Measurement of hydrocarbon liquid flow rate using volumetric and gravimetric methods: comparison between KRISS and PTB hydrocarbon standard systems

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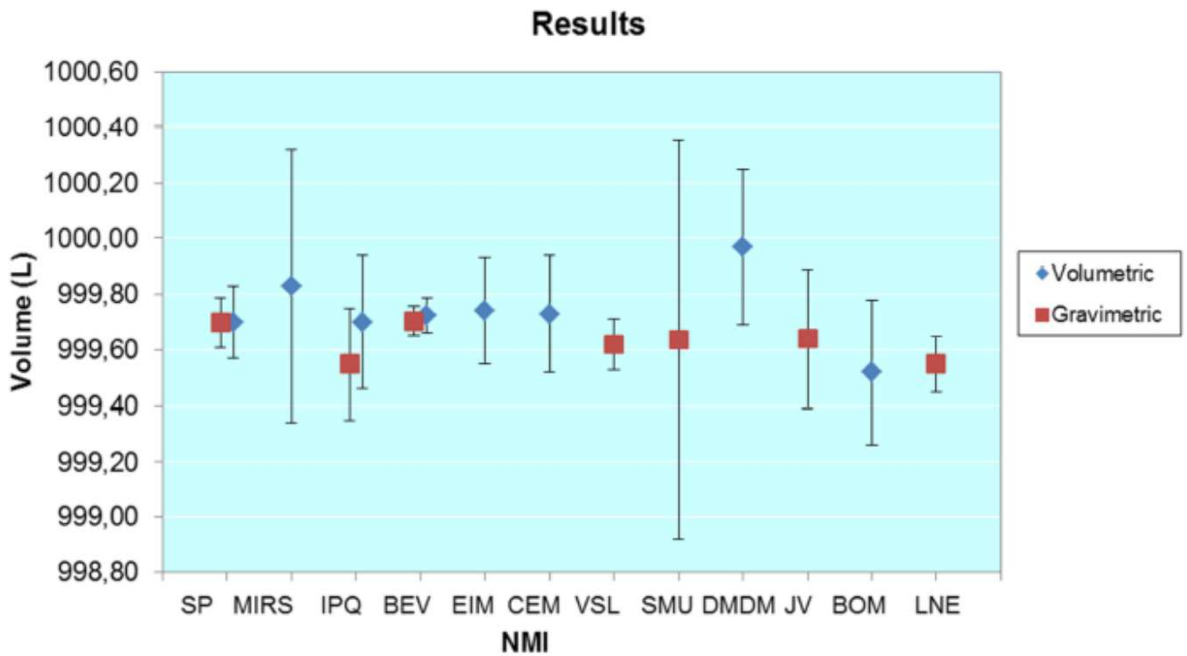
Contents

Introduction

Volumetric V.S Gravimetric methods for volume measurement

- Inter-comparison of a 1000 L proving tank
  - EURAMET Project no. 1157 (2013)
  - Volumetric and gravimetric methods for volume measurement
  - In most cases, the gravimetric method has a lower uncertainty.

Proving tank of 100 L



Volume measurement with error bars representing the laboratory reported uncertainties

Volumetric V.S Gravimetric methods for flow measurement

- Water flow measurement using volumetric and gravimetric methods
  - P. Wongthep et al., the case study of water flow measurement comparison in the range of 12-120 L/min, *J. of Physics : Conf. Series*, 2018
  - The volumetric and gravimetric methods show the same results.
- Lack of study comparing volumetric to gravimetric methods

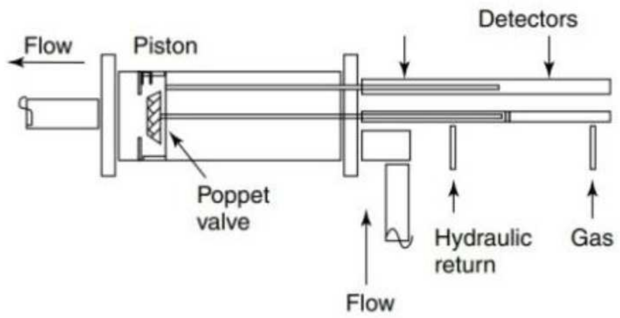
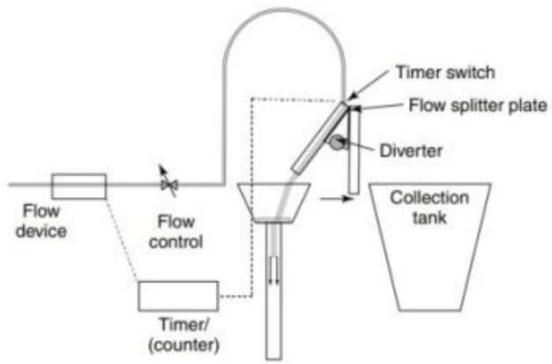


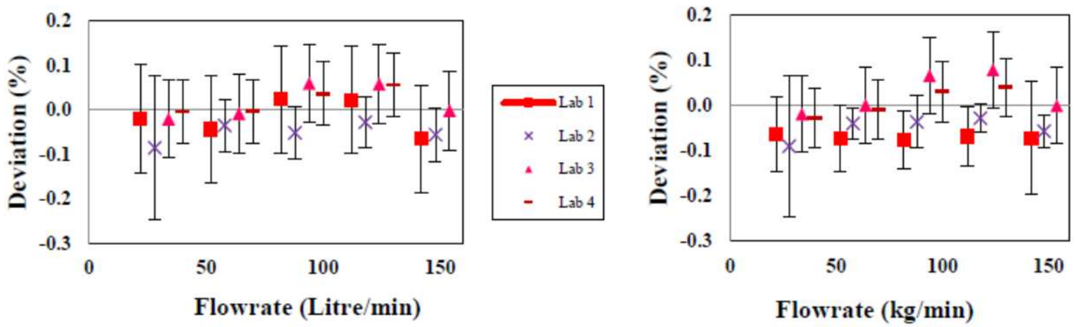
Diagram of piston prover

Lab.	Method	Flow range	Capability
E&H	Comparative	(100-70000) kg/h	-
MIT	Gravimetric	(200 – 70000) kg/h	0.040%
SMG	Gravimetric	(1.39 – 31670) g/s	0.080%
Flowlab	Gravimetric	(54 – 300000) kg/h	(0.014-0.04)%
NIMT	Volumetric	(0.2-150) litre/min	0.075%

Details of low system for each participant



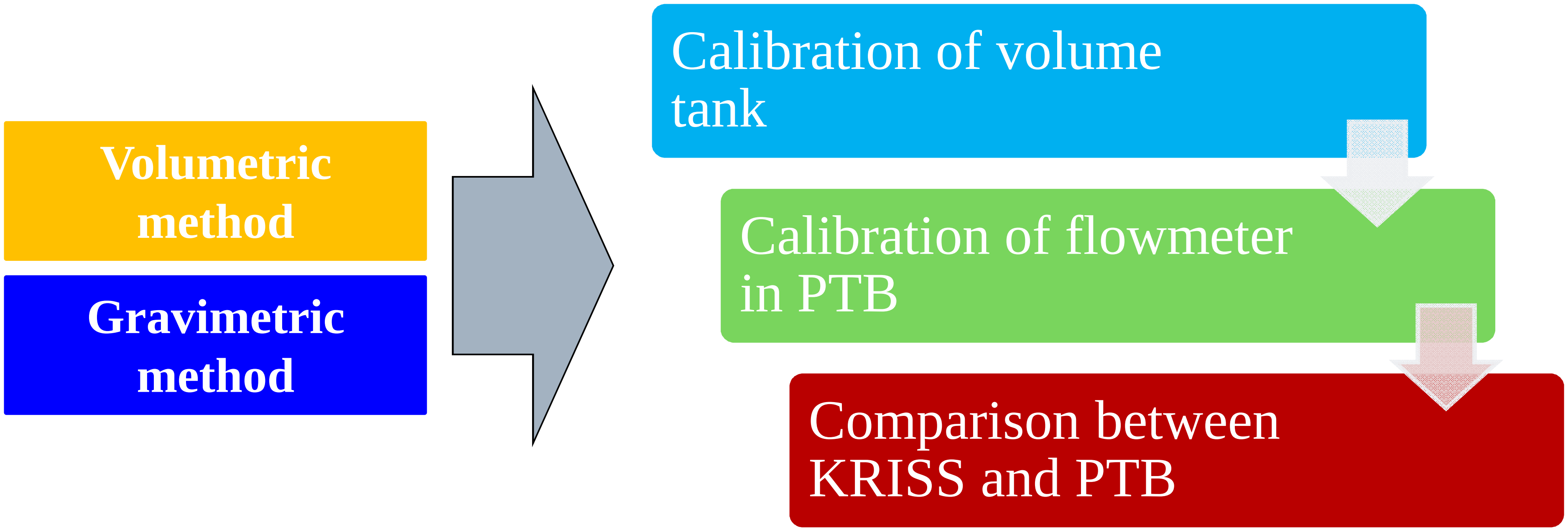
Gravimetric system



Deviation of the volumetric and gravimetric results

Purpose

- Volume tank calibration using volumetric and gravimetric methods in PTB
- Measurement of hydrocarbon flow using volumetric and gravimetric methods in PTB
- Inter comparison of hydrocarbon flow system between KRISS and PTB

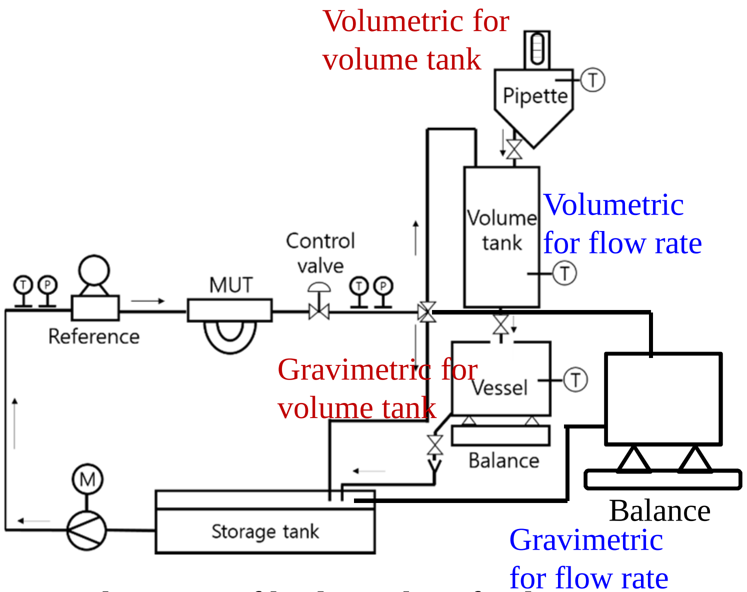


Experimental setup

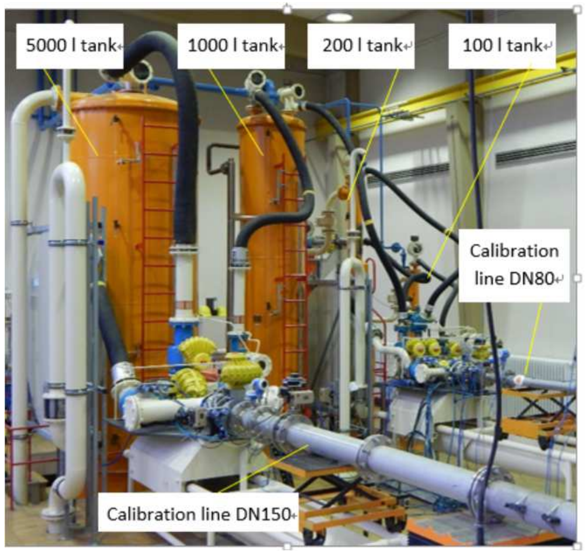
Hydrocarbon facility in PTB

- Measurement of hydrocarbon flow using both volume tank and balance
  - Calibration using both methods at the same pipe line
  - Flow rate :10 – 240 m^3/h (DN 150 mm),
    1-130 m^3/h (DN 80 mm), U=0.05 % (k=2)
  - Temperature 15-25 ^{o}C ± 1 ^{o}C, Pressure 1-4 bar

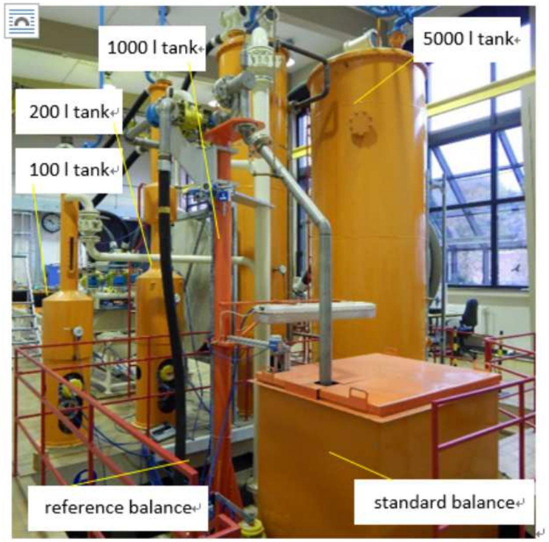
Hydrocarbon flow calibration facility in PTB



Schematic of hydrocarbon facility in PTB



Hydrocarbon flow calibration rig (a) front view to the facility

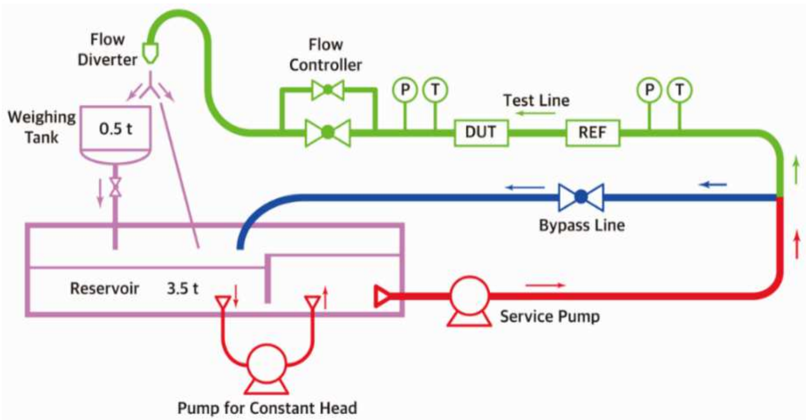


Hydrocarbon flow calibration rig (b) rearview

Hydrocarbon facility in KRISS

- Hydrocarbon flow facility for heavy oil (20 cSt)
  - Gravimetric method with diverter
  - Flow range (1 ~ 25) m^3/h, Weigh-B 500 kg, 0.12 % (k = 2)
- Hydrocarbon flow facility for light oil (3 cSt)
  - Flow range (25 ~ 150) m^3/h, Weigh-B 2500 kg, 0.08 % (k = 2)
  - Flow range (1 ~ 50) m^3/h, Weigh-B 2500 kg, 0.08 % (k = 2)
  - Flow range (200 ~ 1000) L/h, Weigh-B 64 kg, 0.08 % (k = 2)
  - Flow range (10 ~ 200) L/h, Weigh-B 6kg, 0.08 % (k = 2)

Control program for hydrocarbon flow facility



Schematic of hydrocarbon facility (light oil) in KRISS

Hydrocarbon flow calibration facility (light oil) in KRISS

Balance and diverter (KRISS)

Transfer Standard

- Coriolis flowmeter with diameter of 50 mm at low flow rate
  - Flow rage range : 3 ~ 35 t/h
- Coriolis flowmeter with diameter of 100 mm at high flow rate
  - Flow rate range : 30 ~ 120 t/h

Hydrocarbon flow calibration rig with flowmeter installed in PTB

Transfer standard, Coriolis flowmeter, Endress + Hauser / DN 50

Transfer standard, Coriolis flowmeter, Endress + Hauser / DN 100

Comparison based on Re number

- Re number to match different fluid properties of KRISS and PTB
  - Different Re numbers are applied to two different transfer standard
  - DN 50 mm – low flow rate
  - DN 100 – high flow rate
  - Overlap of Re # (DN 50, DN 100)

20 °C, 1 atm	Density (kg/m^3)	Viscosity (mPa · s)
Water	1000	1
Hydrocarbon in PTB	784.816	1.35
Hydrocarbon in KRISS	805.37	2.95

Fluid properties of water and hydrocarbon in KRISS and PTB

Re. number	KRISS flowrate		PTB flowrate	
	t/h	m^3/h	t/h	m^3/h
1.59E+04	3	3.72	2.97	3.79
2.62E+04	5	6.21	4.91	6.25
4.84E+04	9	11.17	9.30	11.85
1.07E+05	20	24.83	19.93	25.40
1.85E+05	35	43.46	35.31	44.988

Mass and volume flow rates of KRISS and PTB according to Re number (low flow rate, DN 50 mm)

Re. number	KRISS flowrate		PTB flowrate	
	t/h	m^3/h	t/h	m^3/h
3.59E+04	30	37.25	13.69	17.45
7.18E+04	60	74.50	27.39	34.90
1.08E+05	90	111.75	41.08	52.35
1.44E+05	120	149.00	54.78	69.80

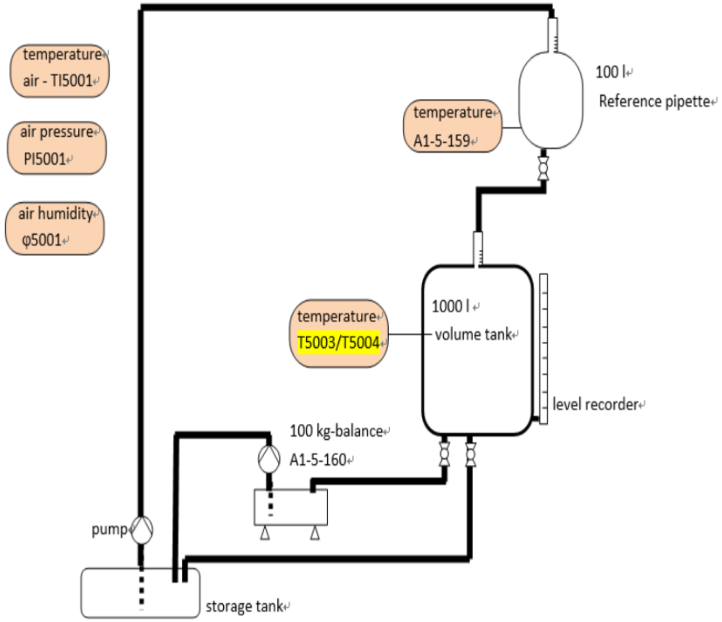
Mass and volume flow rates of KRISS and PTB according to Re number (high flow rate, DN 100 mm)

Calibration of the volume tank

Calibration of the volume tank

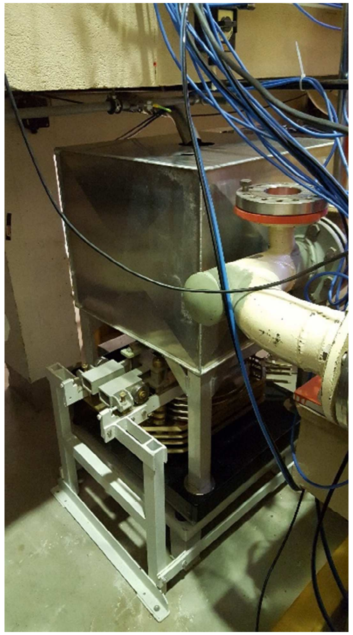
- Calibration of the volume tank using gravimetric and volumetric methods at the same time
  - Reference volume tank (Pipette) : 100 L (99999.312 ± 17 ml)
  - Balance : 100 kg


Installation of reference pipette



Schematic of measurement setup using volumetric and gravimetric methods


Reference volume tank (Pipette)


Balance


Volume tank (1000 L)

KRISS 한국표준과학연구원 Korea Research Institute of Standards and Science

PTB

Calibration of the volume tank

- Mathematical model for volumetric method
  - EURAMET cg-21: Guidelines on the calibration of standard capacity measures using the volumetric method, 2013.

$$V_{T,vol} = V_0[1 - \gamma_{RS}(T_{0RS} - T_{RS}) + \beta(T_{VT} - T_{RS}) + \gamma_{VT}(T_0 - T_{VT})] + \delta V_{men} + \delta V_{rep} + \delta V_{approx} + \delta V_{add}$$

V_0 Volume of reference standard in L
T_{0RS} Water temperature of reference standard in the volume certificate in ˚C
T_{RS} Water temperature of reference standard in ˚C
T_0 Reference temperature of volume tank in ˚C
T_{VT} Water temperature of the volume tank in ˚C
γ_{RS} Coefficient of cubical thermal expansion of reference standard material in $˚C^{-1}$
γ_{VT} Coefficient of cubical thermal expansion of volume tank material in $˚C^{-1}$
β Coefficient of cubical thermal expansion for water in $˚C^{-1}$
dV_{men} Meniscus reading in L
dV_{rep} Measurement repeatability in L
dV_{approx} Approx. function in L
dV_{add} Additional factors in L

Standard unc ertainty comp onent $u(x_i)$	Source of uncertainty	Uncertainty $u_i(V_0)$ = $\lvert c_i \rvert u(x_i)$
$u(V_0)$	Volume of the RS	9.06E-02 (L)
$u(T_{RS})$	Water temperature of RS	5.86E-03 (L)
$u(T_{VT})$	Water temperature of volume tank	1.19E-03 (L)
u(γRS)	Coefficient of cubica l thermal expansion o f the RS	2.23E-04 (L)
u(δVT)	Coefficient of cubica l thermal expansion o f volume tank	3.12E-04 (L)
u(δVmen)	Meniscus reading of the RS	7.22E-04 (L)
u(δVrep)	Measurement repeata bility	8.99E-03 (L)
u(δVapprox)	Approximation funct ion	1.18E-01 (L)
u(δVadd)	Additional factors	6.47E-02 (L)
$U_{T,Vol}$	$U(V_{T,vol})$ 3.25E-01 L (k = 2)	

Results of uncertainty calculation for volume tank calculation using volumetric method

Calibration of the volume tank

- Mathematical model for gravimetric method
  - EURAMET cg-19: Guidelines on the determination of uncertainty in gravimetric volume calibration, 2012.

$$V_{T,Mass} = m\frac{1}{\rho_W - \rho_A}\left(1 - \frac{\rho_A}{\rho_B}\right)[1 - \gamma_{VT}(T_{VT} - T_0)] + \delta V_{rep} + \delta V_{Approx} + \delta V_{Add}$$

m Weighing result in kg
ρ_W Liquid density in kg/m³, at calibration temperature
ρ_A Air density in kg/m³
ρ_B Density of mass pieces during balance calibration = 7900 kg/m³
γ_{VT} Coefficient of cubical thermal expansion of volume tank material in °C^{-1}
T_0 Reference temperature of volume tank in °C
T_{VT} Water temperature of the volume tank in °C
dV_{rep} Measurement repeatability in L
dV_{approx} Approx. function in L
dV_{add} Additional factors in L

Standard uncertainty component $u(x_i)$	Source of uncertainty	Uncertainty $u_i(V_0) = \lvert c_i \rvert u(x_i)$
u(m)	Balance reading	3,44E-06 (L)
$u(T_{VT})$	Water temperature of volume tank	2.43E-07 (L)
ρ_W	Density fluid	3.02E-06 (L)
ρ_A	Density Air	2.53E-08 (L)
ρ_B	Density mass pieces	1.12E-07 (L)
u(δVT)	Coefficient of cubical thermal expansion of volume tank	1.34E-07 (L)
u(δVrep)	Measurement repeatability	3.82E-02 (L)
u(δVapprox)	Approximation function	5.02E-02 (L)
u(δVadd)	Additional factors	5.80E-02 (L)
$U_{T,Mass}$	$U(V_{T,Mass})$ 1.71E-01 L (k = 2)	

Results of uncertainty calculation for volume tank calculation using gravimetric method

Calibration of the volume tank

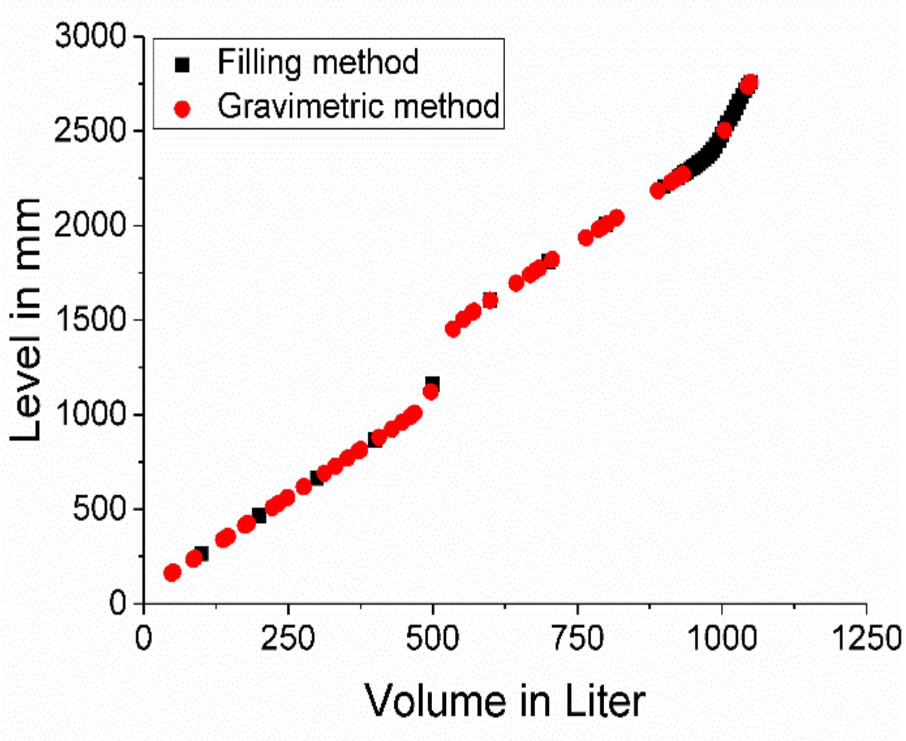
- Comparison of calibration results of volume tank using volumetric and gravimetric methods
  - Volumetric and gravimetric results are almost identical
  - The uncertainty of the gravimetric method is about 2 times lower than that of the volumetric method

Linear range of liquid level in mm	Differences between both models		
	Min in mL	Max in mL	Mean in mL
160 … 950	8.66	237.79	109.46
2000 … 2200	242.92	497.70	370.31
2450 … 2650	5.68	78.06	29.88

Difference between volumetric and gravimetric method results according to volume section

	u (k = 1)		u (k = 2)	
	ml	%	ml	%
Volumetric method	162.59	0.016	325.18	0.031
Gravimetric method	85.69	0.008	171.39	0.016

Comparison of the uncertainties for volume tank calibration



Comparison between filling and gravimetric methods

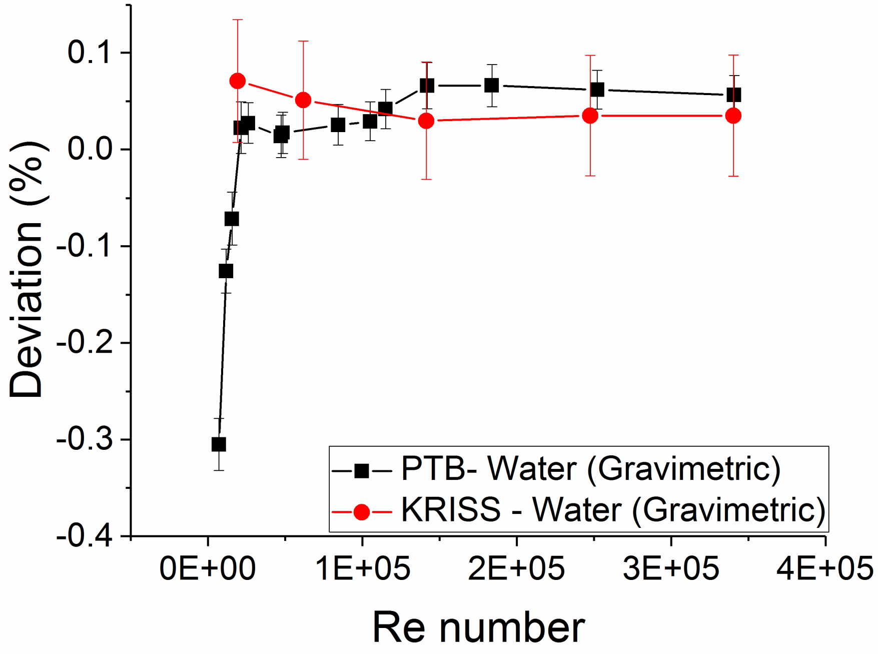
Inter comparison of hydrocarbon flow system between KRISS and PTB

Comparison of water flow facility between PTB and KRISS (DN 50 mm)

- Calibration in water flow facility to analyze flow meter characteristics
  - Uncertainty - PTB : 0.02 %, KRISS : 0.06 %
  - En numbers in water flow facilities are less than1

$$E = 100\frac{q_{indicated} - q_{ref}}{q_{ref}}$$

$$E_n = \frac{E_{KRISS} - E_{PTB}}{\sqrt{U_{KRISS}^2 + U_{PTB}^2}}$$



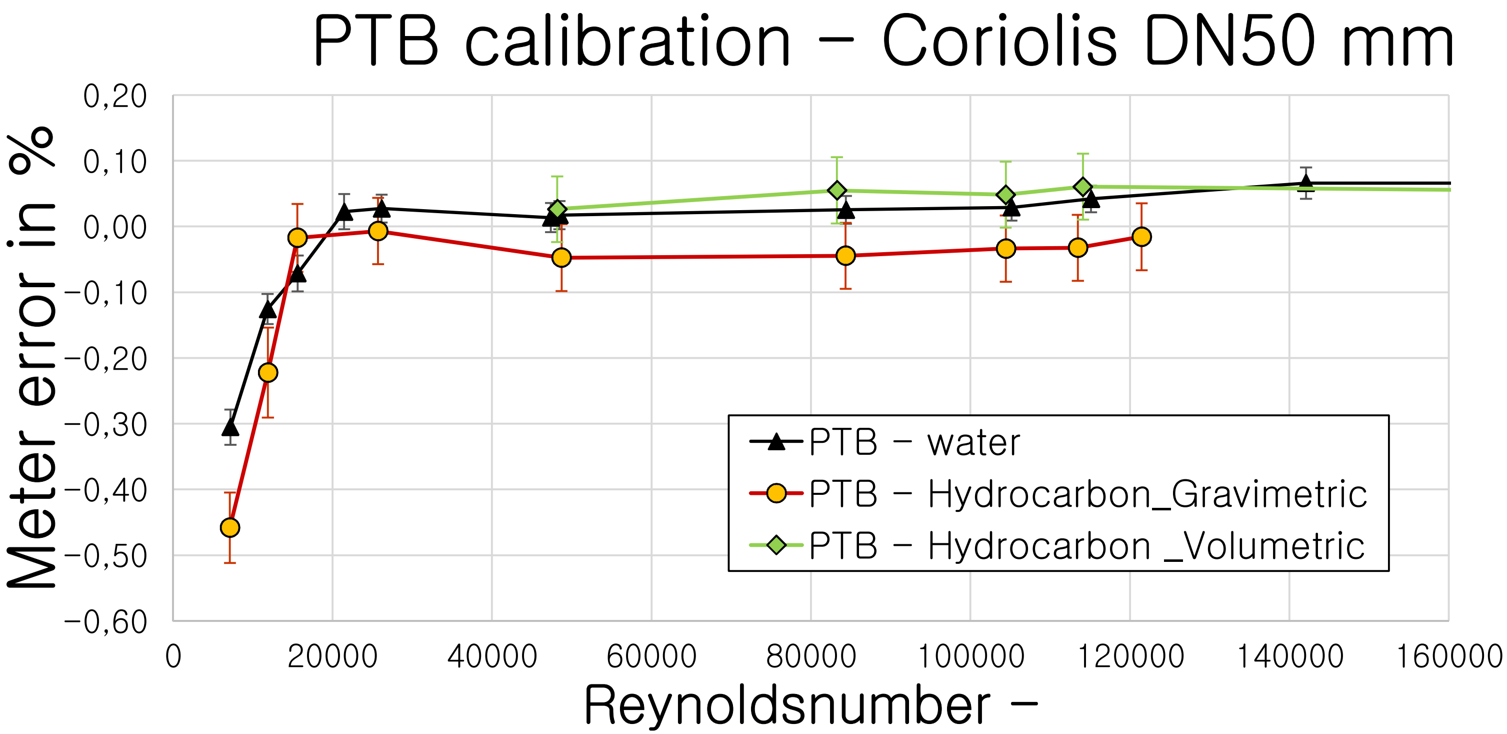
Deviation of flowmeter (DN 50 mm)with Re number in KRISS and PTB water facilities

Re #	Deviation		En #
	PTB	KRISS	
2.15E+04	0.023	0.071	0.765
4.85E+04	0.017	0.051	0.536
1.42E+05	0.066	0.030	0.571
2.52E+05	0.062	0.035	0.423
3.41E+05	0.056	0.035	0.338

En number of calibration results in PTB and KRISS water facilities

Hydrocarbon flow measurement using volumetric and gravimetric methods in PTB (DN 50 mm)

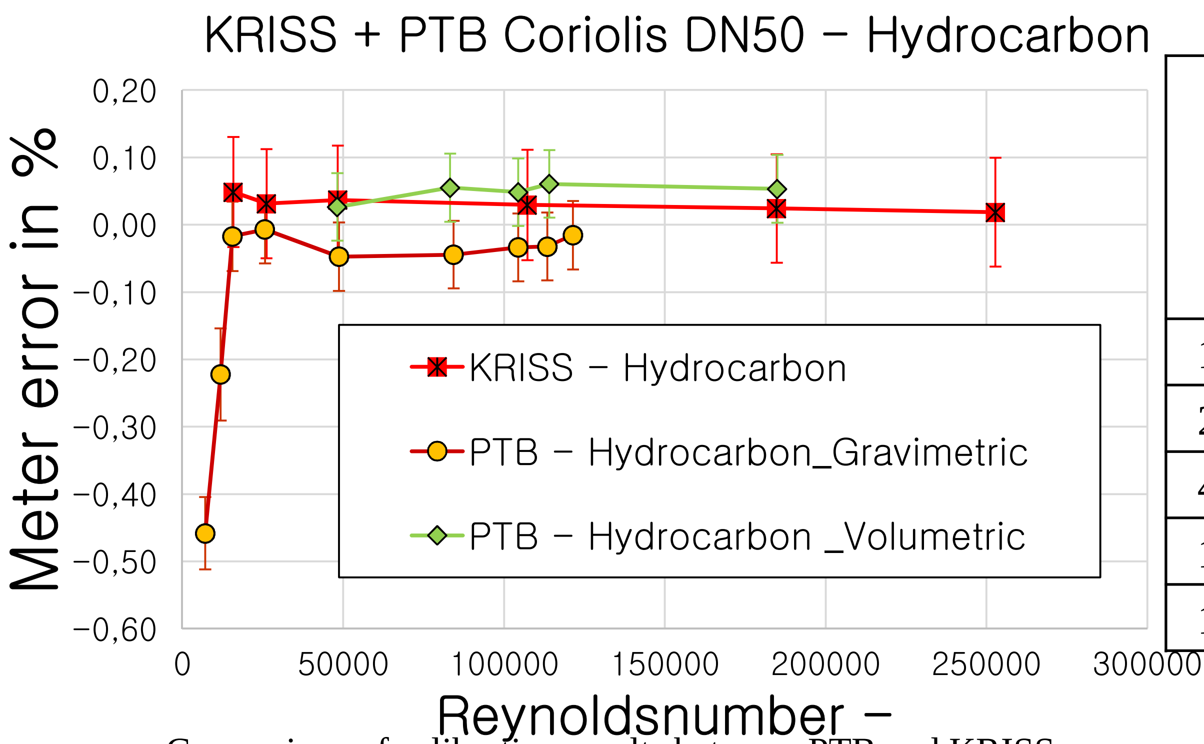
- Calibration results of water and hydrocarbon of gravimetric method are matched according to the Re number
  - The results of the hydrocarbon system and the water system match according to Re number.



Calibration results of water and hydrocarbon facilities with Re number in PTB

Inter comparison of hydrocarbon flow system between KRISS and PTB (DN 50 mm)

- Comparison of hydrocarbon facility between PTB(volumetric and gravimetric) and KRISS (gravimetric)
  - Uncertainty - PTB : 0.05 %, KRISS : 0.08 %
  - En numbers are less than 1 for both volumetric and gravimetric methods



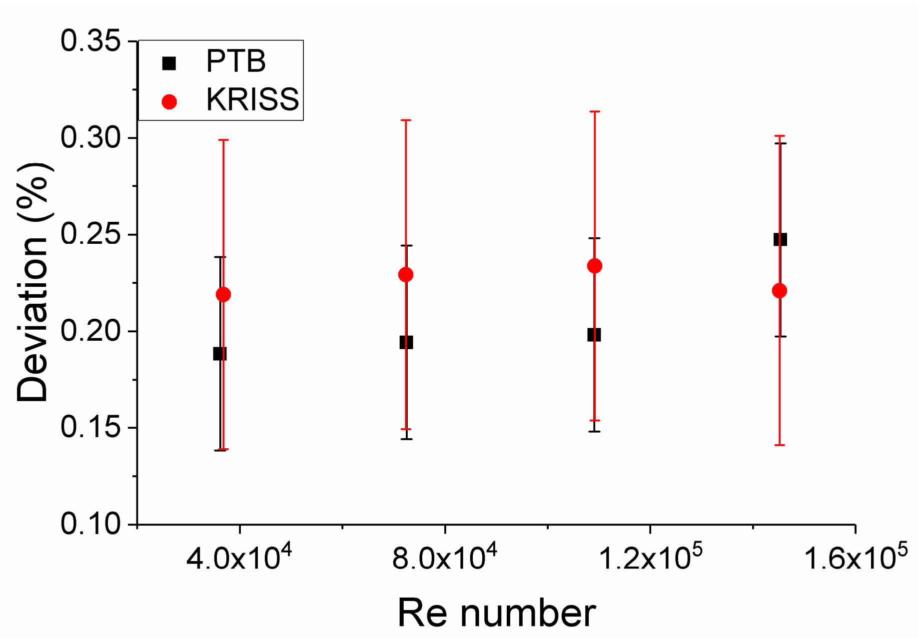
Comparison of calibration results between PTB and KRISS (DN 50 mm)

Re #	En # (KRISS-PTB)	
	Volumetric	Gravimetric
1.59E+04		0.70
2.62E+04		0.40
4.84E+04	0.11	0.89
1.07E+05	0.20	0.67
1.85E+05	0.31	

En number of calibration results in PTB and KRISS hydrocarbon facilities

Inter comparison of hydrocarbon flow system between KRISS and PTB (DN 100 mm)

- Comparison of hydrocarbon facility between PTB(volumetric) and KRISS (gravimetric)
  - En numbers are less than 1
  - The hydrocarbon flow standard systems of KRISS and PTB have traceability when using the volumetric and gravimetric methods



Comparison of calibration results between PTB and KRISS (DN 100 mm)

Re. number	KRISS flowrate		PTB flowrate		En number
	t/h	m^3/h	t/h	m^3/h	
3.59E+04	30	37.25	13.69	17.45	0.32
7.18E+04	60	74.50	27.39	34.90	0.37
1.08E+05	90	111.75	41.08	52.35	0.37
1.44E+05	120	149.00	54.78	69.80	0.27

En number of calibration results in PTB and KRISS hydrocarbon facilities

Concluding remarks

- We used the volumetric and gravimetric methods simultaneously to measure the hydrocarbon flow rate.
- A 1000 L volume tank was calibrated by both a volumetric method using a standard volume tank and a gravimetric method using a calibrated balance.
- The Re number was used to compensate for the density and viscosity differences in the working fluid.
- The results from the gravimetric method at KRISS matched very well with the results from the volumetric and gravimetric methods at PTB, within the estimated uncertainties.
- We confirmed that the hydrocarbon flow standard systems of KRISS and PTB have traceability when using the volumetric and gravimetric methods in the given range of Re number.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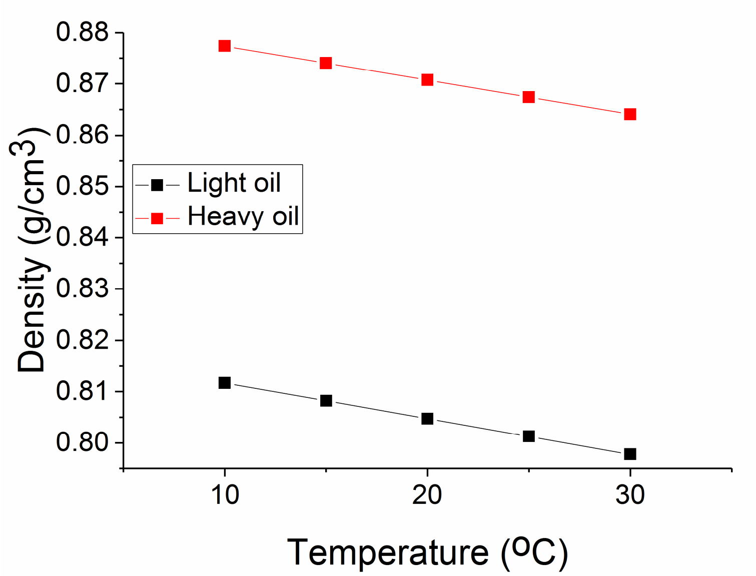
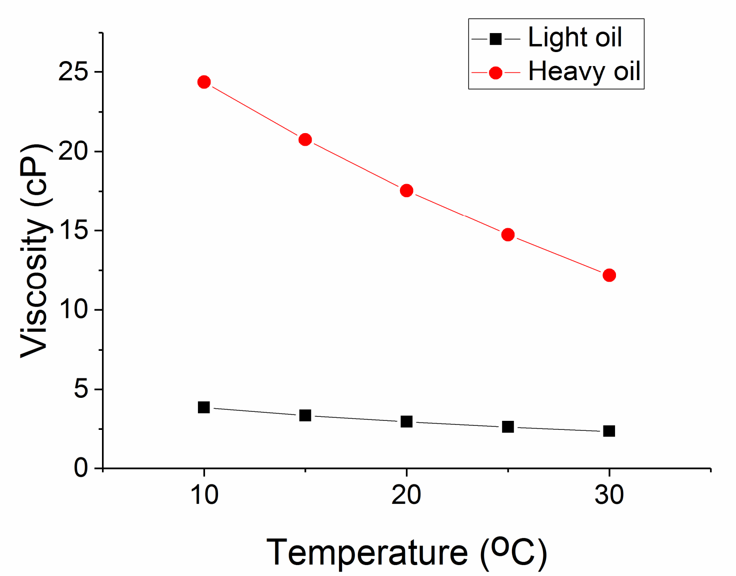
KRISS
Thank you

Volumetric V.S Gravimetric methods

- Water flow measurement comparison
  - Volumetric and gravimetric methods for volume measurement
  - EURAMET Project no. 1157



Density of light and heavy oil according to the temperature



Viscosity of light and heavy oil according to the temperature