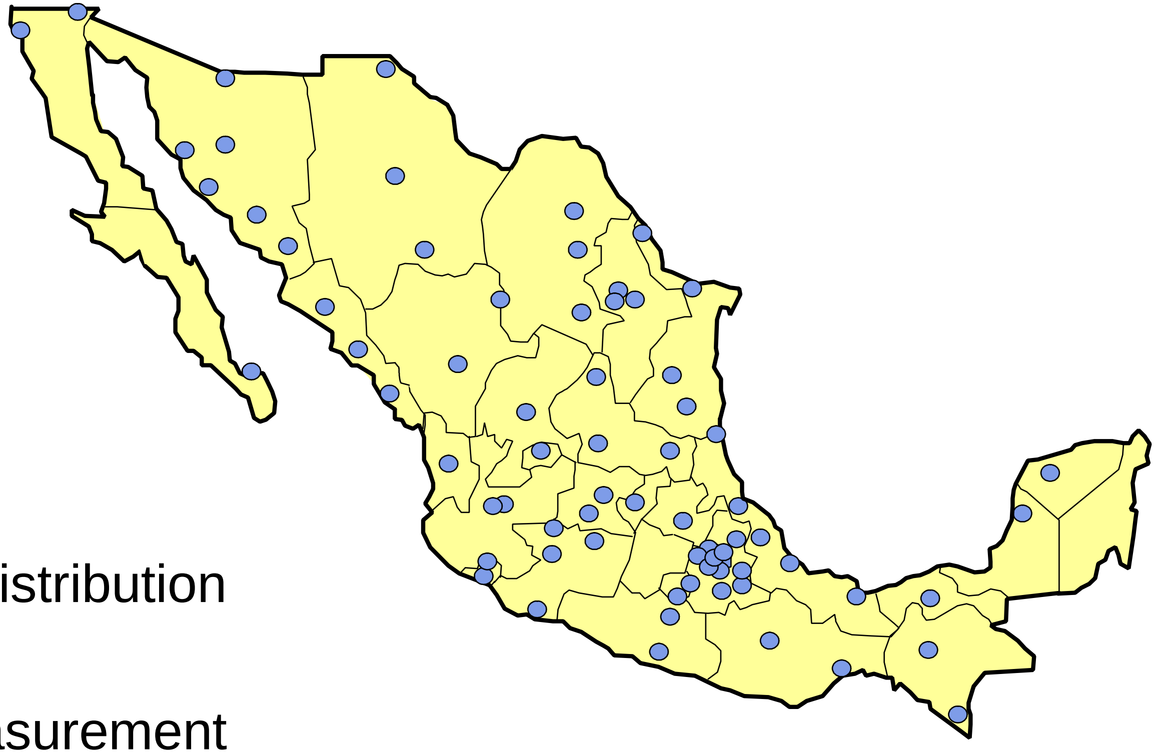


Production and Distribution

9115 km

4647 km

Distribution Terminals



74 Storage and Distribution Terminals nationwide

Over **900** installed measurement skids for loading and/or unloading road- and rail Tanks

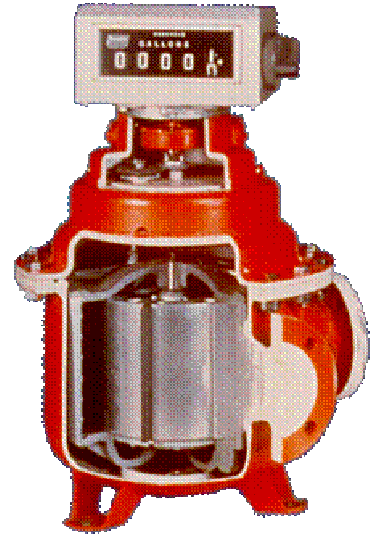
2 Calibration and Traceability Chain

Elements of the Traceability Chain

1. Flowmeter (PD, Turbine, Coriolis, Ultrasonic)
2. Prover (Small Volume Prover, Ball Prover)
3. Tank prover
4. Master Meter
5. Field Test Measures or Masses
6. National Metrology Laboratory

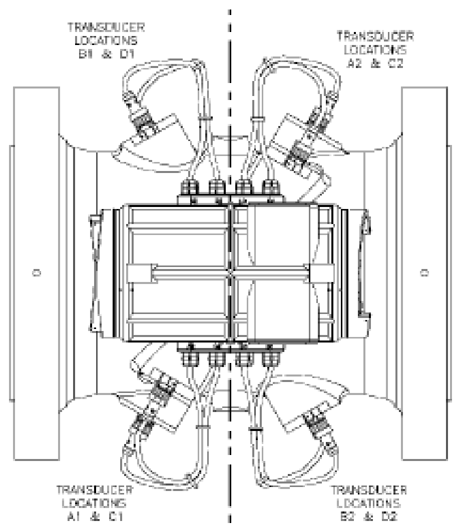
Flowmeter

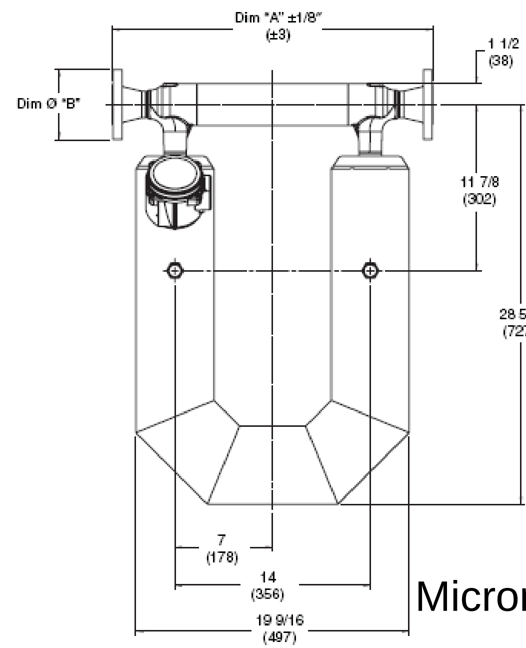
- ❑ Positive Displacement
- ❑ Turbine
- ❑ Ultrasonic
- ❑ Coriolis



Smith

Daniel

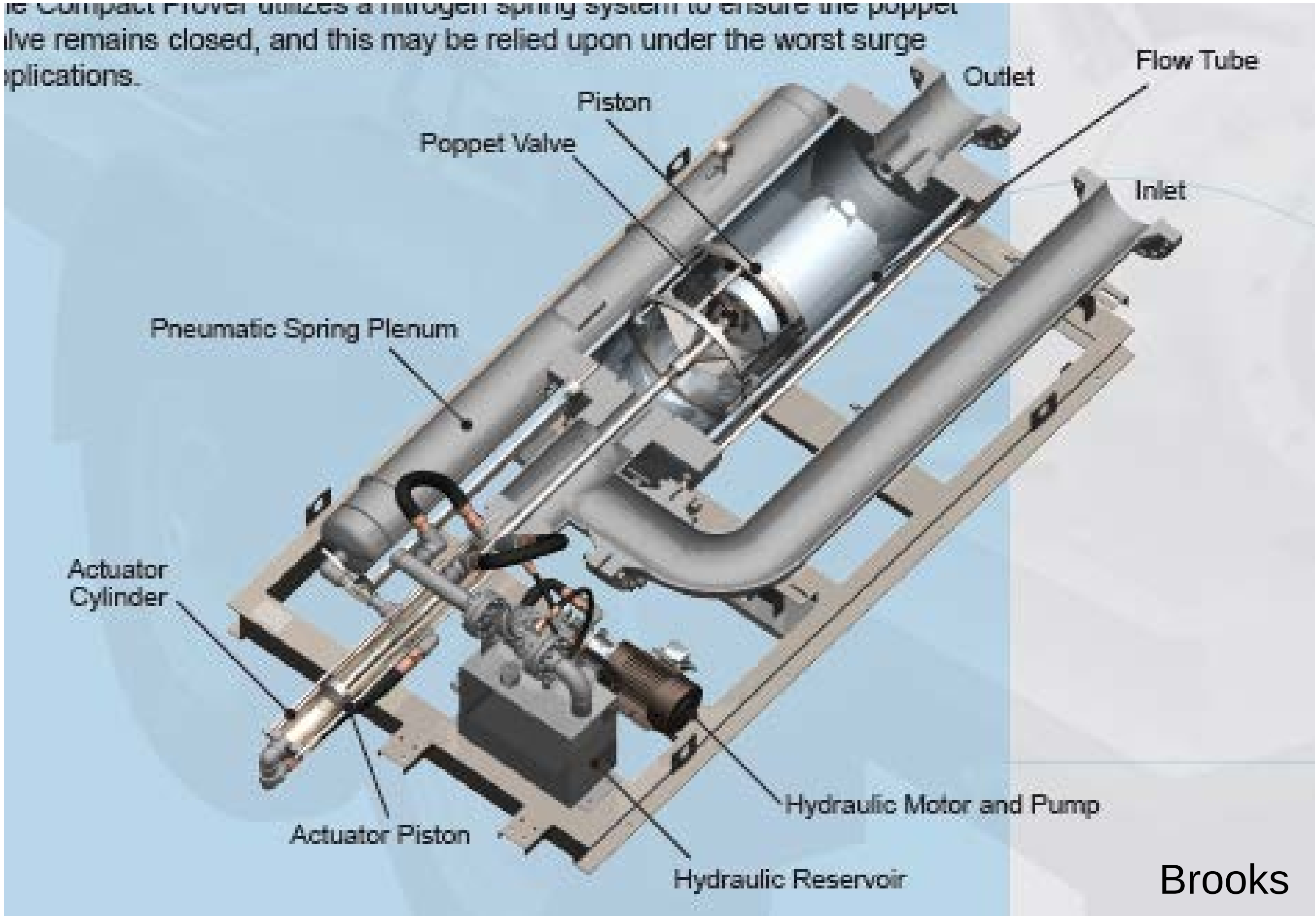




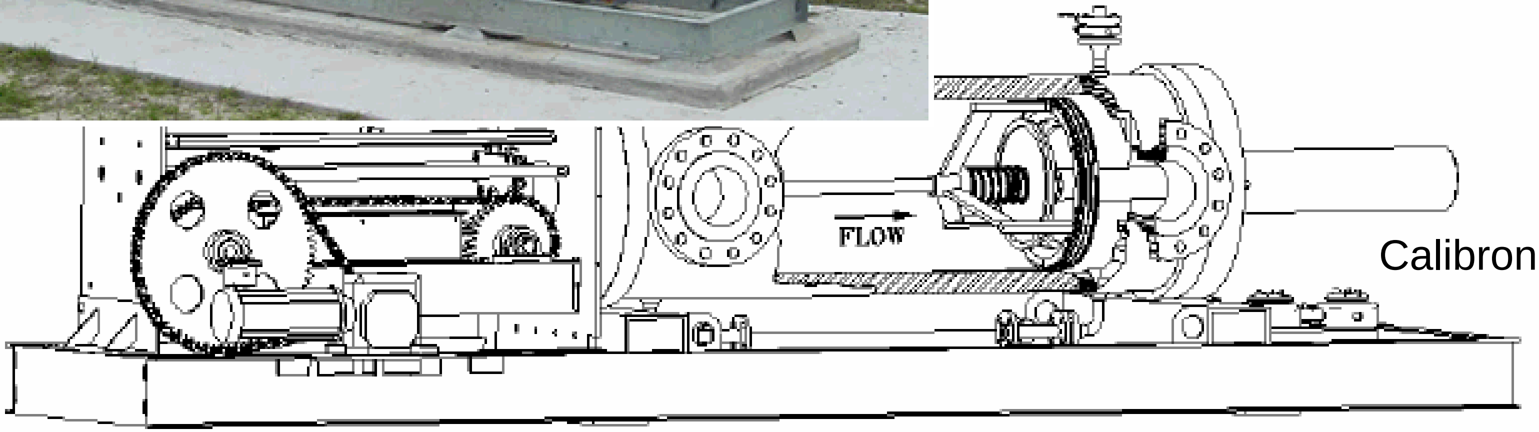
Micromotion

Daniel

Small Volume Prover

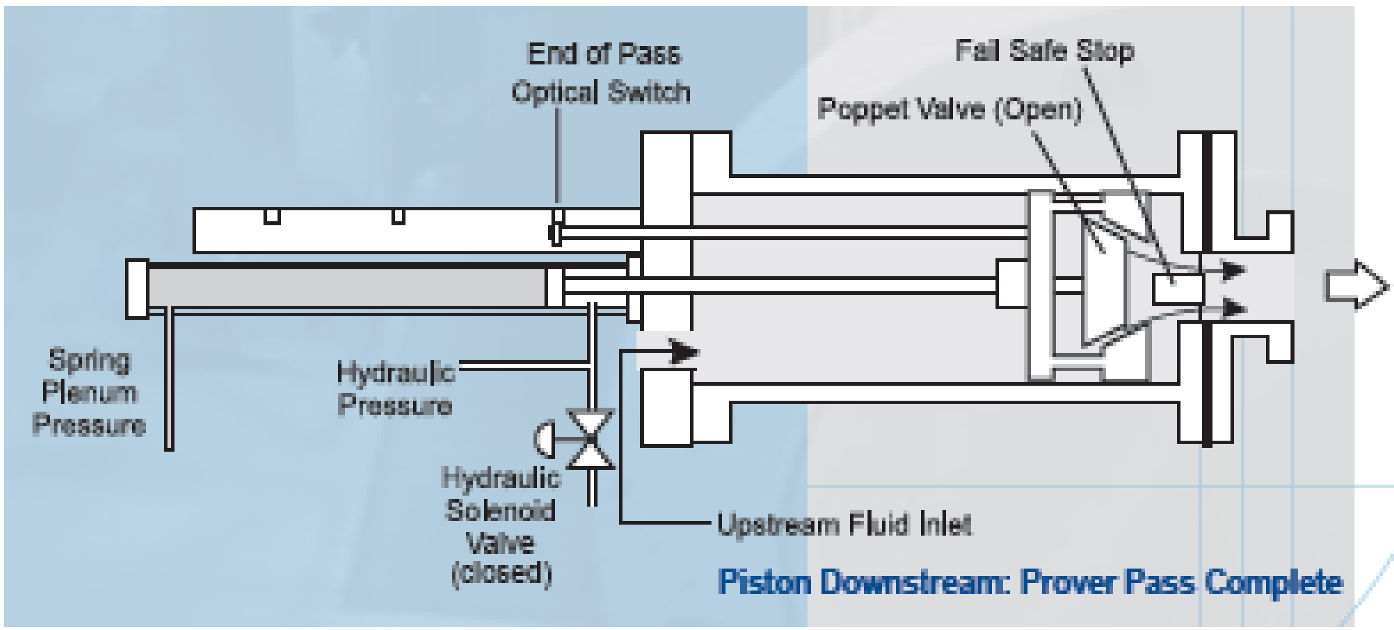


Small Volume Prover



Calibron

Small Volume Prover Operation

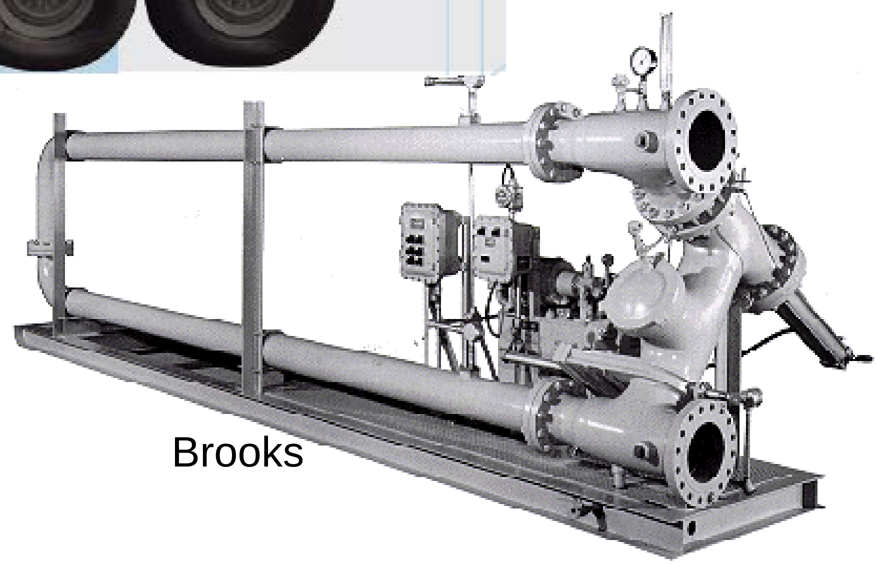


Brooks

Ball Prover

Brooks

Brooks



Brooks

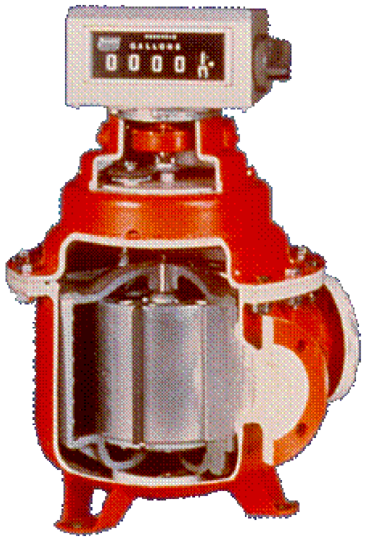
Tank Prover

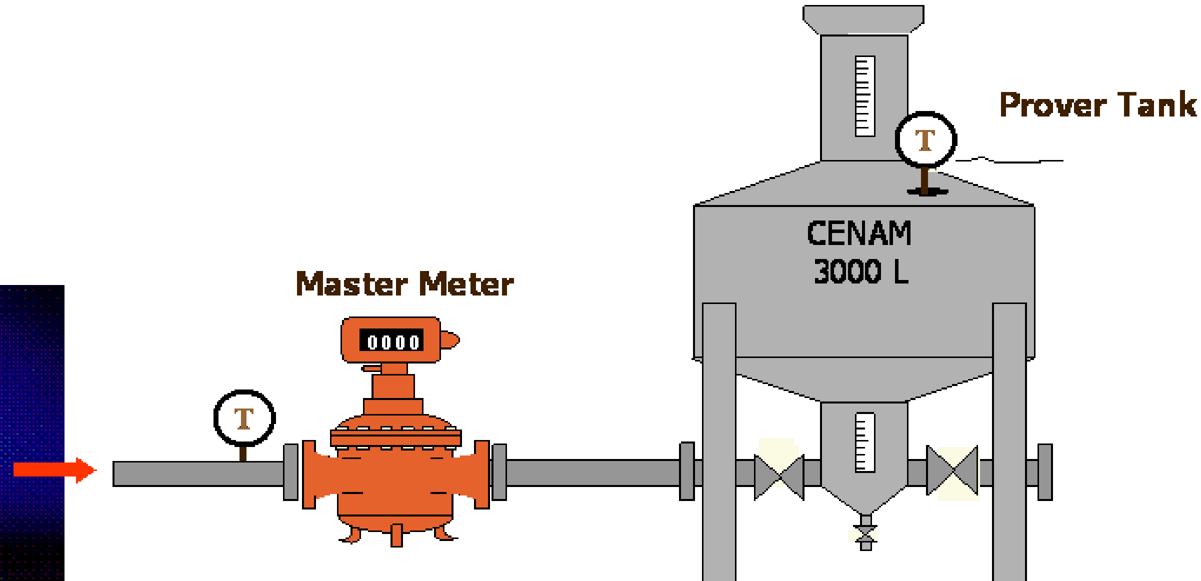
Field Test Measures

Meter Engineers

Seraphin

Master Meters





$$MF = \frac{(V_b \cdot SRu) \cdot CTS_m \cdot CTL_{mp}}{IV_m \cdot CTL_m \cdot CPL_m}$$

Definition of Traceability

JCGM 200:2008

2.41 (6.10)

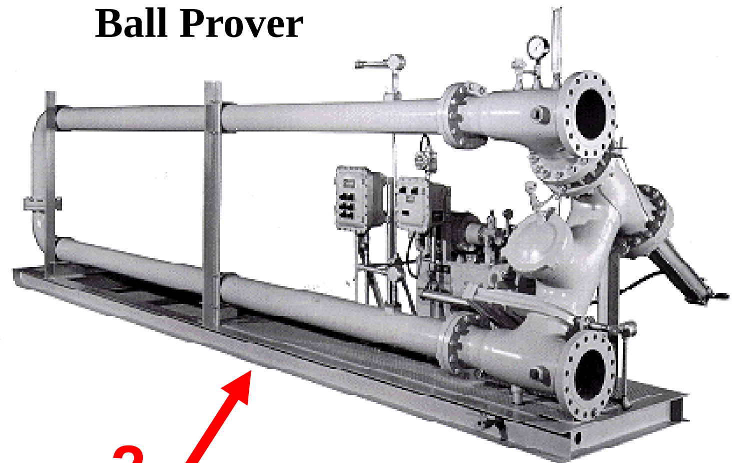
metrological traceability

property of a **measurement result** whereby the result can be related to a reference through a documented unbroken chain of **calibrations,** each contributing to the **measurement uncertainty.**

Volume Traceability

Standards Laboratory T)
(NIST or CENAM)

Ball Prover



1

2

3

Field Test Measures

Flowmeter

Volume Traceability

Standards Laboratory
(NIST or CENAM)

1

Tank Prover

2

3

Field Test Measures

Flowmeter

Volume Traceability

Standards Laboratory T)
(NIST or CENAM)

Small Volume Prover

Flowmeter

1

2

3

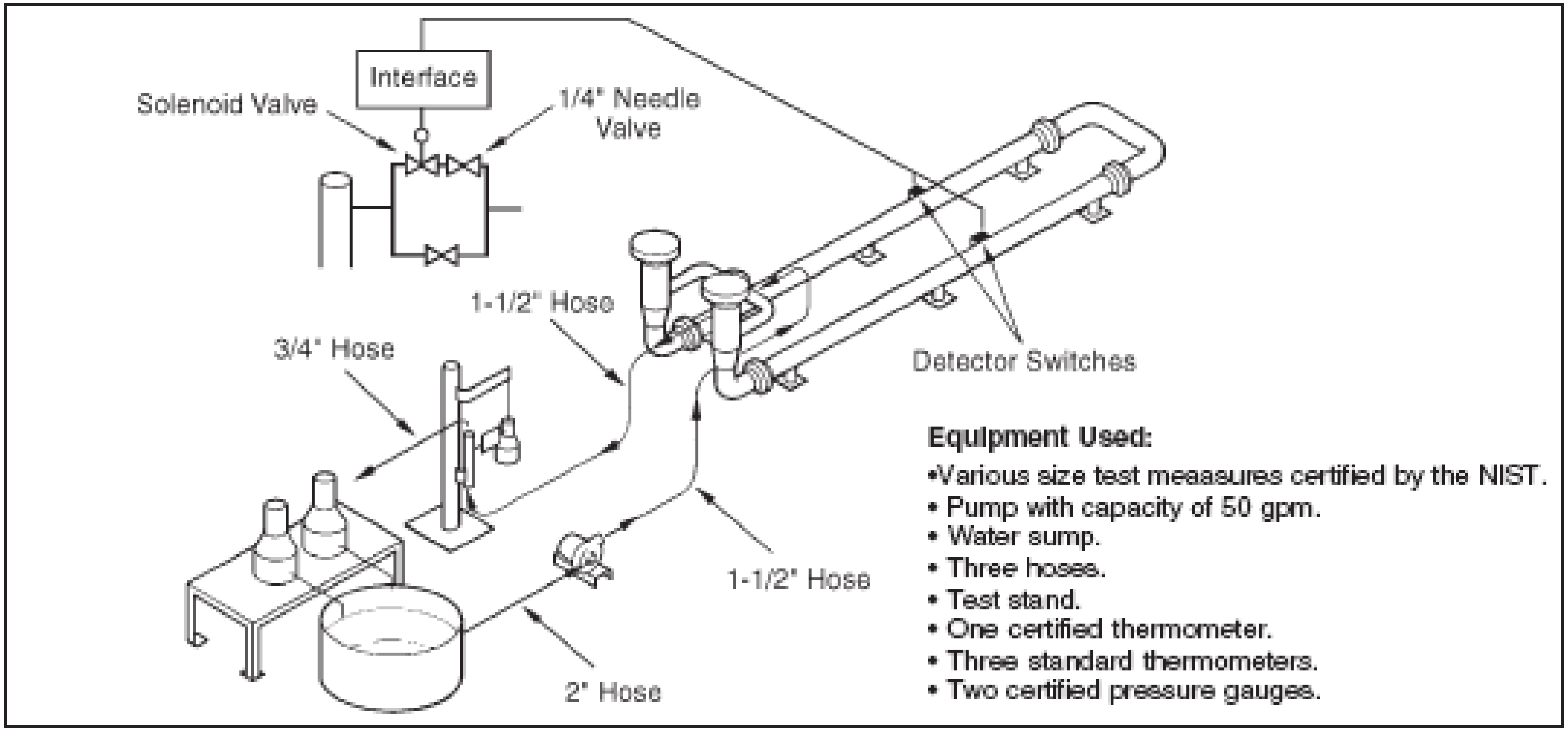
4

Master Meter

Each step adds uncertainty!!!

Water Draw Volume Calibration

Measures volume between start & stop switches of a prover by collecting water in field test measures (or on a weigh scale)



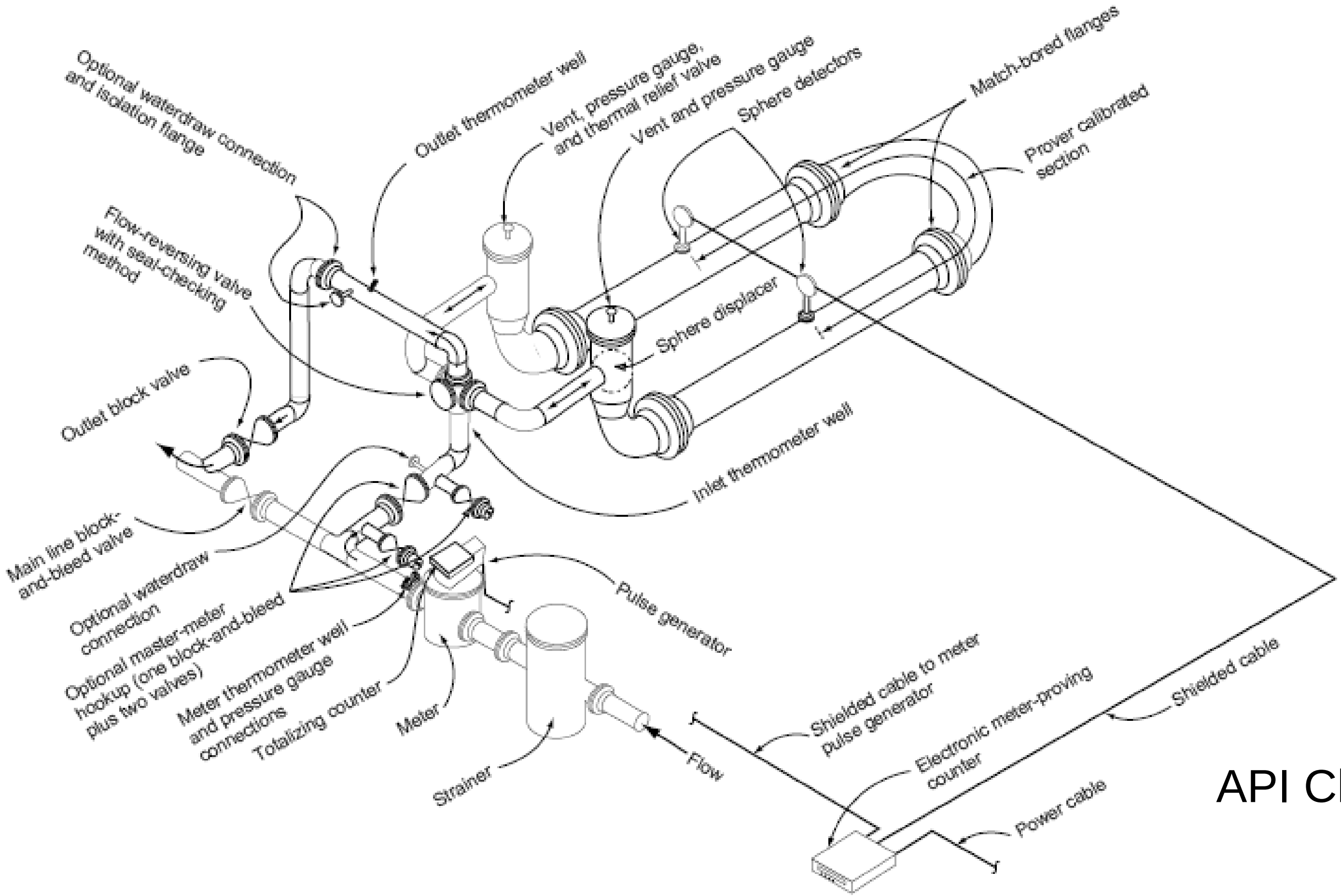
FMC Technologies

Meter Proving

Calibration performed by comparing a flowmeter totalized volume to:

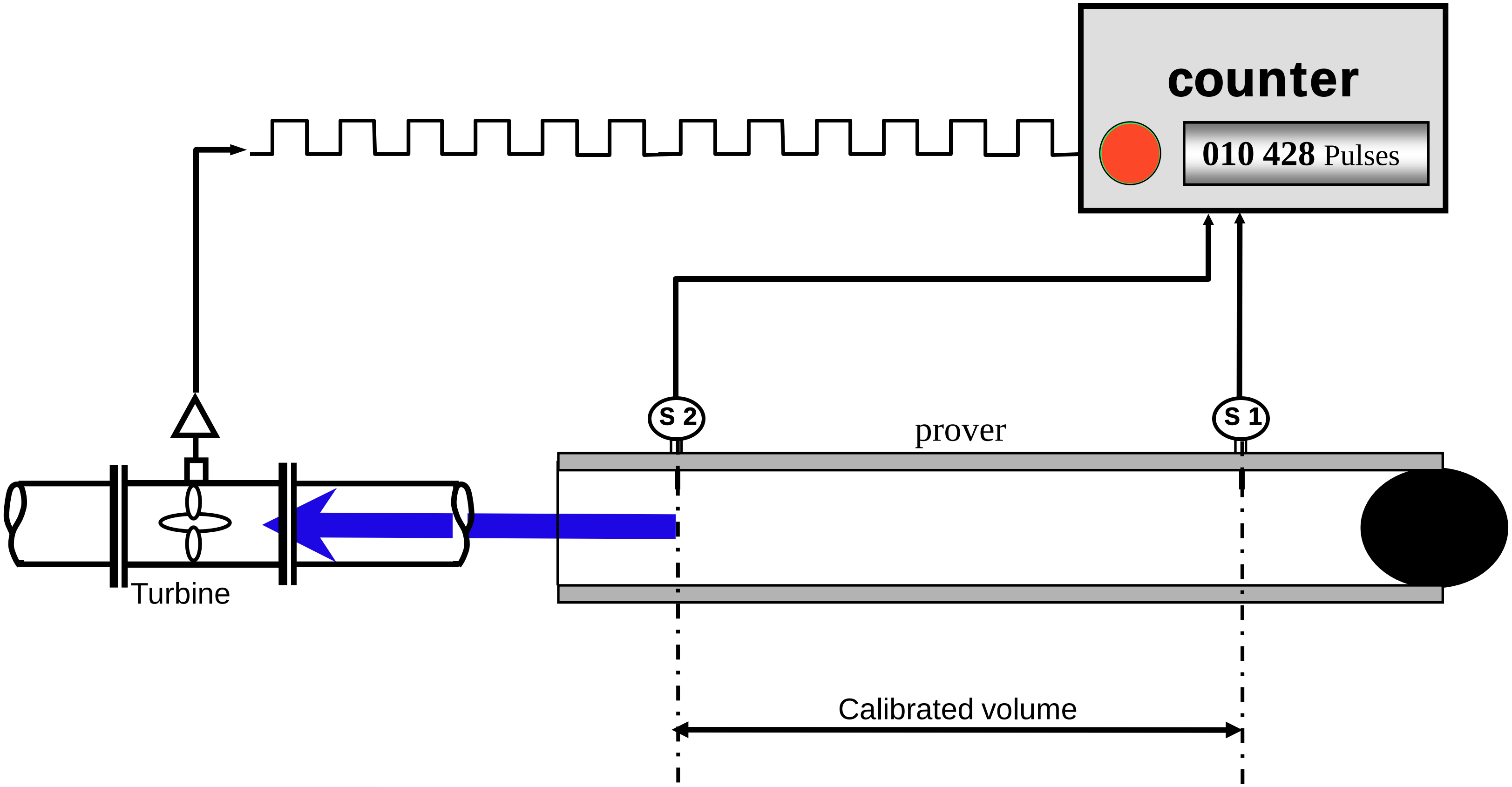
1. ball prover
2. small volume prover
3. tank prover
4. master meter

Meter Proving



API Chapter 4.8

Principle of Operation



3 Volume Calibrations at NIST

NIST Special Publication 250-72

NIST Calibration Services for Liquid Volume
NIST Special Publication 250-72

Vern E. Bean, Pedro I. Espina, John. D. Wright, John F. Houser, Sherry D. Sheckels, and Aaron N. Johnson
November 24, 2009

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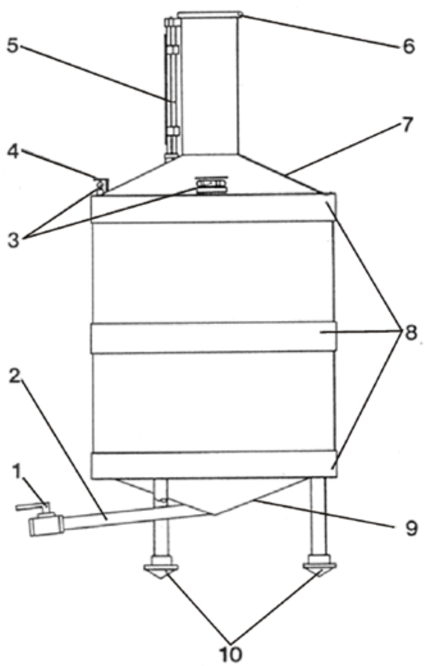
- www.nist.gov
- Documentation for customers
- Methods and equations
- Uncertainty analysis
- Sample reports

Graduated Neck (4 L to 8000 L)



1 Drain valve

2 Drain slope 5°

3 Levels

4 Level cover

5 Gauge mounting

6 Rolled bead

7 Top Cone Pitch 25°

8 Reinforcing bands

9 Bottom cone pitch 20°

10 Adjustable legs

4 L

400 L

2000 L

Direct Weighing Procedure

- Level
- Weigh dry
- Fill to “0”, measure t_W, weight, room t, p, rh
- Drain (30 s after main flow) and weigh
- Repeat 5 times

Contained Volume

$$V_{contain}(t_w) = \frac{m_f - m_e}{\rho(t_w) - \rho_{air}} - h$$

Delivered Volume

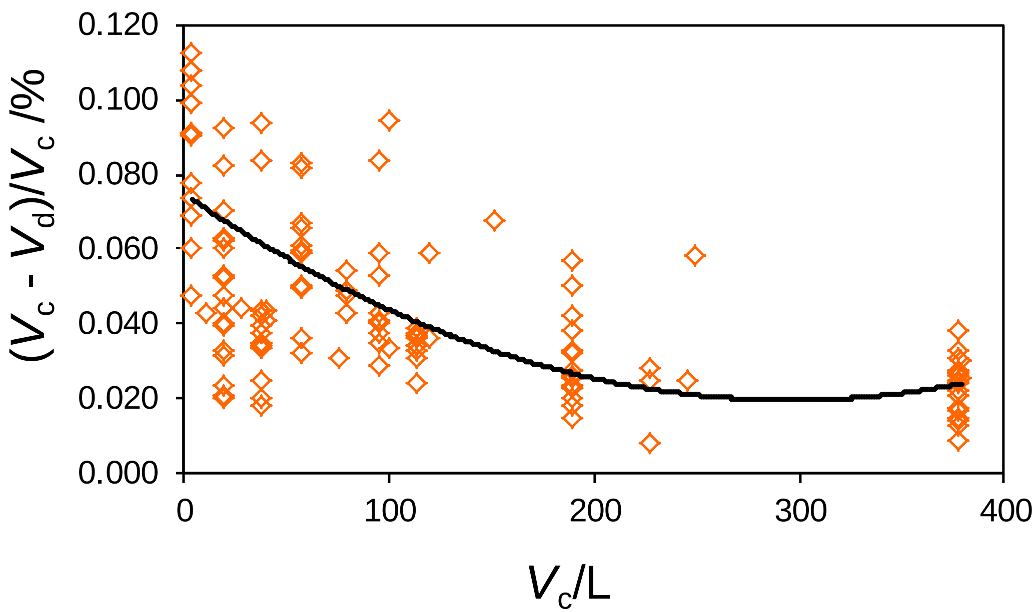
$$V_{deliver}(t_w) = \frac{m_f - m_d}{\rho(t_w) - \rho_{air}} - h$$

Thermal Expansion

$$V(t_{ref}) = V(t_w)\left[1 - \beta_t (t_w - t_{ref})\right]$$

t : temperature
m : mass
ρ : density
h : neck scale reading
β_T : prover coeff. Thermal exp.
w : water
f : full
e : empty (dry)
d : drained (wet)
ref : reference (15.56 °C)

Contained and Delivered Volumes



- Data from 150 volumes
- Differ by 0.02% for a 400 L volume, 0.05% for a 20 L volume
- Ratio of surface area to volume increases as volume decreases

Drainage Uncertainty

- More liquid remains on the walls if the viscosity and surface tension are larger
- Uncertainty in delivered volume due to liquid property changes (t changes)
- Drainage uncertainty is proportional to $V_{\mathrm{c}} - V_{\mathrm{d}}$

$$V_v = \left[V_c(t_w) - V_d(t_w)\right]\left[\frac{\nu(t_{ref})}{\nu(t_w)}\right]^{1/2}$$

- For a 400 L volume at 22 °C, 17 parts in 10^6 more liquid delivered due to a smaller viscosity than if used at 15.56 °C
- For a 20 L volume, the same temperature difference gives 48 parts in 10^6 increase in delivered volume
- We handle as an uncertainty, not a correction

Data Reduction Spreadsheet

42 gal sample.xls

A

Name of Company:	ABC Co.
NIST Seal Number:	1234
Serial Number:	1234
Nominal Volume of Vessel:	42 gallons
Nominal Vol per Scale Div:	0.4 cubic inches
Date Calibrated:	9/28/2005

B

Scale Capacity:	600 [kg]
Scale Coeficient, a_1:	1.0007E+00 [1/kg]
Scale Coeficient, a_2:	-3.1240E-07 [1/kg^2]
Cal Date:	9/28/2005

C

T#4 Coef., b_0:	-3.520000E-02 [C]	T#5 Coef., d_0:	-2.00800E-02 [C]
T#4 Coef., b_1:	9.993000E-01 [1/C]	T#5 Coef., d_1:	9.992500E-01 [1/C]
Cal Date:	10/27/2005	Cal Date:	10/27/2005
T#6 Coef., c_0:	-1.692000E-01 [C]	T#3 Coef., e_0:	-6.560000E-02 [C]
T#6 Coef., c_1:	1.007348E+00 [1/C]	T#3 Coef., e_1:	1.002220E+00 [1/C]
Cal Date:	10/27/2005	Cal Date:	10/27/2005

D E

Water Temperature Corrected #6 [C]	Water Temperature Corrected #3 [C]	Water Temperature Average [C]	Water Density Patterson & Morris [kg/m^3]	Air Temperature Corrected #4 [C]	Air Temperature Corrected #5 [C]	Air Temperature Average [C]	Barometric Pressure Read [kPa]	Barometric Pressure [Pa]	Rel. Humidity Read [%]	Air Density Jaeger & Davis [kg/m^3]
19.810	19.875	19.842	998.238	23.594	23.602	23.598	100.70	100,700	35.0	1.17801
20.335	20.337	20.336	998.136	23.225	23.245	23.235	99.76	99,761	46.0	1.16711
20.351	20.362	20.356	998.131	26.346	26.333	26.339	99.67	99,667	42.0	1.15333
20.361	20.360	20.360	998.131	23.895	24.015	23.955	99.70	99,700	39.0	1.16423
20.426	20.424	20.425	998.117	25.249	25.251	25.250	99.80	99,800	37.0	1.16022

F G H

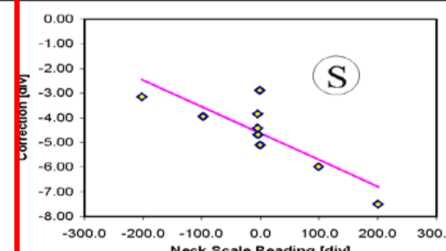
Weight Dry Read [kg]	Weight Dry Corrected [kg]	Weight Full Read [kg]	Weight Full Corrected [kg]	Weight Drained Read [kg]	Weight Drained Corrected [kg]	Scale Reading Read [div]	Scale Reading Corrected [m^3]	Uncorrected Prover Volume Contained [m^3]	Uncorrected Prover Volume Delivered [m^3]
136.9338	137.0283	295.3832	295.5725	136.9824	137.0770	-4.0	-0.000026	0.159038	0.158989
136.9338	137.0283	295.4183	295.6077	136.9970	137.0916	-1.0	-0.000007	0.159068	0.159005
136.9338	137.0283	295.3805	295.5698	136.9899	137.0844	-5.0	-0.000033	0.159055	0.158999
136.9338	137.0283	295.3766	295.5660	136.9916	137.0862	-5.0	-0.000033	0.159053	0.158995
136.9338	137.0283	295.4078	295.5972	136.9989	137.0935	-0.5	-0.000003	0.159056	0.158991

Neck Scale Calibration Q

Reading [div]	calculated [div]	correction [div]
-4.0	-8.7	-4.7
-1.0	-3.9	-2.9
-5.0	-8.8	-3.8
-5.0	-9.4	-4.4
-0.5	-5.6	-5.1
-202	-205.1	-3.1
-98	-101.9	-3.9
99	93.0	-6.0
200.5	193.0	-7.5

R

slope	intercept	
0.989	-4.18	[div]
0.396	-1.67	[in^3]
6.484E-06	-2.741E-05	[m^3]



Ref. Temp. [C]: 15.56

I K L

	Thermal Expansion Corrected Prover Volume Contained [m^3]	Delivered [m^3]	Contained [gal]	Delivered [gal]	Contained [in^3]	Delivered [in^3]	$\Delta x / \sigma_x$
	0.15900543	0.15895664	42.0048	41.9919	9703.11	9700.13	0.58
	0.15903186	0.15896839	42.0118	41.9950	9704.72	9700.85	1.51
	0.15901843	0.15896214	42.0082	41.9934	9703.90	9700.47	0.40
	0.15901641	0.15895837	42.0077	41.9924	9703.78	9700.24	0.27
	0.15901927	0.15895390	42.0084	41.9912	9703.95	9699.96	1.07
Averages, Thermal Expansion Corrected	0.1590183	0.1589599	42.0082	41.9928	9703.89	9700.33	
Averages, Therm. Exp. & Viscosity Corrected		0.1589563		41.9918		9700.11	
Repeatability [x 10^{-6}]	59	35	59	35	59	35	
Expanded Uncertainty [%]	0.016	0.012	0.016	0.012	0.016	0.012	

J

Temperature [C]	Water Density Patterson & Morris [kg/m^3]	Kin. Visc. CRC & Kell [m^2/s]
15.560	999.015	1.125E-06
20.264	998.151	1.000E-06

M

Estimation of Uncertainty k = 2.36 ν_{eff} = 7 95% confidence, Taylor & Kuyatt

N O P

x_i	Value	$1/V\ \partial V/\partial x_i$	Value of $1/V\ \partial V/\partial x_i$	$u(x_i)$ for k=1	$1/V\ \partial V/\partial x_i\, u(x_i)$ [x 10^{-6}]	
h	--- [m^3]	$1/V$	0 [1/m^3]	1.6E-06 [m^3]	0.0	0.00
m_f	295.58 [kg]	$1/(m_f-m_e)$	0.01 [1/kg]	3.6E-03 [kg]	22.6	508.95
m_e	137.03 [kg]	$-1/(m_f-m_e)$	-0.01 [1/kg]	3.6E-03 [kg]	-22.6	508.95
ρ_0	1000 [kg/m^3]	$-1/\rho_0$	-1E-03 [m^3/kg]	2.0E-03 [kg/m^3]	-2.0	4.00
β_W	2.0E-04 [1/C]	$-(T_W-T_{ref,W})$	-20.3 [C]	3.3E-07 [1/C]	-6.7	44.72
β_t	4.8E-05 [1/C]	$-(T_W-T_{ref})$	-4.7 [C]	7.0E-07 [1/C]	-3.3	10.84
T_W	20.3 [C]	$\beta_W-\beta_t$	2E-04 [1/C]	4.0E-02 [C]	6.1	37.11
ρ_{air}	1.17 [kg/m^3]	$1/\rho_0$	1E-03 [m^3/kg]	2.0E-03 [kg/m^3]	2.0	4.00
ν					12.9	165.91

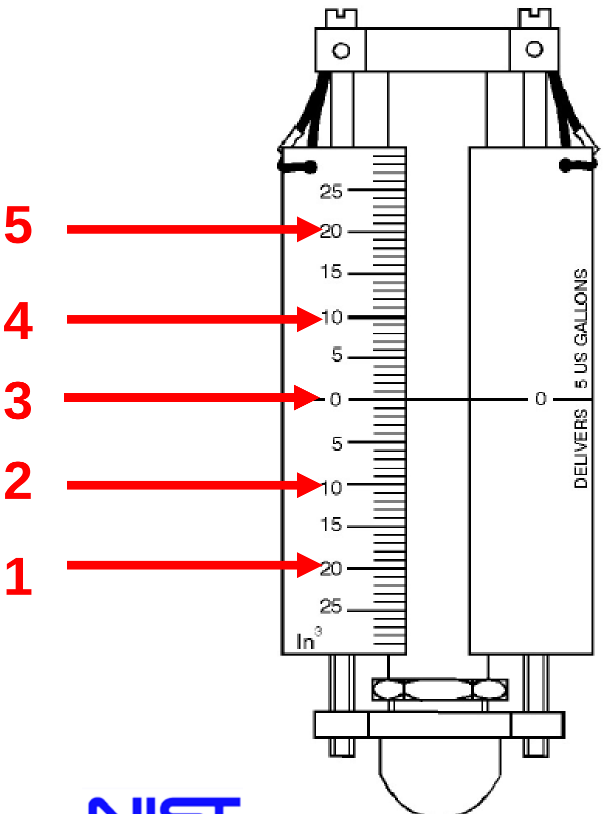
maker:	Can Co.
min scale:	-250
max scale:	250
levels:	bubble
valve:	butterfly valve
old / new:	old
drain time (s):	30

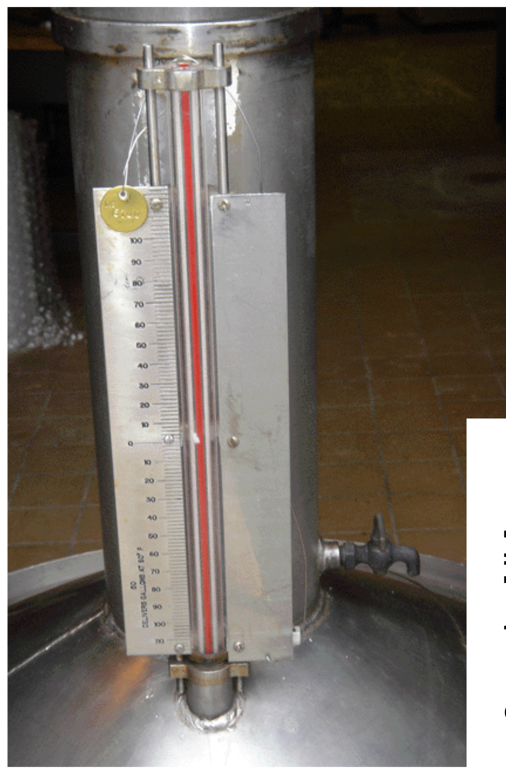
42 gal

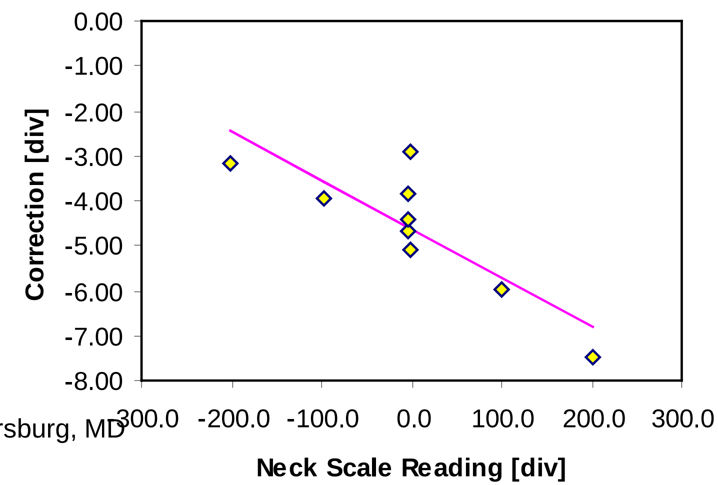
Neck Scale Calibrations

- Done gravimetrically at -80%, -40%, 0%, 40%, and 80%

Neck Scale Calibration		
Reading [div]	calculated [div]	correction [div]
-4.0	-8.7	-4.7
-1.0	-3.9	-2.9
-5.0	-8.8	-3.8
-5.0	-9.4	-4.4
-0.5	-5.6	-5.1
-202	-205.1	-3.1
-98	-101.9	-3.9
99	93.0	-6.0
200.5	193.0	-7.5
slope	intercept	
0.989	-4.18	[div]
0.396	-1.67	[in^3]
6.484E-06	-2.741E-05	[m^3]





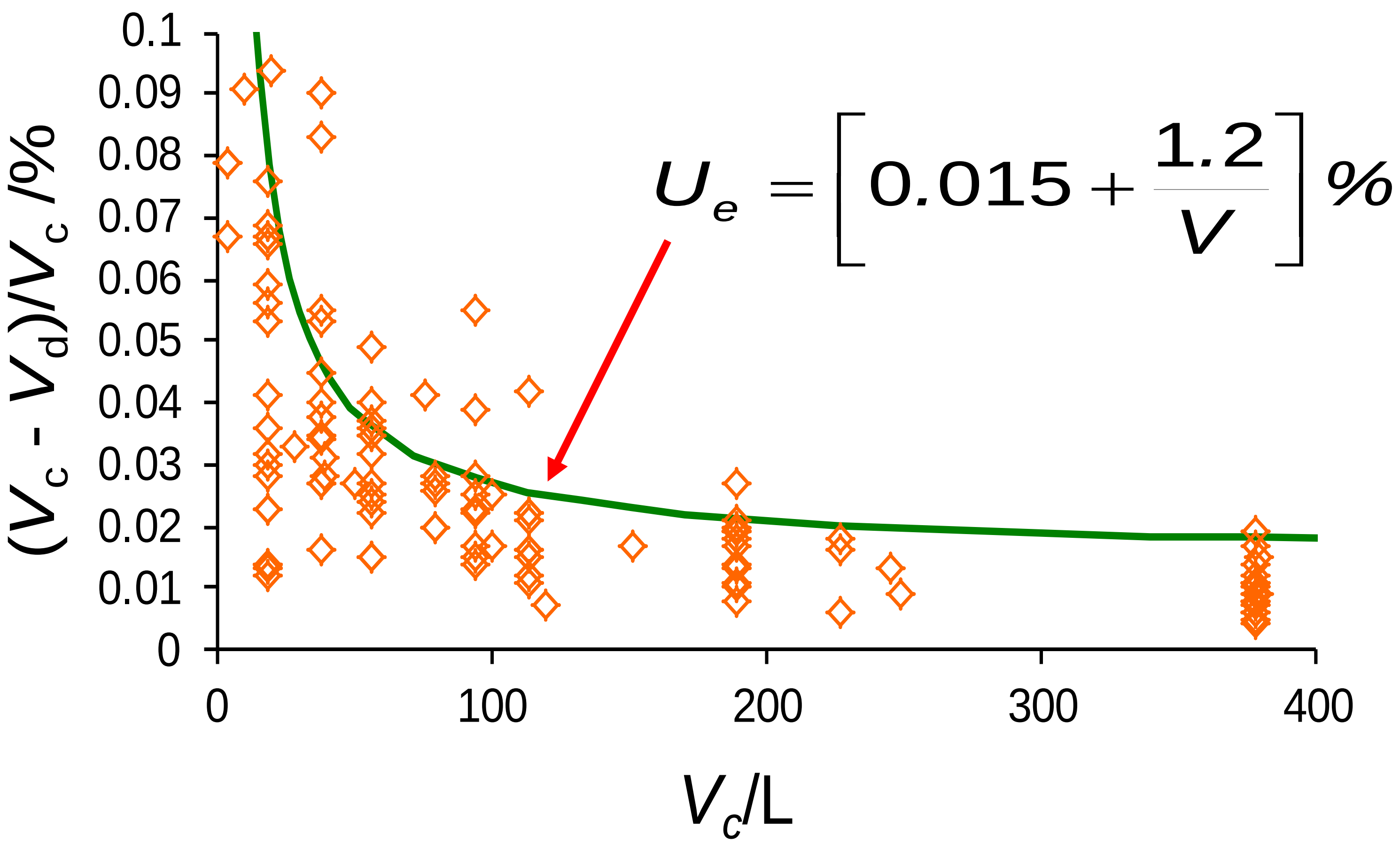


Uncertainty

Ref. Temp.	Thermal Expansion Corrected Prover Volume						Δx / σx	Water	
[C]	Contained	Delivered	Contained	Delivered	Contained	Delivered	$\Delta x / \sigma_x$	Temperature	Density
15.56	[m^3]		[gal]		[in^3]				Patterson & Morris
	0.15900543	0.15895664	42.0048	41.9919	9703.11	9700.13	0.58	[C]	[kg/m^3]
	0.15903186	0.15896839	42.0118	41.9950	9704.72	9700.85	1.51	15.560	999.015
	0.15901843	0.15896214	42.0082	41.9934	9703.90	9700.47	0.40	20.264	998.151
	0.15901641	0.15895837	42.0077	41.9924	9703.78	9700.24	0.27		
	0.15901927	0.15895390	42.0084	41.9912	9703.95	9699.96	1.07		
	0.1590183	**0.1589599**	**42.0082**	**41.9928**	**9703.89**	**9700.33**	**Averages, Thermal Expansion Corrected**		
		0.1589563		41.9918		9700.11	Averages, Therm. Exp. & Viscosity Corrected		
	59	35	59	35	59	35	Repeatability [x 10^{-6}]		
	0.016	**0.012**	**0.016**	**0.012**	**0.016**	**0.012**	**Expanded Uncertainty [%]**		

Estimation of Uncertainty			***k*** **=**	**2.36**	ν_{eff}=	**7**	95% confidence, Taylor & Kuyatt		
x_i	Value		$1/V\ \delta V/\delta x_i$	Value of $1/V\ \delta V/\delta x_i$		$u(x_i)$ for $k=1$		$1/V\ \delta V/\delta x_i\, u(x_i)$ [x 10^{-6}]	
h	---	[m^3]	$1/V$	0	[$1/m^3$]	1.6E-06	[m^3]	0.0	0.00
m_f	295.58	[kg]	$1/(m_f - m_e)$	0.01	[1/kg]	3.6E-03	[kg]	22.6	508.95
m_e	137.03	[kg]	$-1/(m_f - m_e)$	-0.01	[1/kg]	3.6E-03	[kg]	-22.6	508.95
ρ_0	1000	[kg/m^3]	$-1/\rho_0$	-1E-03	[m^3/kg]	2.0E-03	[kg/m^3]	-2.0	4.00
β_W	2.0E-04	[1/C]	$-(T_W - T_{ref,W})$	-20.3	[C]	3.3E-07	[1/C]	-6.7	44.72
β_t	4.8E-05	[1/C]	$-(T_W - T_{ref})$	-4.7	[C]	7.0E-07	[1/C]	-3.3	10.84
T_W	20.3	[C]	$\beta_W - \beta_t$	2E-04	[1/C]	4.0E-02	[C]	6.1	37.11
ρ_{air}	1.17	[kg/m^3]	$1/\rho_0$	1E-03	[m^3/kg]	2.0E-03	[kg/m^3]	2.0	4.00
ν								12.9	165.91

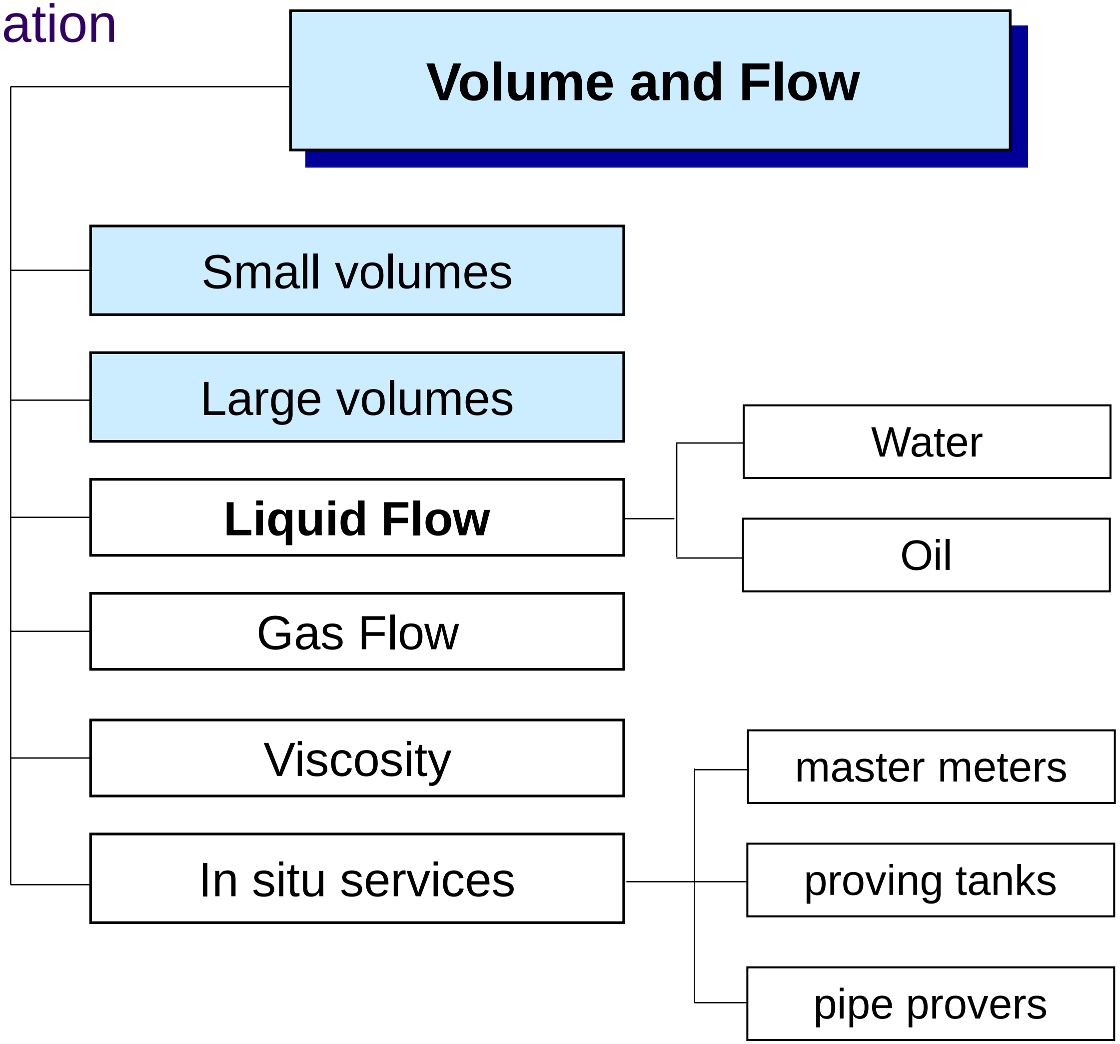
Uncertainty



4 Volume Calibrations at CENAM

CENAM

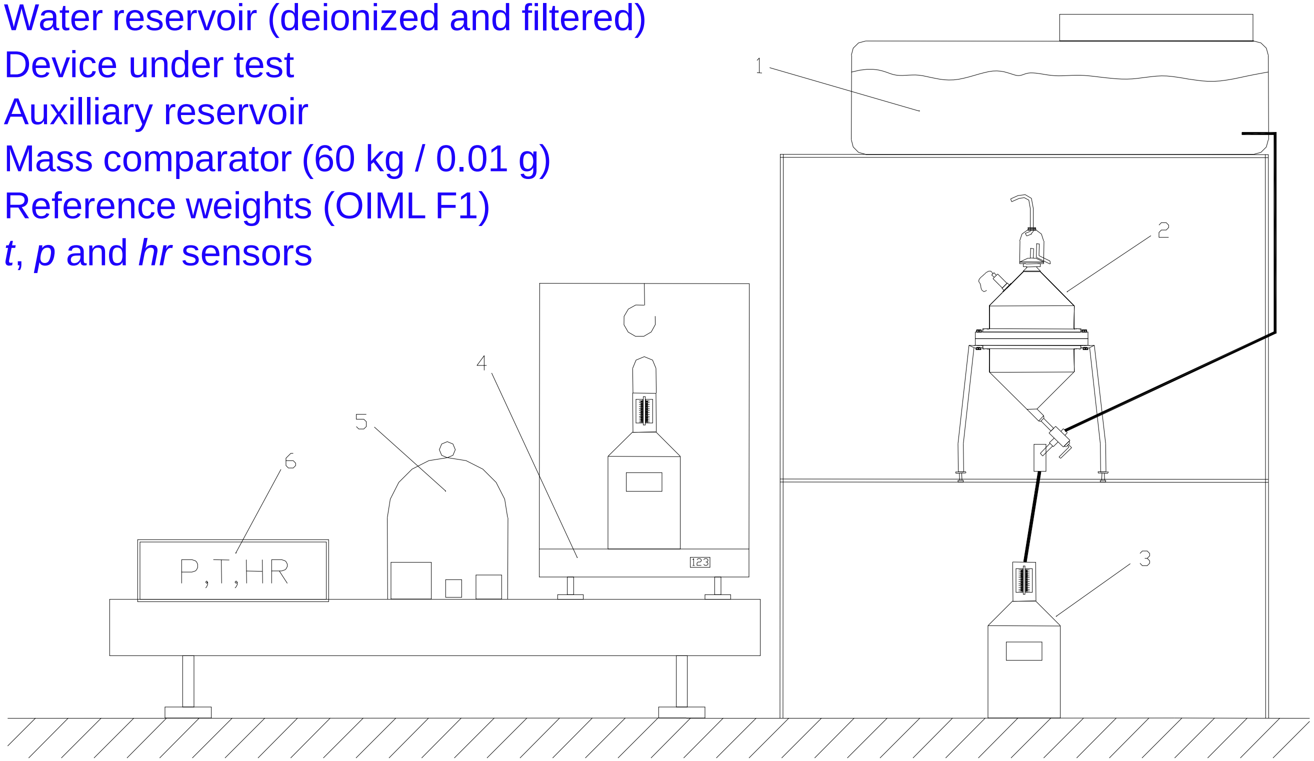
Organization



Laboratory Layout

Gravimetric Method

1 Water reservoir (deionized and filtered)
2 Device under test
3 Auxilliary reservoir
4 Mass comparator (60 kg / 0.01 g)
5 Reference weights (OIML F1)
6 *t*, *p* and *hr* sensors



Laboratory Layout

Volumetric Transfer

Water quality: tap water (filtered)

Reference standards: (50 ± 0.002) L

(500 ± 0.090) L

Calibration capabilities: up to 3 000 L

Typical uncertainties: (0.02 to 0.04) %; *(k=2)*

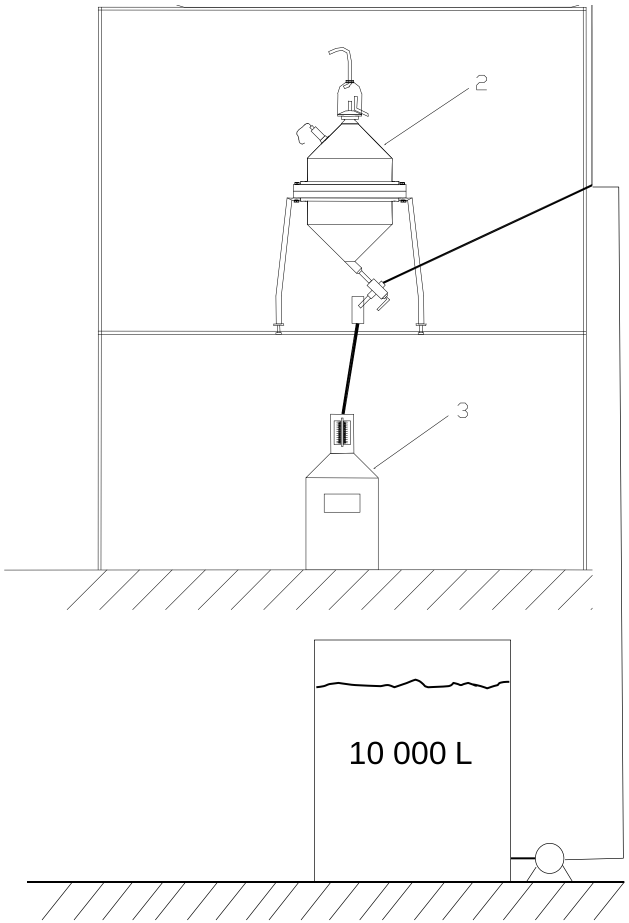
Applications: Verification of fuel dispensers (20 L)

Verification of LPG meters (500 L)

Calibration of compact provers

Calibration of pipe provers

Calibration of master meters (3 000 L)



Math Models

Gravimetric: double substitution

$$V_{20\,°C} = \frac{\left(\sum_{i=1}^{n} m_{\mathrm{f}} - \sum_{i=1}^{n} m_{\mathrm{i}}\right)\cdot\left(1-\frac{\rho_{\mathrm{a}}}{\rho_{\mathrm{m}}}\right) + A_{\mathrm{f}} - A_{\mathrm{i}}}{\rho_{\mathrm{w}} - \rho_{\mathrm{a}}}\cdot\left[1-\beta\cdot\left(t_{\mathrm{w}}-20\right)\right]$$

$$A_f = \frac{L_{f2}+L_{f3}-L_{f1}-L_{f4}}{2}\cdot\frac{m_s\left(1-\frac{\rho_a}{\rho_{ms}}\right)}{L_{f3}-L_{f2}}$$

$$A_i = \frac{L_{i2}+L_{i3}-L_{i1}-L_{i4}}{2}\cdot\frac{m_s\left(1-\frac{\rho_a}{\rho_{ms}}\right)}{L_{i3}-L_{i2}}$$

m_f: mass of the final reference weights

m_i mass of the initial reference weights

ρ_a: air density

ρ_w: water density

ρ_m: reference weights density

A_f: final mass differential

A_i: initial mass differential

L: balance readings

ρ_{ms}: density of sensitivity weights

α: prover thermal coefficient of expansion

t_w: water temperature

Math Models

gravimetric: direct reading

$$V_{20\,°C} = \frac{(I_f - I_e)\cdot\left(1-\dfrac{\rho_a}{\rho_m}\right)}{\rho_w - \rho_a}\cdot\left[1-\beta\cdot(t_w-20)\right]$$

I_f: balance indication at full condition

I_e balance indication at empty condition

ρ_a: air density

ρ_w: water density

α: stainless steel thermal coefficient of expansion

t_w: water temperature

Math Models

water density; Tanaka et. al.

metrologia

Recommended table for the density of water between 0 °C and 40 °C based on recent experimental reports[1]

M. Tanaka, G. Girard, R. Davis, A. Peuto and N. Bignell

$$\rho = a_5\left[1 - \frac{(t+a_1)^2(t+a_2)}{a_3(t+a_4)}\right],$$

where

$$a_1/°\mathrm{C} = -3.983\,035 \pm 0.000\,67$$
$$a_2/°\mathrm{C} = 301.797$$
$$a_3/°\mathrm{C}^2 = 522\,528.9$$
$$a_4/°\mathrm{C} = 69.348\,81$$
$$a_5/(\mathrm{kg\ m^{-3}}) = 999.974\,950 \pm 0.000\,84$$

Other models:

Patterson & Morris
Bettin
Masui & Fujii
Kell
Watanabe
IAPWS

Math Models

air density

IOP PUBLISHING METROLOGIA

Metrologia **45** (2008) 149–155 doi:10.1088/0026-1394/45/2/004

Revised formula for the density of moist air (CIPM-2007)

A Picard[1], R S Davis[1], M Gläser[2] and K Fujii[3]

2. The CIPM-2007 equation and its uncertainty

2.1. The CIPM-2007 equation

Formally, the derivation of the CIPM-2007 equation is the same as that of its predecessors [1, 2].

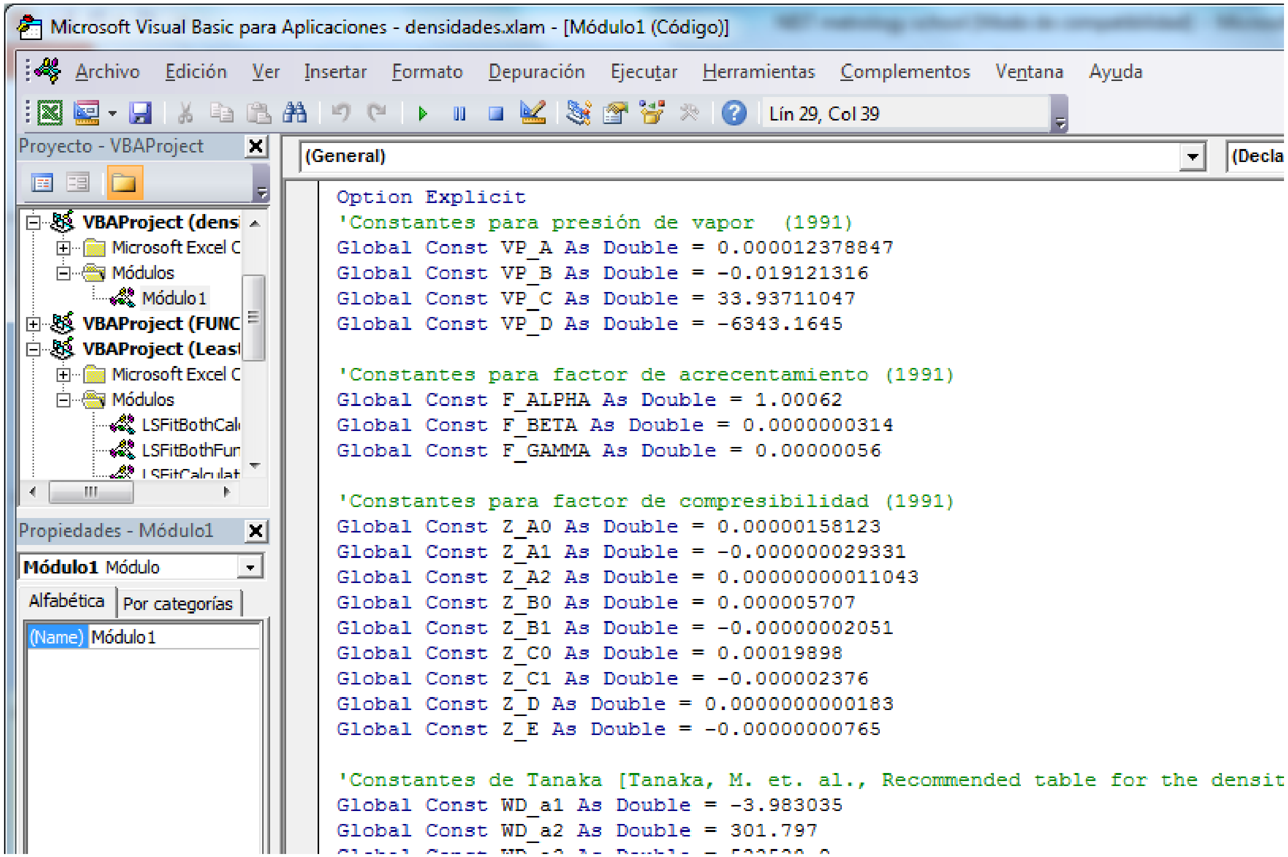
The density of moist air is evaluated using an equation of state

$$\rho_a = \frac{pM_a}{ZRT}\left[1 - x_v\left(1 - \frac{M_v}{M_a}\right)\right], \qquad (1)$$

where the quantities and units are p/Pa: pressure, $t/°\mathrm{C}$: air temperature, T/K: thermodynamic temperature $= 273.15 + t/°\mathrm{C}$, x_v: mole fraction of water vapour, $M_a/(\mathrm{g\,mol^{-1}})$: molar mass of dry air, $M_v/(\mathrm{g\,mol^{-1}})$: molar mass of water, Z: compressibility factor, $R/(\mathrm{J\,mol^{-1}\,K^{-1}})$: molar gas constant.

Math Models

air density; Excel add-in



Math Models

data processing

PESAS UTILIZADAS

	MASA DE SENSIBILIDAD		PESAS UTILIZADAS		Juego de pesas						CERTIFICADO
	VACIO	***LLENO***	***VACIO***	***LLENO***	Masa	Corrección	Masa Corr.	Incertidumbre	Volumen	Densidad	
					g	mg	g	g	cm3	g/cm3	
62					0.001	0.0011	0.001001	0.000002	0.0004	2.50	
63					0.002	-0.0028	0.001997	0.000002	0.0007	2.85	
64					**0.002**	-0.003	0.001997	0.000002	0.0007	2.85	
65					0.005	0.0019	0.005002	0.000002	0.0019	2.63	
66					0.01	-0.0054	0.009995	0.0000027	0.0013	7.69	
67					0.02	0.0006	0.020001	0.0000033	0.0025	8.00	
68					**0.02**	0.0007	0.020001	0.0000033	0.0025	8.00	CNM-CC-730-211/2005
69					0.05	-0.0058	0.049994	0.000004	0.0063	7.94	
70					0.1	-0.0029	0.099997	0.0000053	0.0126	7.94	
71					0.2	-0.0103	0.199990	0.0000066	0.0252	7.94	
72					**0.2**	-0.001	0.199999	0.0000066	0.0252	7.94	
73					0.5	-0.0272	0.499973	0.0000083	0.062	8.06	
74					1	-0.004	0.999996	0.00001	0.1262	7.92	
75					2	0.0034	2.00000	0.000013	0.2517	7.95	
76					**2**	-0.0166	1.99998	0.000013	0.2511	7.96	
77					5	-0.0148	4.99999	0.000017	0.6302	7.93	
78	1	1			10	-0.016	9.99998	0.00002	1.2549	7.97	
79					20	-0.001	20.00000	0.000027	2.5156	7.95	CNM-CC-730-132/2011
80					**20**	0.02	20.00002	0.000027	2.5175	7.94	
81				1	50	0.023	50.00002	0.000033	6.2852	7.96	
82			1		100	0.094	100.00009	0.000053	12.5841	7.95	
83					200	0.17	200.0002	0.0001	25.17	7.95	
84					**200**	0.15	200.00015	0.0001	25.134	7.96	
85			1	1	500	0.37	500.00037	0.00027	62.921	7.95	
86					1000	1.65	1000.00165	0.00053	125.887	7.94	
87					1000	0.8	1000.00080	0.0017	125.562	7.96	CNM-CC-730-150/2011
88					2000	2.3	2000.00230	0.0033	251.19	7.96	CNM-CC-730-151/2011
89					**2000**	1.7	2000.00170	0.0033	251.19	7.96	CNM-CC-730-156/2011
90			1	1	5000	7.4	5000.00740	0.0083	629.29	7.95	CNM-CC-730-152/2011
91					10000	5	10000.00500	0.017	1251.29	7.99	[illegible]

Math Models

RECIPIENTE VACIO O MOJADO								
Condiciones ambientales			Densidad	Masa	Recipiente	Recipiente	Masa	
Presión	Humedad	Temp.	Aire	patron	Vacio	vacio + Ws	patron + Ws	A1
hPa.	%	°C	g/cm3	g	g	g	g	g
-90	-3.1	-0.08						
815.63	40.5	19.5	0.00096707	5600.08	5601.51	5611.52	5610.1	1.423574146
814.92	40.0	19.7	0.00096556	5600.05	5601.53	5611.52	5610.07	1.46646412
811.98	36.4	19.9	0.00096173	5600.03	5601.45	5611.46	5610	1.438559137
812.17	36.2	19.9	0.00096198	5600.04	5601.6	5611.58	5610.05	1.548093715
813.675	**38.3**	**19.8**	**0.00096409**	**5600.05**	**5601.5225**	**5611.52**	**5610.055**	**1.46917278**

RECIPIENTE LLENO										
Condiciones ambientales			Densidad	Temp.	Densidad	Masa	Recipiente	Recipiente	Masa	
Presión	Humedad	Temp.	Aire	Agua	Agua	patron	Lleno	Lleno + Ws	patron + Ws	A2
hPa.	%	°C	g/cm3	°C	g/cm3	g	g	g	g	g
-90	-3.1	-0.08								
815.440	40.5	19.6	0.00096649	19.45	0.998304	25550.2	25550.04	25560.09	25560.13	-0.099502
814.850	40.1	19.7	0.00096547	19.48	0.998298	25550.17	25549.91	25559.88	25560.17	-0.275827
811.990	35.8	19.9	0.00096181	19.79	0.998235	25550.17	25549.07	25559.06	25560.16	-1.101099
812.290	35.7	19.9	0.00096217	19.83	0.998227	25550.14	25549.04	25559.02	25560.16	-1.122243
813.643	**38.0**	**19.8**	**0.00096398**	**19.6375**	**0.998266**	**25550.17**	**25549.515**	**25559.5125**	**25560.16**	**-0.64967**

VOLUMEN a 20 °C			
Masa agua	Volumen de agua	Volumen 20°C	
g	ml	ml	
19965.4	19999.363	19999.89	-0.058
19965.2	19999.246	19999.74	0.087
19964.3	19999.643	19999.84	-0.014
19964.2	19999.682	19999.84	-0.015
19964.673	**19999.563**	**19999.83**	
0.61	**0.21**	**0.06**	

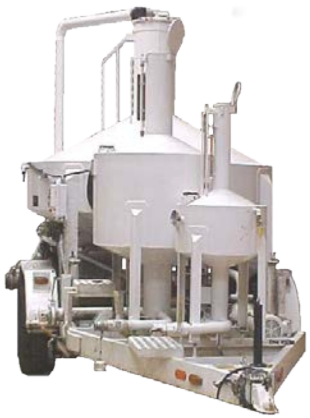
Suma [ci*ui(y)]^2	0.129
Raiz(suma)	0.359
k al 95,45 % aprox.	**2.00**
Inc. Expandida [cm3]	0.72

Hoja1 Hoja2 Hoja3

Volume Measurements

Large volume Laboratory

(2 – 3 000) L



Small volume Laboratory

(0.01 mL – 2 L)   -glassware-

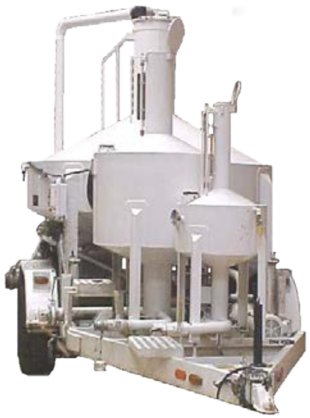
Volume Measurements,

Main Customers

Large volume Laboratory

(2 – 3 000) L

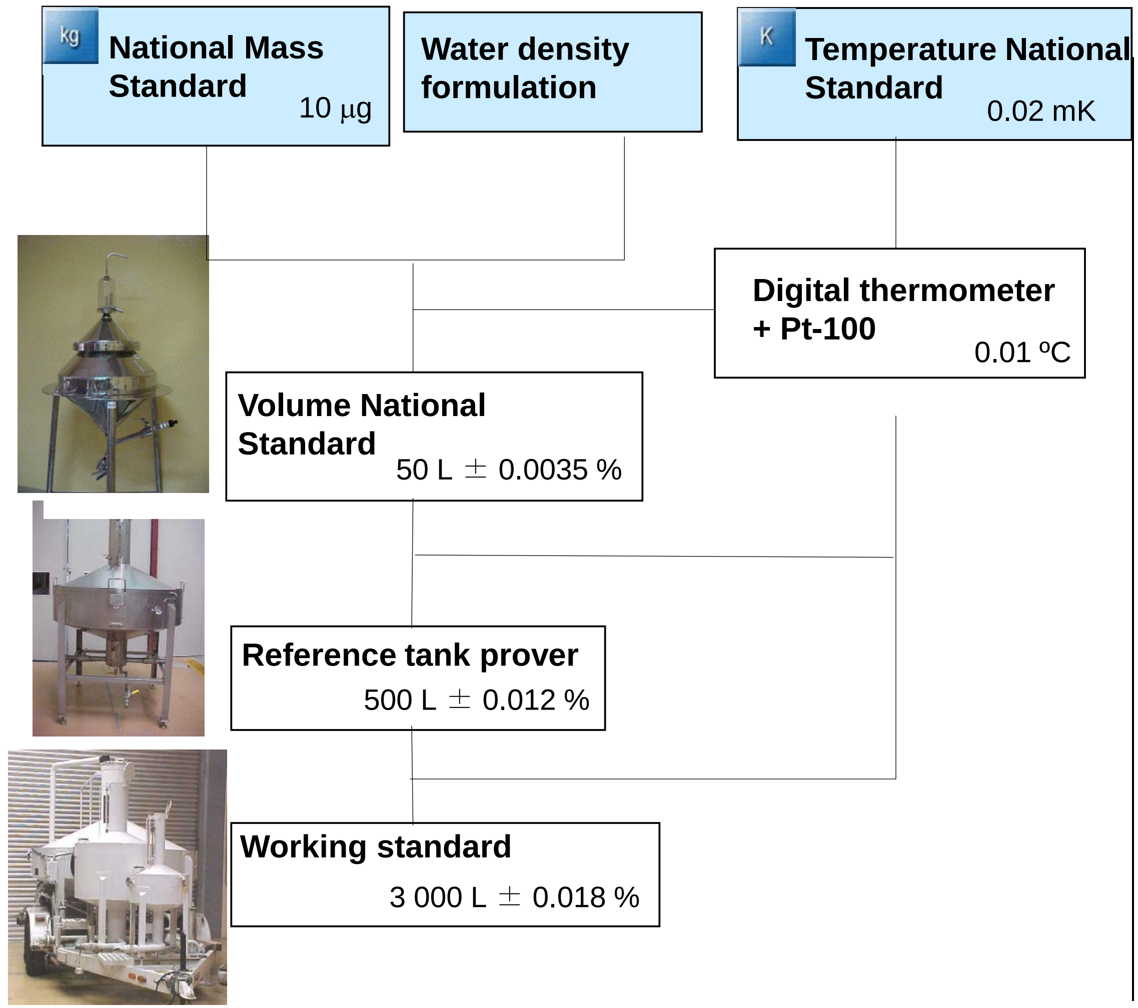
- ❑ Secondary laboratories
- ❑ Verification officers
- ❑ Petrol stations
- ❑ PEMEX



Small volume Laboratory

(0.01 mL – 2 L) -glassware-

- ❑ Secondary laboratories
- ❑ Food industry; Pharmaceutical,
- ❑ Chemical industry



Traceability chart for volume of liquids measurements by using tank provers.

Volume working standard

3 000 L $\pm$ 0.018 %

Bi-directional pipe prover

$V_{20\ ºC,\ 0\ Pa} \pm 0.03\ \%$

water draw method

In line Turbine or PD meter

$V_{t,p} \pm 0.1\ \%$

Direct volume comparison method

Traceability chart for volume of liquids measurements by using bi-directional pipe prover

5 International comparability

CCM.FF-K4

Transfer standard artifacts

Glass pycnometer (6 items)

Type: Gay-Lussac

Volume: 100 mL

Stainless steel pipette (3 items)

Type: overflow

Volume: 20 L

Temperature: Pt-100

Design: to deliver

CCM.FF-K4; APMP.M.FF-K4;EURAMET.M.FF-K4 AND SIM.M.FF-K4