Kuwait 4th Flow Measurement Technology Conference

3-5 December 2019
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DAVID J WOODS

CEng MIMechE MInstMC

Flow Specialist
KOC Export & Marine Operations Support Services Group

Flow Measurement Uncertainty:
Combination of Uncertainties for Multi Stream Metering Systems

Manual of Petroleum Measurement Standards Chapter 13.3

Measurement Uncertainty

FIRST EDITION, MAY 2016

energy API

AMERICAN PETROLEUM INSTITUTE

JCGM 100:2008

GUM 1995 with minor corrections

Evaluation of measurement data — Guide to the expression of uncertainty in measurement

Évaluation des données de mesure — Guide pour l'expression de l'incertitude de mesure

Document produced by Working Group 1 of the Joint Committee for Guides in Metrology (JCGM/WG 1).

NOTE 3 It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion.

BRITISH STANDARD

BS ISO 5168:2005

Measurement of fluid flow — Procedures for the evaluation of uncertainties

Manual of Petroleum Measurement Standards
Chapter 13—Statistical Aspects of Measuring and Sampling

Section 1—Statistical Concepts and Procedures in Measurement

FIRST EDITION, JUNE 1985
REAFFIRMED, MARCH 1990
Reaffirmed 3/2002

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005

Manual of Petroleum Measurement Standards Chapter 13.3

Measurement Uncertainty

FIRST EDITION, MAY 2016

AMERICAN PETROLEUM INSTITUTE

This is from API 13.3 paragraph 5.4 an “Uncertainty Table”

Measurand Identification	Nominal Measurand Value	Independent or Correlated	Distribution (normal, rectangular)	Type A or B	Given Uncertainty	Standard Uncertainty	Sensitivity Coefficient	$(S \times u)^2$	Contribution to Volume Uncertainty
Pulses									
MF									
CTL									
CPL									
SUM	X	X	X	X	X	X	X		

10.2 Uncertainty budget

In reports providing an uncertainty estimate, an uncertainty budget table should be presented, (or referenced) providing at least the information set out in Table 3.

Table 3 — Uncertainty budget

Symbol	Source of uncertainty	Input uncertainty	Probability distribution	Divisor [see Equations (9) to (14)]	Standard uncertainty $u(x_i)$	Sensitivity coefficient c_i	Contribution to overall uncertainty $[c_i\, u(x_i)]^2$
$u(x_1)$	e.g. calibration	5	Normal	2	2,5	0,5	1,56
$u(x_2)$	e.g. output resolution	1	Rectangular	$\sqrt{3}$	0,58	2,0	1,35
...							
$u(x_i)$							
$u(x_N)$							
u_c	Combined uncertainty	—	—	—	$u_c(y) = \sqrt{\Sigma}$	←[a]	$= \sum [c_i\, u(x_i)]^2$
U	Expanded uncertainty	$= k\, u_c(y)$	←[a]	k	↵[a]	—	—

[a] The arrows in the last two rows of the table indicate that, whereas in the upper rows the calculation proceeds from left to right, in these rows the calculation of the final expanded uncertainty proceeds from right to left.

5 Evaluation of the uncertainty in a measurement process

The first stage in an uncertainty evaluation is to define the measurement process.

For the measurement of flow-rate, it will normally be necessary to combine the values of a number of input quantities to obtain a value for the output.

The definition of the process should include the enumeration of all the relevant input quantities.

8.3 Numerical solution

Where no mathematical relationship is available, or the functional relationship is complex, it is easier to obtain the sensitivity coefficients numerically, by calculating the effect of a small change in the input variable, x_i, on the output value, y.

Manual of Petroleum Measurement Standards Chapter 11—Physical Properties Data

Section 1—Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils

Adjunct to: ASTM D 1250-04 and IP 200/04

MAY 2004

ASTM INTERNATIONAL
Standards Worldwide

IP

American Petroleum Institute

Helping You Get The Job Done Right.℠

11.1.6.1 Method to Correct a Measured Volume to Base Conditions and Density from Base Conditions to an Alternate Temperature and Pressure

5 Evaluation of the uncertainty in a measurement process

Each of the individual components of uncertainty, *u(xi)*, is evaluated using one of the following methods:

- Type A evaluation: calculated from a series of readings using statistical methods, as described in Clause 6;
- Type B evaluation: calculated using other methods, such as engineering judgement, as described in Clause 7.

SIA uncertainty calculation **01 April to 31 August 2016** **253 days**

all uncertainties are expressed to 95% confidence level

(highlighted cell) = input data

Meter SIA Stream input data

Product group	5		
Meter reproducibility ±%	0.036	60	proves
n pulses	1		
Meter factor	1		
K factor	1		
Temperature °F	109.2		
Base temp °F	60		
Pressure psig	182		
Rho base density API	30.0		
BS&W %	0.028		
Equilibrium pressure Pe	0		

Prover input data

Prover volume bbls	1
Coeft cub expansion g	1.86E-05
Prover internal dia inch	35.25
Prover wall thickness t	0.375
Modulus of elasticity E	3.00E+07
Pulse count	1
K factor	1
Prover temp °F	109.2
Prover Pressure psig	177

Common Errors to Metering Skid

API measurement °API	0.668	**Uapi**
Prover Base Volume %	0.030	**Uvb**
BS & W %	0.068	**Ubsw**

Data entered by:

David Woods

KOC Flow Specialist

KOC Export Maintenance Team

24 September 2016

Measurement Error at operating condition

Meter Pressure psi	**UpM**	0.00
Meter Temperature °F	**UtM**	-0.01
Prover Pressure psi	**UpP**	0.00
Prover Temperature°F	**UtP**	-0.02

Root sum of squares method for combined metering errors

			Uncertainty ±%	**Type**
Ensv = $(E_{mf}^2 + E_{cal}^2 + ET_{rp}^2 + ET_r^2 + E_{tlm}^2 + E_{plm}^2 + E_{API}^2 + E_{BSW}^2 + ECTL^2 + EFm^2)^{0.5}$			0.092 %	Combined
E_{nsv} = Error in measurement of the net standard volume (NSV) total (NSV = dry volume corrected to 60°F and 0 psig)				
$E_{GSTD} = (E_{mf}^2 + E_{cal}^2 + ET_{rp}^2 + ET_r^2 + E_{tlm}^2 + E_{plm}^2 + E_{API}^2 + ECTL^2 + E_{fm}^2)^{0.5}$			0.063 %	Combined
E_{GSTD} = Error in measurement of the gross standard volume (GSTD) total (GSTD = wet volume corrected to 60°F and 0 psig)				
E_{mf} = error in meter factor due to meter proving error (considered separately)			0.000 %	Random
E_{cal} = error due to calculation tolerance			0.010 %	Random
ET_{rp} = error due to turbine meter reproducibility between last 25 proves			0.036 %	Random
ET_r = error in turbine meter proving repeatability			0.021 %	Random
E_{tlm} = error due to temperature measurement on the liquid in the meter			0.000 %	Random
E_{plm} = error due to pressure measurement on the liquid in the meter			0.000 %	Random
E_{API} = error due to API measurement on the liquid in the meter			-0.019 %	Random
E_{BSW} = error due to BS&W measurement on the liquid in the meter			0.068 %	Random
ECTL = error due to CTL uncertainty at	109.2	°F	0.041 %	Systematic
Efm = error due to compressibility factor uncertainty at	182	psig	0.006 %	Systematic

Root sum of squares method for combined proving errors

Emf = $(Evb^2 + Eptemp^2 + Eppress^2 + EmfAPI^2 + ECTL^2 + EFm^2 + EFp^2)^{0.5}$			0.030 %	Combined
Evb = error in prover base volume			0.030 %	Systematic
Eptemp =error due to prover temperature measurement			-0.001 %	Random
E_{ppress} = error due to prover pressure measurement			0.000 %	Random
Emf_{API} = error due to API measurement			0.000 %	Random
ECTL = error due to CTL uncertainty at	109.19	°F (EαP/EαM=1)	0.000 %	Systematic
Efm & Efp = error due to compressibility factor uncertainty at	177	psig	0.000	Systematic

API MPMS 13.1.7.2 REPRODUCIBILITY

Reproducibility is the range of uncertainty (95 percent confidence level) for the difference between two measurements obtained under the same conditions.

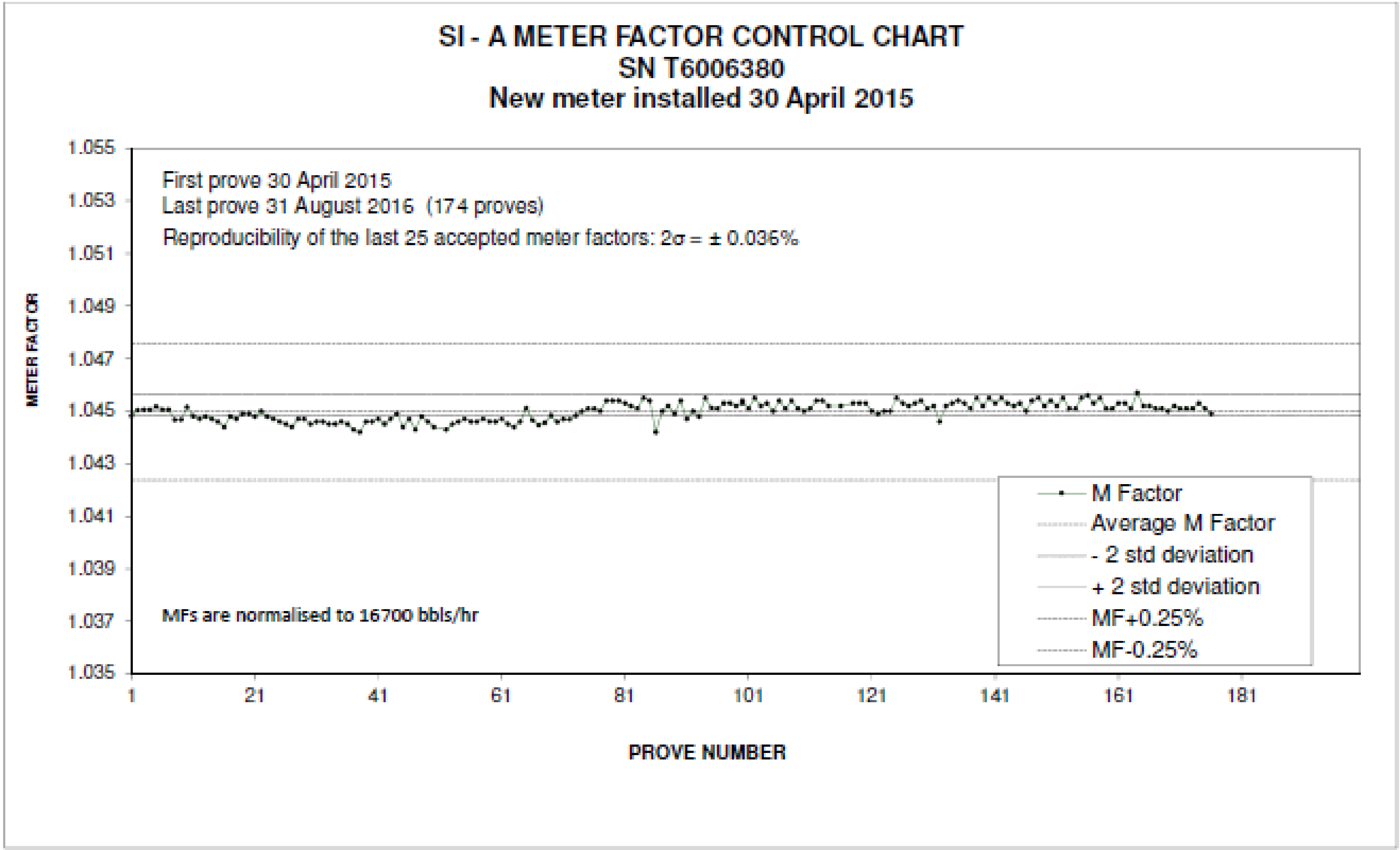
13.1.8.1.1 Number of Repeated Measurements Required

There is no fixed value for the optimum number of measurements required to establish a true value and a range of uncertainty.

Very often it is only practical to obtain from five to ten measurements in the field. This is perfectly acceptable for the day-to-day estimate of a mean value, but greater reliability is required for a statistic that is to be used as a standard measure.

Table E.2—Student *t* Factors for Individual Measurements at Various Confidence Levels

Number of Measurements *n*	dof	90 %	95 %	99 %
2	1	6.3138	12.7062	63.6567
3	2	2.9200	4.3027	9.9248
4	3	2.3534	3.1825	5.8409
5	4	2.1318	2.7765	4.6041
6	5	2.0150	2.5706	4.0321
7	6	1.9432	2.4469	3.7074
8	7	1.8946	2.3646	3.4995
9	8	1.8595	2.3060	3.3554
10	9	1.8331	2.2622	3.2498
11	10	1.8125	2.2281	3.1693
12	11	1.7959	2.2010	3.1058
13	12	1.7823	2.1788	3.0545
14	13	1.7709	2.1604	3.0123
15	14	1.7613	2.1448	2.9768
16	15	1.7531	2.1315	2.9467
17	16	1.7459	2.1199	2.9208
18	17	1.7396	2.1098	2.8982
19	18	1.7341	2.1009	2.8784
20	19	1.7291	2.0930	2.8609
21	20	1.7247	2.0860	2.8453
22	21	1.7207	2.0796	2.8314
23	22	1.7171	2.0739	2.8188
24	23	1.7139	2.0687	2.8073
25	24	1.7109	2.0639	2.7969
∞	∞	1.6449	1.9600	2.5758


SI - A METER FACTOR CONTROL CHART
SN T6006380
New meter installed 30 April 2015
First prove 30 April 2015
Last prove 31 August 2016 (174 proves)
Reproducibility of the last 25 accepted meter factors: 2σ = ± 0.036%
MFs are normalised to 16700 bbls/hr
METER FACTOR
1.055
1.053
1.051
1.049
1.047
1.045
1.043
1.041
1.039
1.037
1.035
1
21
41
61
81
101
121
141
161
181
PROVE NUMBER
M Factor
Average M Factor
- 2 std deviation
+ 2 std deviation
MF+0.25%
MF-0.25%

SIA uncertainty calculation **01 April to 31 August 2016** **253 days**

all uncertainties are expressed to 95% confidence level

(yellow cell) = input data

Meter SIA Stream input data

Product group	5		
Meter reproducibility ±%	0.036	60	proves
n pulses	1		
Meter factor	1		
K factor	1		
Temperature °F	109.2		
Base temp °F	60		
Pressure psig	182		
Rho base density API	30.0		
BS&W %	0.028		
Equilibrium pressure Pe	0		

Prover input data

Prover volume bbls	1
Coeft cub expansion g	1.86E-05
Prover internal dia inch	35.25
Prover wall thickness t	0.375
Modulus of elasticity E	3.00E+07
Pulse count	1
K factor	1
Prover temp °F	109.2
Prover Pressure psig	177

Common Errors to Metering Skid

API measurement °API	0.668	**Uapi**
Prover Base Volume %	0.030	**Uvb**
BS & W %	0.068	**Ubsw**

Data entered by:

David Woods

KOC Flow Specialist

KOC Export Maintenance Team

24 September 2016

Measurement Error at operating condition

Meter Pressure psi	**UpM**	0.00
Meter Temperature °F	**UtM**	-0.01
Prover Pressure psi	**UpP**	0.00
Prover Temperature°F	**UtP**	-0.02

Root sum of squares method for combined metering errors

			Uncertainty ±%	Type
$E_{nsv} = (E_{mf}^2 + E_{cal}^2 + ET_{rp}^2 + ET_r^2 + E_{tlm}^2 + E_{plm}^2 + E_{API}^2 + E_{BSW}^2 + ECTL^2 + EFm^2)^{0.5}$			0.092 %	Combined
E_{nsv} = Error in measurement of the net standard volume (NSV) total (NSV = dry volume corrected to 60°F and 0 psig)				
$E_{GSTD} = (E_{mf}^2 + E_{cal}^2 + ET_{rp}^2 + ET_r^2 + E_{tlm}^2 + E_{plm}^2 + E_{API}^2 + ECTL^2 + E_{fm}^2)^{0.5}$			0.063 %	Combined
E_{GSTD} = Error in measurement of the gross standard volume (GSTD) total (GSTD = wet volume corrected to 60°F and 0 psig)				
E_{mf} = error in meter factor due to meter proving error (considered separately)			0.000 %	Random
E_{cal} = error due to calculation tolerance			0.010 %	Random
ET_{rp} = error due to turbine meter reproducibility between last 25 proves			0.036 %	Random
ET_r = error in turbine meter proving repeatability			0.021 %	Random
E_{tlm} = error due to temperature measurement on the liquid in the meter			0.000 %	Random
E_{plm} = error due to pressure measurement on the liquid in the meter			0.000 %	Random
E_{API} = error due to API measurement on the liquid in the meter			-0.019 %	Random
E_{BSW} = error due to BS&W measurement on the liquid in the meter			0.068 %	Random
ECTL = error due to CTL uncertainty at	109.2	°F	0.041 %	Systematic
Efm = error due to compressibility factor uncertainty at	182	psig	0.006 %	Systematic

Root sum of squares method for combined proving errors

$Emf = (Evb^2 + Eptemp^2 + Eppress^2 + EmfAPI^2 + ECTL^2 + EFm^2 + EFp^2)^{0.5}$			0.030 %	Combined
Evb = error in prover base volume			0.030 %	Systematic
Eptemp =error due to prover temperature measurement			-0.001 %	Random
E_{ppress} = error due to prover pressure measurement			0.000 %	Random
Emf_{API} = error due to API measurement			0.000 %	Random
ECTL = error due to CTL uncertainty at	109.19	°F (EαP/EαM=1)	0.000 %	Systematic
Efm & Efp = error due to compressibility factor uncertainty at	177	psig	0.000	Systematic

Kuwait Oil Company Calculations for liquid flow

calc without truncation or rounding

BASE CASE NO ERRORS

Meter Stream input data

Product group	5
n pulses	1
Meter factor	1
K factor	1
Temperature °F	109.19046876
Base temp °F	60
Pressure psig	182.0
Rho base density API	30.0
BS&W %	0.028189655
Equilibrium pressure Pe	0
Gross Vol calculated bbl	1.000000
GST	0.977962563
GSV (GSTD)	0.978928418
MassTons	0.1362285
Dry Volume NSV	0.978652462
Dry Vol Sbbl NSV	0.978652462
CTL calculated	0.9779626
Fm calculated	0.542113088
CPL calculated	1.00098762

TABLE 4, Coeficients for API 11.2.1/11.2.1M

Coeff	Degrees F	Degrees C
A	-1.99470	-1.62080
B	0.00013427	0.00021592
C	0.79392	0.87096
D	0.0023260	0.0042092

0.875 gm/cc = 875.2953437 kg/m3

TABLE 1, K0 & K1 Values for API Product Groups 1, 2, 4, 5

API Group	Product	Degrees F		Degrees C	
		K0	K1	K0	K1
1	Fuel Oils	103.8720	0.2701	186.9696	0.4862
2	Jet Fuels	330.3010	0.0	594.5418	0.0
4	Gasolines	192.4571	0.2438	346.4228	0.4388
5	Crudes	341.0957	0.0	613.9723	0.0

Iterations for K0 and K1

		K0	K1
341.0957	0	341.0957	0
341.0957	0		
341.0957	0		
341.0957	0		

7.2 Calculation procedure

Type B evaluations of uncertainty require a knowledge of the probability distribution associated with the uncertainty.

7.3 Rectangular probability distribution

Typical examples of rectangular probability distributions include

- maximum instrument drift between calibrations,

- error due to limited resolution of an instrument’s display,

- manufacturers' tolerance limits.

METER ERRORS

Kuwait Oil Company Calculations for liquid flow

calc without truncation or rounding

ERROR DUE TO METER TEMPERATURE

Meter Stream input data

Product group	5
n pulses	1
Meter factor	1
K factor	1
Temperature °F	109.18346876
Base temp °F	60
Pressure psig	182.0
Rho base density API	30.0
BS&W %	0.028189655
Equilibrium pressure Pe	0
Gross Vol calculated bbl	1.000000
GST	0.977965717
GSV (GSTD)	0.978931555
MassTons	0.136228936
Dry Volume NSV	0.978655597
Dry Vol Sbbl NSV	0.978655597
CTL calculated	0.9779657
Fm calculated	0.542101057
CPL calculated	1.000987598

TABLE 4, Coeficients for API 11.2.1/11.2.1M

Coeff	Degrees F	Degrees C
A	-1.99470	-1.62080
B	0.00013427	0.00021592
C	0.79392	0.87096
D	0.0023260	0.0042092

0.875 gm/cc = 875.2953437 kg/m3

TABLE 1, K0 & K1 Values for API Product Groups 1, 2, 4, 5

API Group	Product	Degrees F		Degrees C	
		K0	K1	K0	K1
1	Fuel Oils	103.8720	0.2701	186.9696	0.4862
2	Jet Fuels	330.3010	0.0	594.5418	0.0
4	Gasolines	192.4571	0.2438	346.4228	0.4388
5	Crudes	341.0957	0.0	613.9723	0.0

Iterations for K0 and K1

		K0	K1
341.0957	0	341.0957	0
341.0957	0		
341.0957	0		
341.0957	0		

Kuwait Oil Company Calculations for liquid flow

calc without truncation or rounding

ERROR DUE TO METER PRESSURE

Meter Stream input data

Product group	5
n pulses	1
Meter factor	1
K factor	1
Temperature °F	109.19046876
Base temp °F	60
Pressure psig	182.0
Rho base density API	30.0
BS&W %	0.028189655
Equilibrium pressure Pe	0
Gross Vol calculated bbl	1.000000
GST	0.977962563
GSV (GSTD)	0.978928418
MassTons	0.1362285
Dry Volume NSV	0.978652462
Dry Vol Sbbl NSV	0.978652462
CTL calculated	0.9779626
Fm calculated	0.542113088
CPL calculated	1.00098762

TABLE 4, Coeficients for API 11.2.1/11.2.1M

Coeff	Degrees F	Degrees C
A	-1.99470	-1.62080
B	0.00013427	0.00021592
C	0.79392	0.87096
D	0.0023260	0.0042092

0.875 gm/cc = 875.2953437 kg/m3

TABLE 1, K0 & K1 Values for API Product Groups 1, 2, 4, 5

API Group	Product	Degrees F		Degrees C	
		K0	K1	K0	K1
1	Fuel Oils	103.8720	0.2701	186.9696	0.4862
2	Jet Fuels	330.3010	0.0	594.5418	0.0
4	Gasolines	192.4571	0.2438	346.4228	0.4388
5	Crudes	341.0957	0.0	613.9723	0.0

Iterations for K0 and K1

		K0	K1
341.0957	0	341.0957	0
341.0957	0		
341.0957	0		
341.0957	0		

Kuwait Oil Company Calculations for liquid flow

calc without truncation or rounding

ERROR DUE TO API

Meter Stream input data

Product group	5
n pulses	1
Meter factor	1
K factor	1
Temperature °F	109.19046876
Base temp °F	60
Pressure psig	182.0
Rho base density API	30.7
BS&W %	0.028189655
Equilibrium pressure Pe	0
Gross Vol calculated bbl	1.000000
GST	0.977769968
GSV (GSTD)	0.978747188
MassTons	0.135615473
Dry Volume NSV	0.978471282
Dry Vol Sbbl NSV	0.978471282
CTL calculated	0.9777700
Fm calculated	0.548593129
CPL calculated	1.000999437

TABLE 4, Coeficients for API 11.2.1/11.2.1M

Coeff	Degrees F	Degrees C
A	-1.99470	-1.62080
B	0.00013427	0.00021592
C	0.79392	0.87096
D	0.0023260	0.0042092

0.872 gm/cc = 871.5178668 kg/m3

TABLE 1, K0 & K1 Values for API Product Groups 1, 2, 4, 5

API Group	Product	Degrees F		Degrees C	
		K0	K1	K0	K1
1	Fuel Oils	103.8720	0.2701	186.9696	0.4862
2	Jet Fuels	330.3010	0.0	594.5418	0.0
4	Gasolines	192.4571	0.2438	346.4228	0.4388
5	Crudes	341.0957	0.0	613.9723	0.0

Iterations for K0 and K1

		K0	K1
341.0957	0	341.0957	0
341.0957	0		
341.0957	0		
341.0957	0		

Kuwait Oil Company Calculations for liquid flow

calc without truncation or rounding

ERROR DUE TO UNCERTAINTY IN Fm

For this calculation use Fm uncertainty 6.5% API 11.1.4)

Meter Stream input data

Product group	5
n pulses	1
Meter factor	1
K factor	1
Temperature °F	109.19046876
Base temp °F	60
Pressure psig	182.0
Rho base density API	30.0
BS&W %	0.028189655
Equilibrium pressure Pe	0
Gross Vol calculated bbl	1.000000
GST	0.977962563
GSV (GSTD)	0.978991265
MassTons	0.136237246
Dry Volume NSV	0.978715291
Dry Vol Sbbl NSV	0.978715291
CTL calculated	0.9779626
Fm calculated	0.577350438
CPL calculated	1.001051883

TABLE 4, Coeficients for API 11.2.1/11.2.1M

Coeff	Degrees F	Degrees C
A	-1.99470	-1.62080
B	0.00013427	0.00021592
C	0.79392	0.87096
D	0.0023260	0.0042092

0.875 gm/cc = 875.2953437 kg/m3

TABLE 1, K0 & K1 Values for API Product Groups 1, 2, 4, 5

API	Product	Degrees F		Degrees C	
Group		K0	K1	K0	K1
1	Fuel Oils	103.8720	0.2701	186.9696	0.4862
2	Jet Fuels	330.3010	0.0	594.5418	0.0
4	Gasolines	192.4571	0.2438	346.4228	0.4388
5	Crudes	341.0957	0.0	613.9723	0.0

Iterations for K0 and K1

		K0	K1
341.0957	0	341.0957	0
341.0957	0		
341.0957	0		
341.0957	0		

PROVER ERRORS

Kuwait Oil Company Calculations for liquid flow

BASE CASE NO ERRORS

Prover input data

Product group	5	
Prover volume	1.0000	bbls
Coeft cub expansion g	1.86E-05	/deg F
Prover internal dia	35.25	ins
Prover wall thickness t	0.375	ins
Modulus of elasticity E	3.00E+07	/psi
Pulse count	1	
K factor	1	
Meter temp F	109.190469	deg F
Prover temp F	109.1904688	
Base temp F	60.0	deg F
Meter Pressure psig	182.000000	psig
Prover Pressure psig	177.00000	
API density	30.0	
Rho base density gm/cc	0.87534	875.3 kg/m3
Equilibrium pressure Pe	0.00	kg/m3
MF calculated	1.001442883	
CTSP calculated	1.000914943	
CPSP calculated	1.0005546000	
CTLP calculated	0.977965	
CPLP calculated	1.0009603	
Fp calculated	0.542033937	
CTLM calculated	0.977964929	
Fm calculated	0.542033937	
CPLM calculated	1.000987476	
CCFP calculated	0.980343128	
CCFM calculated	0.978930646	

TABLE 1, K0 & K1 Values for API Product Groups 1, 2, 4, 5

API Group	Product	Degrees F		Degrees C	
		K0	K1	K0	K1
1	Fuel Oils	103.8720	0.2701	186.9696	0.4862
2	Jet Fuels	330.3010	0.0	594.5418	0.0
4	Gasolines	192.4571	0.2438	346.4228	0.4388
5	Crudes	341.0957	0.0	613.9723	0.0

Alpha calc	Iterations for K0 and K1		K0	K1
	341.0957	0.0000	341.0957	0
	341.0957	0.0000		
	341.0957	0.0000		
	341.0957	0.0000		

TABLE 4, Coeficients for API 11.2.1/11.2.1M

Coeff	Degrees F	Degrees C
A	-1.99470	-1.62080
B	0.00013427	0.00021592
C	0.79392	0.87096
D	0.0023260	0.0042092

ERROR DUE TO PROVER TEMPERATURE

Kuwait Oil Company Calculations for liquid flow

Prover input data

Product group	5	
Prover volume	1.0000	bbls
Coeft cub expansion g	1.86E-05	/deg F
Prover internal dia	35.25	ins
Prover wall thickness t	0.375	ins
Modulus of elasticity E	3.00E+07	/psi
Pulse count	1	
K factor	1	
Meter temp F	109.190469	deg F
Prover temp F	109.1724688	
Base temp F	60.0	deg F
Meter Pressure psig	182.000000	psig
Prover Pressure psig	177.00000	
API density	30.0	
Rho base density gm/cc	0.87534	875.3 kg/m3
Equilibrium pressure Pe	0.00	kg/m3
MF calculated	1.001450798	
CTSP calculated	1.000914608	
CPSP calculated	1.0005546000	
CTLP calculated	0.977973	
CPLP calculated	1.0009603	
Fp calculated	0.54200301	
CTLM calculated	0.977964929	
Fm calculated	0.542033937	
CPLM calculated	1.000987476	
CCFP calculated	0.980350877	
CCFM calculated	0.978930646	

TABLE 1, K0 & K1 Values for API Product Groups 1, 2, 4, 5

API Group	Product	Degrees F		Degrees C	
		K0	K1	K0	K1
1	Fuel Oils	103.8720	0.2701	186.9696	0.4862
2	Jet Fuels	330.3010	0.0	594.5418	0.0
4	Gasolines	192.4571	0.2438	346.4228	0.4388
5	Crudes	341.0957	0.0	613.9723	0.0

Alpha calc	Iterations for K0 and K1		K0	K1
	341.0957	0.0000	341.0957	0
	341.0957	0.0000		
	341.0957	0.0000		
	341.0957	0.0000		

TABLE 4, Coeficients for API 11.2.1/11.2.1M

Coeff	Degrees F	Degrees C
A	-1.99470	-1.62080
B	0.00013427	0.00021592
C	0.79392	0.87096
D	0.0023260	0.0042092

Kuwait Oil Company Calculations for liquid flow

Prover input data

Product group	5	
Prover volume	1.0000	bbls
Coeft cub expansion g	1.86E-05	/deg F
Prover internal dia	35.25	ins
Prover wall thickness t	0.375	ins
Modulus of elasticity E	3.00E+07	/psi
Pulse count	1	
K factor	1	
Meter temp F	109.190469	deg F
Prover temp F	109.1904688	
Base temp F	60.0	deg F
Meter Pressure psig	182.000000	psig
Prover Pressure psig	177.00000	
API density	30.0	
Rho base density gm/cc	0.87534	875.3 kg/m3
Equilibrium pressure Pe	0.00	kg/m3
MF calculated	1.001442883	
CTSP calculated	1.000914943	
CPSP calculated	1.0005546000	
CTLP calculated	0.977965	
CPLP calculated	1.0009603	
Fp calculated	0.542033937	
CTLM calculated	0.977964929	
Fm calculated	0.542033937	
CPLM calculated	1.000987476	
CCFP calculated	0.980343128	
CCFM calculated	0.978930646	

ERROR DUE TO PROVER PRESSURE

TABLE 1, K0 & K1 Values for API Product Groups 1, 2, 4, 5

API Group	Product	Degrees F		Degrees C	
		K0	K1	K0	K1
1	Fuel Oils	103.8720	0.2701	186.9696	0.4862
2	Jet Fuels	330.3010	0.0	594.5418	0.0
4	Gasolines	192.4571	0.2438	346.4228	0.4388
5	Crudes	341.0957	0.0	613.9723	0.0

Alpha calc	Iterations for K0 and K1		K0	K1
	341.0957	0.0000	341.0957	0
	341.0957	0.0000		
	341.0957	0.0000		
	341.0957	0.0000		

TABLE 4, Coeficients for API 11.2.1/11.2.1M

Coeff	Degrees F	Degrees C
A	-1.99470	-1.62080
B	0.00013427	0.00021592
C	0.79392	0.87096
D	0.0023260	0.0042092

Kuwait Oil Company Calculations for liquid flow

Prover input data

Product group	5	
Prover volume	1.0000	bbls
Coeft cub expansion g	1.86E-05	/deg F
Prover internal dia	35.25	ins
Prover wall thickness t	0.375	ins
Modulus of elasticity E	3.00E+07	/psi
Pulse count	1	
K factor	1	
Meter temp F	109.190469	deg F
Prover temp F	109.1904688	
Base temp F	60.0	deg F
Meter Pressure psig	182.000000	psig
Prover Pressure psig	177.00000	
API density	30.7	
Rho base density gm/cc	0.87174	871.7 kg/m3
Equilibrium pressure Pe	0.00	kg/m3
MF calculated	1.001442572	
CTSP calculated	1.000914943	
CPSP calculated	1.0005546000	
CTLP calculated	0.977781	
CPLP calculated	1.0009713	
Fp calculated	0.548215121	
CTLM calculated	0.977781141	
Fm calculated	0.548215121	
CPLM calculated	1.000998748	
CCFP calculated	0.980169627	
CCFM calculated	0.978757698	

ERROR DUE TO PROVER API

TABLE 1, K0 & K1 Values for API Product Groups 1, 2, 4, 5

API Group	Product	Degrees F		Degrees C	
		K0	K1	K0	K1
1	Fuel Oils	103.8720	0.2701	186.9696	0.4862
2	Jet Fuels	330.3010	0.0	594.5418	0.0
4	Gasolines	192.4571	0.2438	346.4228	0.4388
5	Crudes	341.0957	0.0	613.9723	0.0

Alpha calc	Iterations for K0 and K1		K0	K1
	341.0957	0.0000	341.0957	0
	341.0957	0.0000		
	341.0957	0.0000		
	341.0957	0.0000		

TABLE 4, Coeficients for API 11.2.1/11.2.1M

Coeff	Degrees F	Degrees C
A	-1.99470	-1.62080
B	0.00013427	0.00021592
C	0.79392	0.87096
D	0.0023260	0.0042092

ERROR DUE TO UNCERTAINTY IN Fm & Fp

For this calculation use Fm uncertainty 6.5% API 11.1.4)

Kuwait Oil Company Calculations for liquid flow

Prover input data

Product group	5	
Prover volume	1.0000	bbls
Coeft cub expansion g	1.86E-05	/deg F
Prover internal dia	35.25	ins
Prover wall thickness t	0.375	ins
Modulus of elasticity E	3.00E+07	/psi
Pulse count	1	
K factor	1	
Meter temp F	109.190469	deg F
Prover temp F	109.1904688	
Base temp F	60.0	deg F
Meter Pressure psig	182.000000	psig
Prover Pressure psig	177.00000	
API density	30.0	
Rho base density gm/cc	0.87534	875.3 kg/m3
Equilibrium pressure Pe	0.00	kg/m3
MF calculated	1.001441115	
CTSP calculated	1.000914943	
CPSP calculated	1.0005546000	
CTLP calculated	0.977965	
CPLP calculated	1.0010228	
Fp calculated	0.577266143	
CTLM calculated	0.977964929	
Fm calculated	0.577266143	
CPLM calculated	1.001051729	
CCFP calculated	0.980404326	
CCFM calculated	0.978993484	

TABLE 1, K0 & K1 Values for API Product Groups 1, 2, 4, 5

API Group	Product	Degrees F		Degrees C	
		K0	K1	K0	K1
1	Fuel Oils	103.8720	0.2701	186.9696	0.4862
2	Jet Fuels	330.3010	0.0	594.5418	0.0
4	Gasolines	192.4571	0.2438	346.4228	0.4388
5	Crudes	341.0957	0.0	613.9723	0.0

Alpha calc	Iterations for K0 and K1		K0	K1
	341.0957	0.0000	341.0957	0
	341.0957	0.0000		
	341.0957	0.0000		
	341.0957	0.0000		

TABLE 4, Coeficients for API 11.2.1/11.2.1M

Coeff	Degrees F	Degrees C
A	-1.99470	-1.62080
B	0.00013427	0.00021592
C	0.79392	0.87096
D	0.0023260	0.0042092

Designation: D 4007 – 81 (Reapproved 1995)$^{\epsilon 1}$

An American National Standard

Designation: Manual of Petroleum Measurement Standards Chapter 10.3 (MPMS)

Designation: IP 359/82

AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428

Standard Test Method for Water and Sediment in Crude Oil by the Centrifuge Method (Laboratory Procedure)[1]

ASTM D 4007

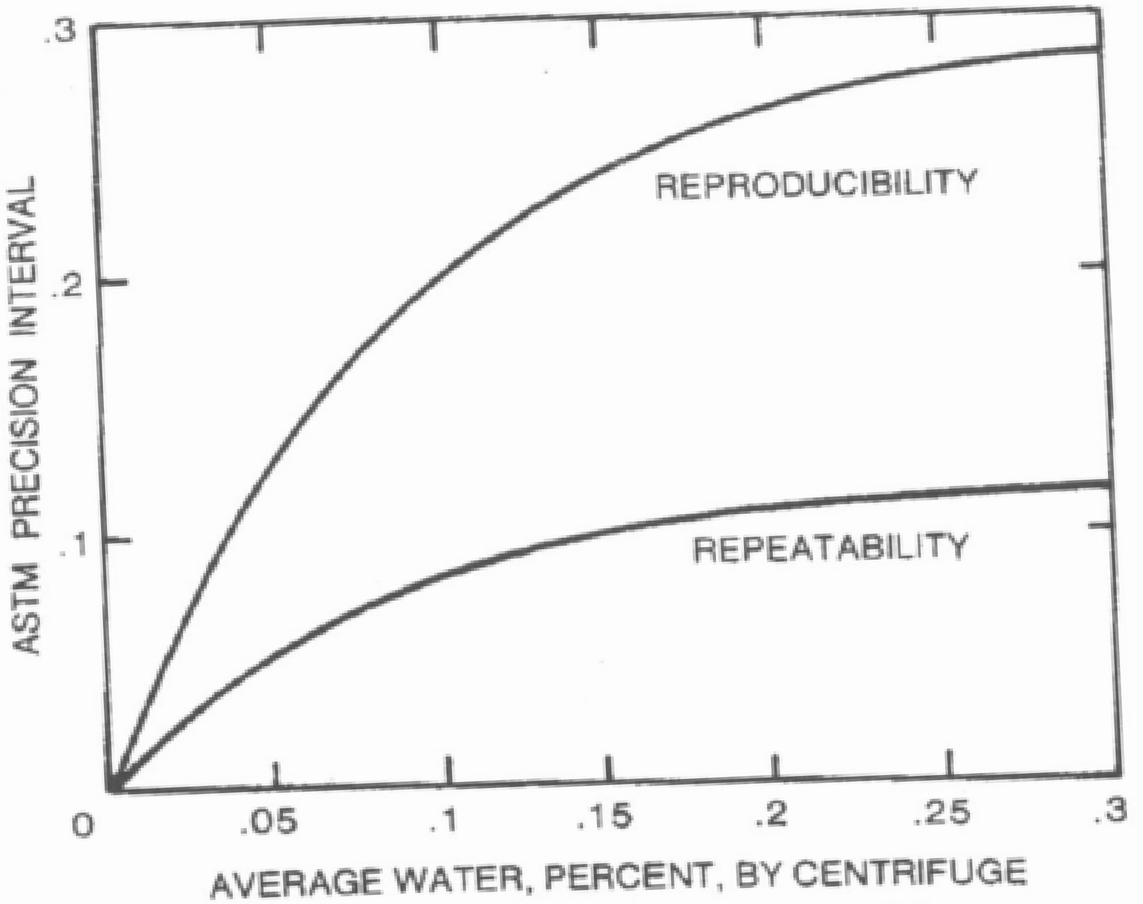


FIG. 3 Basic Sediment and Water Precision

Designation: D5002 – 13

Standard Test Method for
Density and Relative Density of Crude Oils by Digital Density Analyzer[1]

14.1.2 *Reproducibility*—The difference between two single and independent results, obtained by different operators working in different laboratories on identical test material, would, in the long run, in the normal and correct operation of the test method, exceed the following values only in 1 case in 20 (see Table 2):

range	reproducibility
0.75 to 0.95	$0.00412X$

API MPMS 11 .I .4 Summary and Precision Statement

	CTL precision at 95 % confidence level			
Temperature	100°F	150°F	200°F	250°F
Crudes and Products	±0.05%	±0.15%	±0.25%	±0.35%

Manual of Petroleum Measurement Standards Chapter 4—Proving Systems

Section 1—Introduction

THIRD EDITION, FEBRUARY 2005

American Petroleum Institute

Table 3—Hypothetical Uncertainty Limits in General Liquid Metering Hierarchy

Level	Description of Hierarchy Level	Uncertainty Limit, + or – %	
		Per Event	Per Year
1	Primary Standards	0.002	0.002
2	Secondary Working Standards	0.005	0.005
3	Field Transfer Standards	0.015	0.015
4	Meter Prover Base Volume	0.03	0.03
5	Meter Indicated Volume	0.10	0.05
6	Correction for Quality and/or Quantity	0.15	0.07
7	Custody Transfer Ticket	0.20	0.10

Standard uncertainty = (NSV error - NSV base case) ÷ NSV base case %

Expanded uncertainty = Standard Uncertainty x 2 ÷ probability distribution factor

BS ISO 5168:2005 Annex B (normative)

Probability distributions

Figures B.1 to B.5 illustrate the types of probability distributions.

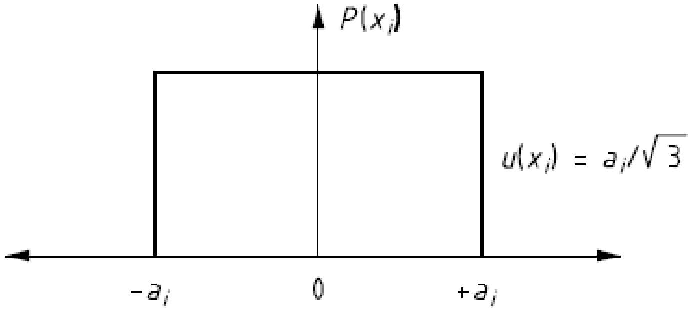
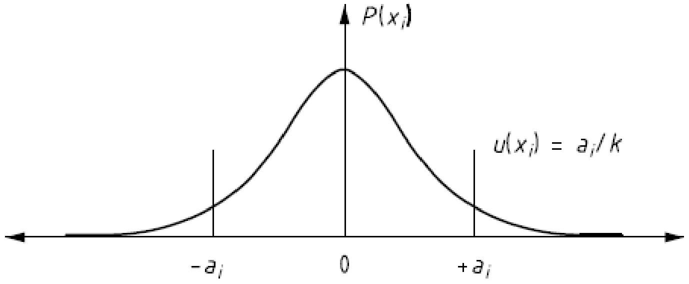


Figure B.1 — Rectangular probability distribution



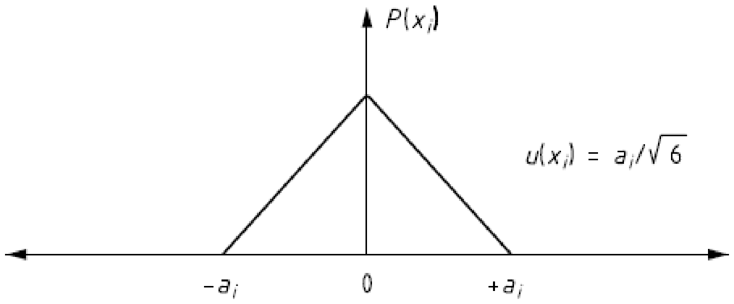


Figure B.3 — Triangular probability distribution

For the Normal Distribution k is the coverage factor appropriate to the range, $\pm a_i$.

7.3 Rectangular probability distribution

Typical examples of rectangular probability distributions include

— maximum instrument drift between calibrations,

— error due to limited resolution of an instrument's display,

— manufacturers' tolerance limits.

The standard uncertainty of a measured value, x_i, is calculated from Equation (9):

$$u(x_i) = \frac{a_i}{\sqrt{3}}$$

7.5 Triangular probability distribution

$$u(x_i) = \frac{a_i}{\sqrt{6}}$$

E_{mf} = error in meter factor due to meter proving error (considered separately)			0.000%
E_{cal} = error due to calculation tolerance			0.010%
ET_{rp} = error due to turbine meter reproducibility between last 25 proves			0.036%
ET_{r} = error in turbine meter proving repeatability			0.021%
E_{tlm} = error due to temperature measurement on the liquid in the meter			0.000%
E_{plm} = error due to pressure measurement on the liquid in the meter			0.000%
E_{API} = error due to API measurement on the liquid in the meter			-0.019%
E_{BSW} = error due to BS&W measurement on the liquid in the meter			0.068%
ECTL = error due to CTL uncertainty at	109.2	°F	0.041%
Efm = error due to compressibility factor uncertainty at	182	psig	0.006%

Emf = error in meter factor due to meter proving error (considered separately)		0%	
Ecal = error due to calculation tolerance		0.01%	API MPMS 21.2 para 9.2.7.4
ETrp = error due to turbine meter reproducibility between last 25 proves		0.036%	2 standard deviations%
ETr = error in turbine meter proving repeatability		0.02135%	API 13.1.8.1, see also API 4.2 App C & 4.8 App A)
Etlm = error due to temperature measurement on the liquid in the meter		0.00037%	ISO 5168 eqn 9 x k = 2
Eplm = error due to pressure measurement on the liquid in the meter		0%	ISO 5168 eqn 9 x k = 2
EAPI = error due to API measurement on the liquid in the meter		-0.0185%	ASTM D5002 14.1.2
EBSW = error due to BS&W measurement on the liquid in the meter		0.06766%	API MPMS 10.3 Fig 3 interpolation
ECTL = error due to CTL uncertainty at	109.19˚F	0.04105%	Δ K0 and KOC measured α60
Efm = error due to compressibility factor uncertainty at	182 psig	0.00642%	6.5% at 95% confidence per API 11.1.4

Root sum of squares method for combined metering errors

$$Ensv = (E_{mf}^2 + E_{cal}^2 + ET_{rp}^2 + ET_r^2 + E_{tlm}^2 + E_{plm}^2 + E_{API}^2 + E_{BSW}^2 + ECTL^2 + EFm^2)^{0.5}$$

E_{nsv} = Error in measurement of the net standard volume (NSV) total
(NSV = dry volume corrected to 60°F and 0 psig)

$$E_{GSTD} = (E_{mf}^2 + E_{cal}^2 + ET_{rp}^2 + ET_r^2 + E_{tlm}^2 + E_{plm}^2 + E_{API}^2 + ECTL^2 + E_{fm}^2)^{0.5}$$

E_{GSTD} = Error in measurement of the gross standard volume (GSTD) total
(GSTD = wet volume corrected to 60°F and 0 psig)

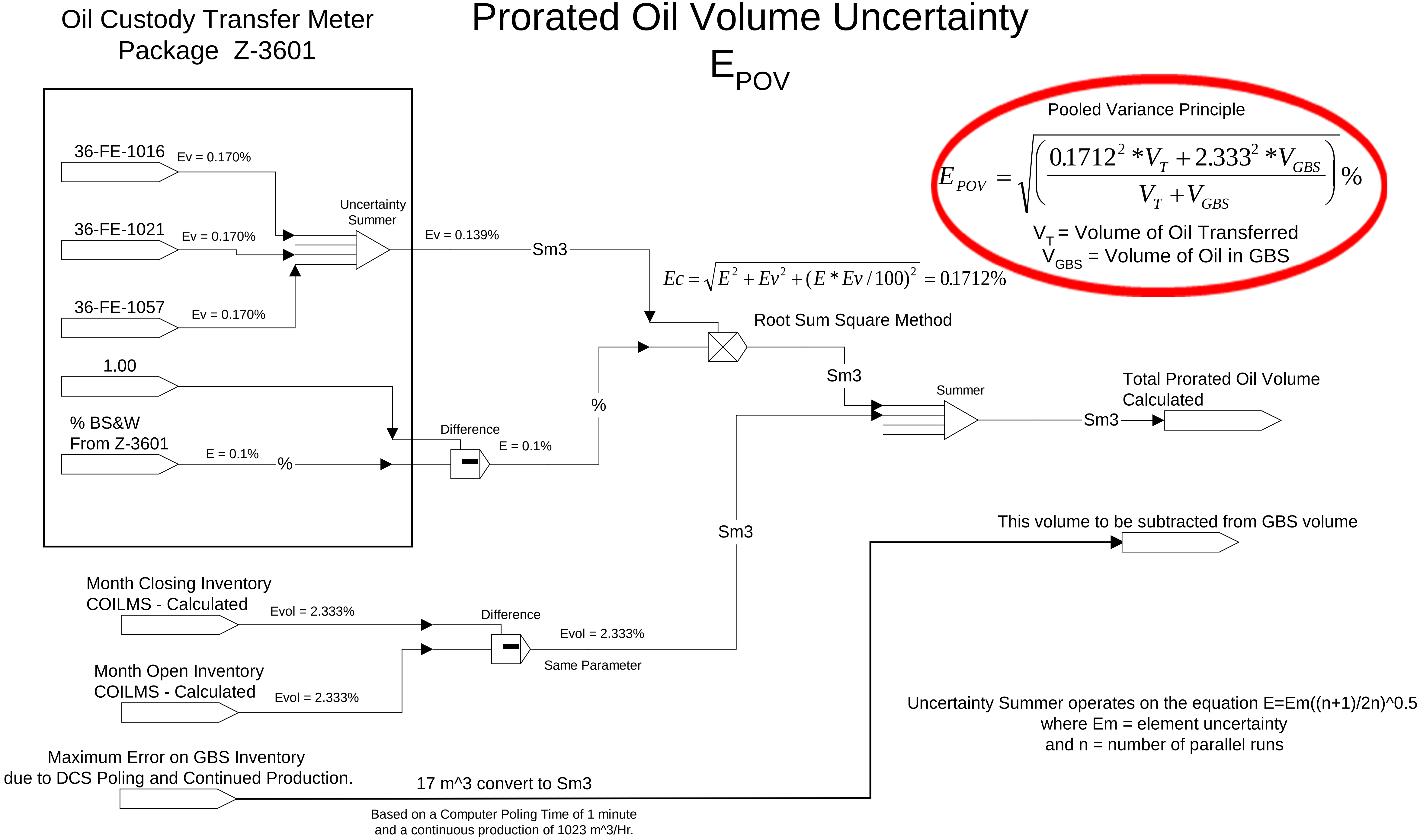
ISO 5168 paragraph

3.1 uncertainty

parameter, associated with the results of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

NOTE Uncertainties are expressed as an absolute value and do not take a positive or negative sign.

Prorated Oil Volume Uncertainty E_{POV}



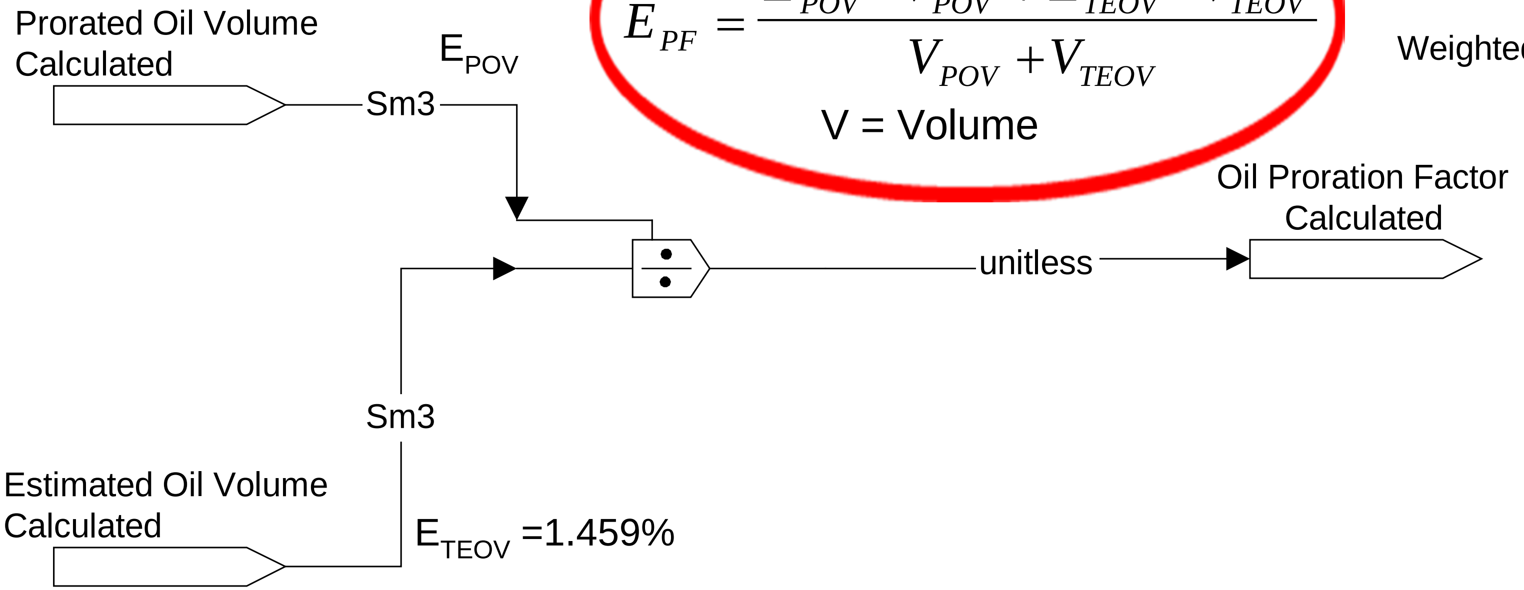
Oil Proration Factor Uncertainty

E_{PF}

$$E_{PF} = \frac{E_{POV} * V_{POV} + E_{TEOV} * V_{TEOV}}{V_{POV} + V_{TEOV}}$$

V = Volume

Weighted Uncertainty Principle



Meter No	Meter run Uncert % GSTD U	Meter run Batch vol % usage	Meter run Uncert vol GSTD Ubvol	Skid Ubv%	Meters > 15% used 1 or 0
A	0.063	28.77	0.018	---	1
B	0.068	28.80	0.020	---	1
C	0.065	26.22	0.017	---	1
D	0.059	12.52	0.007	---	0
E	0.056	2.09	0.001	---	0
F	0.057	1.61	0.001	---	0
sum →		100.00	0.064	0.064	3

INSTITUTE OF PETROLEUM

PETROLEUM MEASUREMENT MANUAL

PART XIV
Statistics for Static and Dynamic Measurement

August 1993

Published on behalf of
THE INSTITUTE OF PETROLEUM
A charitable company limited by guarantee

1.4.5 Reduced Uncertainty with Multiple Meters

If a measurement is made not with a single meter, bnt by combining the measurements of ℓ meters in parallel, a reduction in uncertainty is both predicted and has been observed. If as is usually the case the ℓ smaller meters have the same percentage uncertainty as one larger one, then the separate $U_{RL}(M)$ values will be expected to vary at random, and thus the total measurement will have the smaller uncertainty given by $U_L(\ell M)$ where:

$$U_L(\ell M) = \frac{U_{RL}(M)}{\sqrt{\ell}} + U_S(P) \qquad (41)$$

Note that since only one prover will be used to prove all ℓ meters its own contribution, $U_S(P)$, is not reduced.

JCGM 100:2008 (GUM 1995 with minor corrections)

Evaluation of measurement data — Guide to the expression of uncertainty in measurement

5.2 Correlated input quantities

For the very special case where all of the input estimates are correlated with correlation coefficients … The combined standard uncertainty uc(y) is thus simply a linear sum of terms representing the variation of the output.

$U_L(\ell M) =$	$U_{RL}(M)$	$+$	$U_s(P)$
	$\sqrt{\ell}$		
$U_L(\ell M) =$	0.064	$+$	0.03
	$\sqrt{3}$		
$U_L(\ell M) =$	0.067%		

Total GSTD Volume calculated relative, combined expanded range of uncertainty =

0.067 %, 95% confidence level, 109 proves

JCGM_100_2008_E (GUM)

7.2.6 The numerical values of the estimate y and its standard uncertainty uc(y) or expanded uncertainty U should not be given with an excessive number of digits. It usually suffices to quote uc(y) and U [as well as the standard uncertainties u(xi) of the input estimates xi] to at most two significant digits, although in some cases it may be necessary to retain additional digits to avoid round-off errors in subsequent calculations.

From: Desinger, Mark
Sent: Thursday, July 21, 2016 8:03 AM
To: 'david woods'
Subject: RE: Committee of Petroleum Measurement (COPM) Measurement Uncertainty Chapter 13.3

Hey David,

I don't have the expertise to comment on your comment – I'm just the editor. Having said that, several of WG who make their living performing these calculations stated that the parallel meter problem has not been definitively solved. Accordingly, we did not address this issue.

I am open to discussion. Thanks.

Mark Desinger
Alyeska Pipeline Service Company
Corporate Measurement Specialist

From: Desinger, Mark [mailto:Mark.Desinger@alyeska-pipeline.com]
Sent: Tuesday, July 26, 2016 11:57 AM
To: Jennifer Jones
Cc: david woods (a4woo54@hotmail.com)
Subject: FW: Committee of Petroleum Measurement (COPM) Measurement Uncertainty Chapter 13.3

Jennifer, Would you please put this in the "red file" for 13.3? All of these point should be considered at the next revision of 13.3. Thanks.

Mark Desinger
Alyeska Pipeline Service Company
Corporate Measurement Specialist

From: Jennifer Jones <jonesj@api.org>
Sent: 27 July 2016 23:04
To: Desinger, Mark
Cc: david woods (a4woo54@hotmail.com)
Subject: RE: Committee of Petroleum Measurement (COPM) Measurement Uncertainty Chapter 13.3

Hi Mark & David,

These comments have been filed for future review.

Thanks,

Jennifer M. Jones
Senior Standards Associate
API
1220 L Street NW
Washington, DC 20005
202-682-8073
202-682-8070 (fax)

API MPMS Chapter 13.3 – Measurement Uncertainty – Second Edition December 2017

Introduction

This standard serves as a standardized method to determine the uncertainty associated with various aspects of petroleum measurement. This standard supersedes API *MPMS* Chapter 13.1, *Statistical Concepts and Procedures in Measurement*, which has been withdrawn. Content from the superseded standard has been merged with this document to prevent duplication and promote alignment of content among the Chapter 13 standards.

This method is based on the 2008 edition of the International Organization of Standards (ISO) *Guide to the Expression of Uncertainty in Measurement* (GUM)-JCGM 100:2008-which was developed to be a guide for the writers of technical standards.

Although this document could be used for analysis of an entire system or facility, that use is outside the scope of the document.

THANK YOU