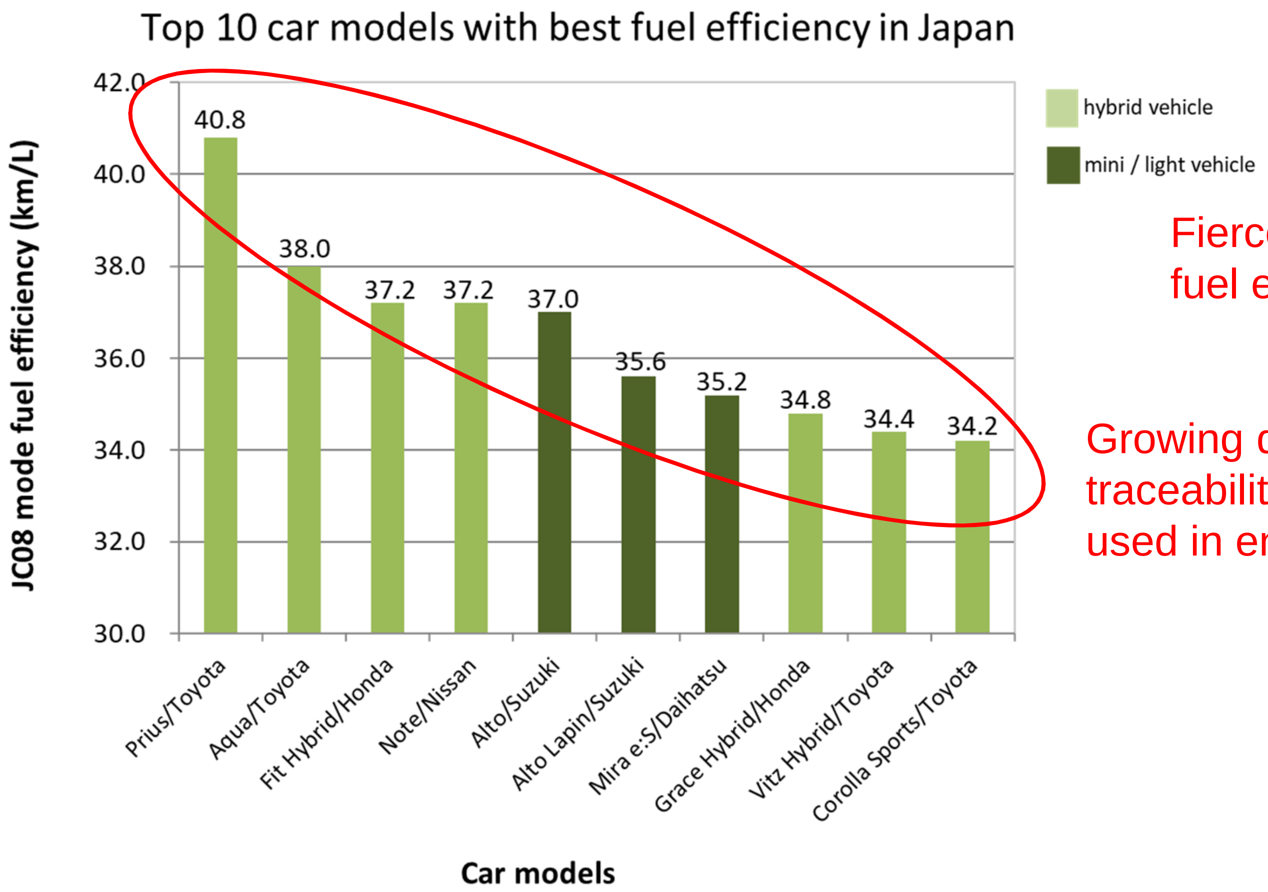
FLOMEKO 2019, Lisbon, Portugal, June 26-28, 2019

Primary standard for liquid hydrocarbon at low flow rates using light oil, kerosene and industrial gasoline

Kar-Hooi CHEONG
Ryouji DOIHARA
Noriyuki FURUICHI
Takashi SHIMADA
Yoshiya TERAO

Liquid Flow Standards Group,
Research Institute for Engineering Measurement,
NMIJ, AIST

Background and Motivation



Source: http://e-nenpi.com

Fierce competition in fuel efficiency

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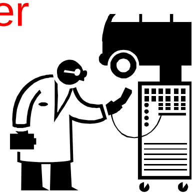
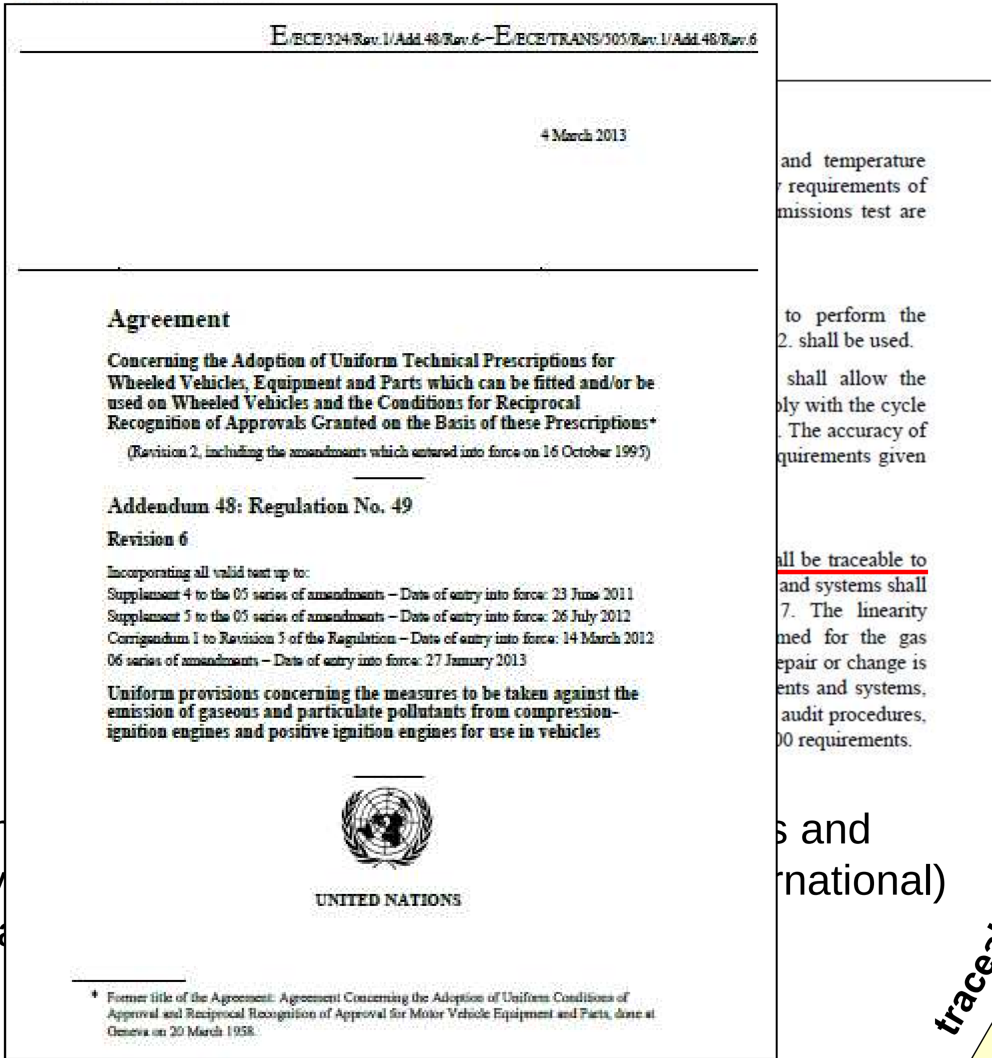
Growing demand for accuracy and traceability of fuel flowmeter used in engine test bench.



Background and Motivation

One example of the international regulations related to automobiles.


E/ECE/324/Rev.1/Add.48/Rev.6−E/ECE/TRANS/505/Rev.1/Add.48/Rev.6

4 March 2013

Agreement

Concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be fitted and/or be used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions*

(Revision 2, including the amendments which entered into force on 16 October 1995)

Addendum 48: Regulation No. 49

Revision 6

Incorporating all valid text up to:
Supplement 4 to the 05 series of amendments – Date of entry into force: 23 June 2011
Supplement 5 to the 05 series of amendments – Date of entry into force: 26 July 2012
Corrigendum 1 to Revision 5 of the Regulation – Date of entry into force: 14 March 2012
06 series of amendments – Date of entry into force: 27 January 2013

Uniform provisions concerning the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines and positive ignition engines for use in vehicles

UNITED NATIONS

* Former title of the Agreement: Agreement Concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipment and Parts, done at Geneva on 20 March 1958.

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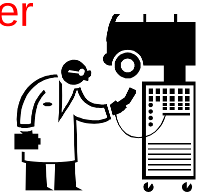
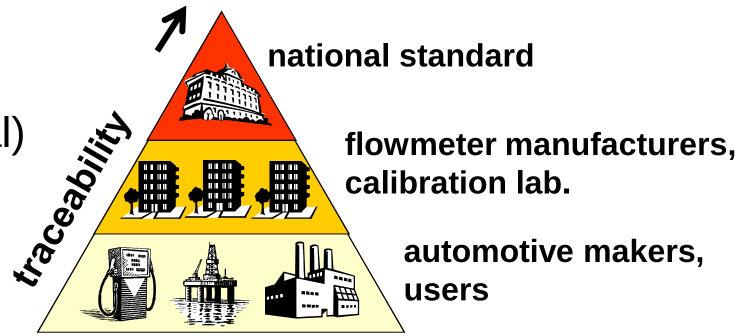
Fierce competition in fuel efficiency

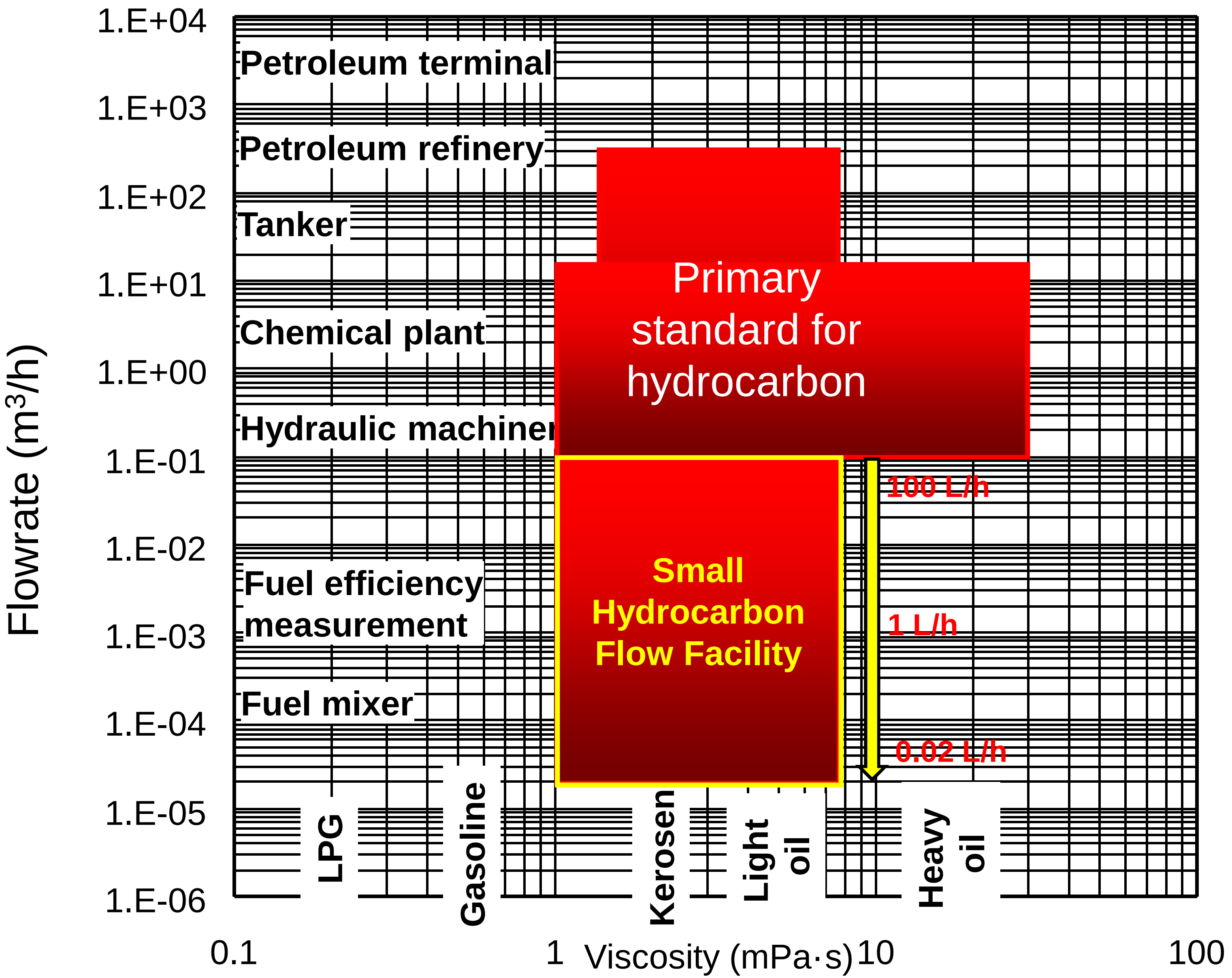
Growing demand for accuracy and traceability of fuel flowmeter used in engine test bench.



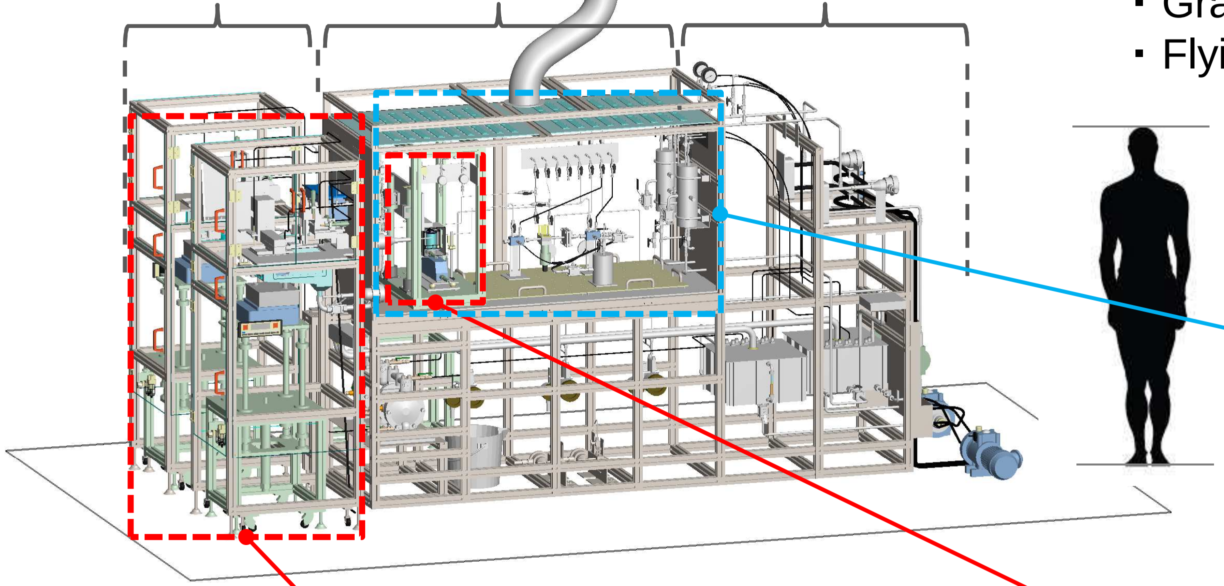
Need for establishment of national standard.



Primary standards for hydrocarbon at NMIJ



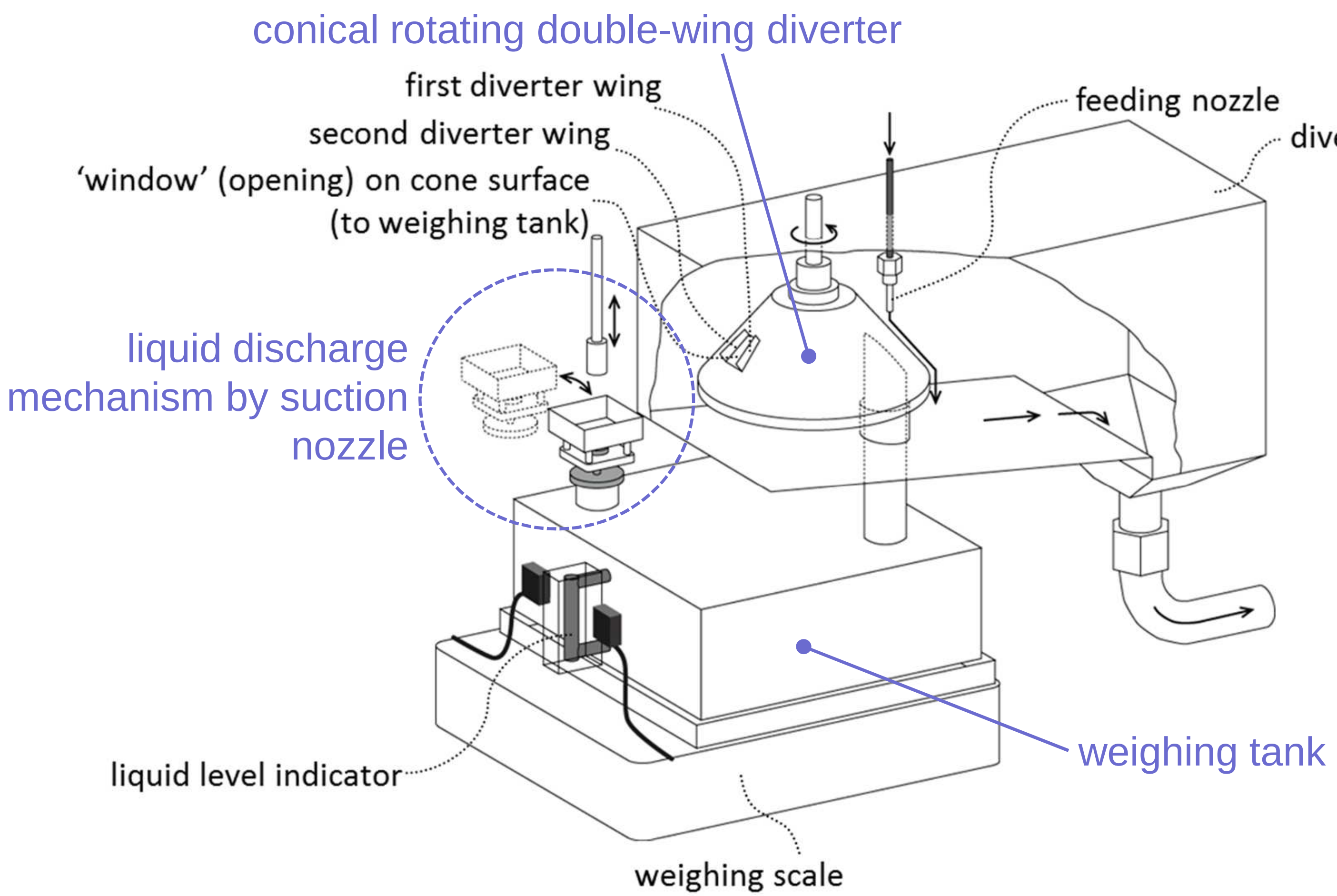
Calibration Facility



Calibration method

- Gravimetric (static weighing)
- Flying-start-and-finish

Gravimetric system using a conical rotating double-wing diverter (CRDWD) for 1-100 L/h



Flow Measurement and Instrumentation, Vol. 56, pp. 1-13, 2017

Question: Is diverter feasible for lower liquid flow rates, such as down to 0.02 L/h (0.33 mL/min)?

Problems

1) Liquid residue adheres to the diverter's wall and liquid splashing occurs. ⇒ Significant error of mass loss relative to small amount of liquid collection.

2) Droplets form at the tip of the feeding nozzle on top of diverter. ⇒ Unstable flow rate.

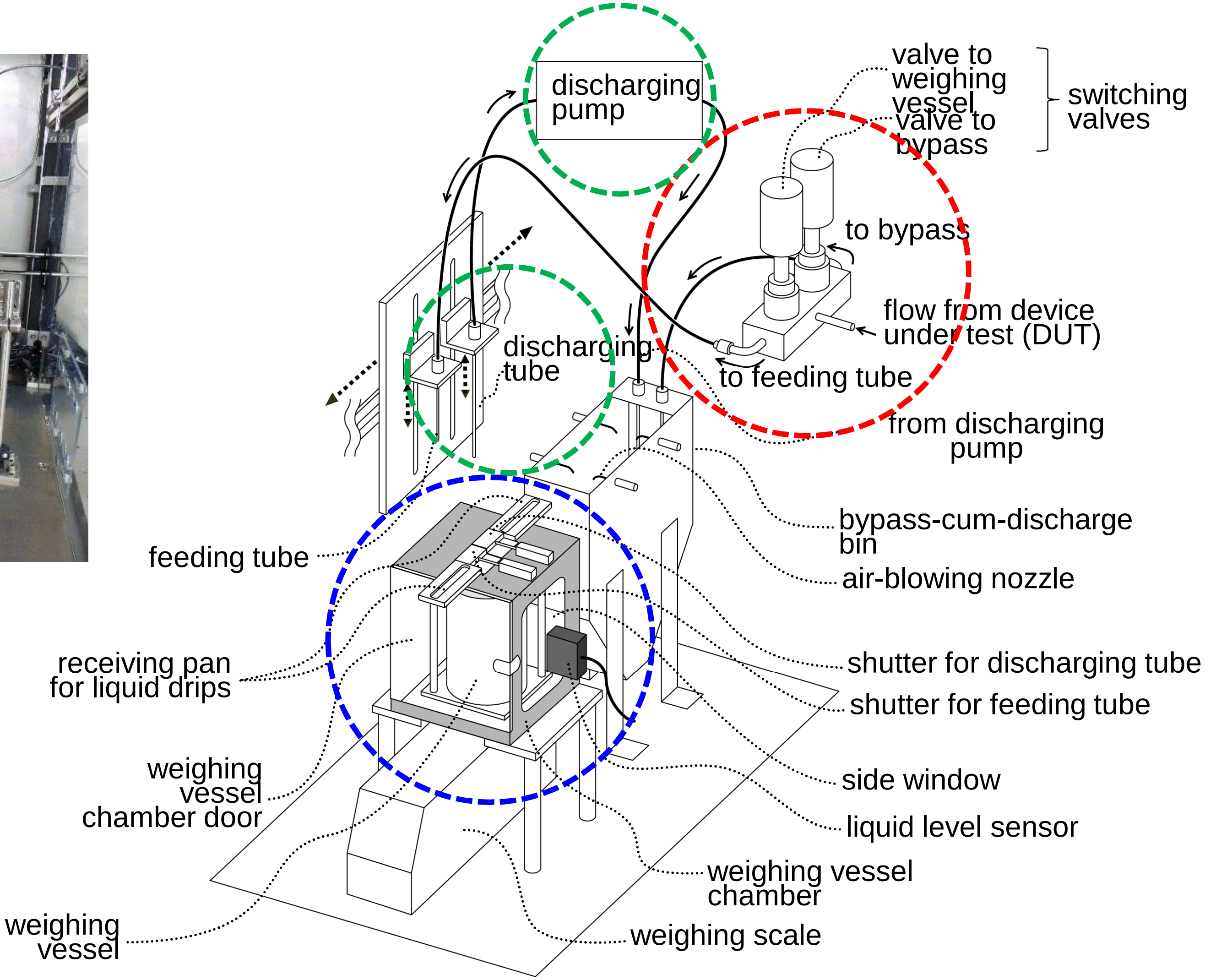
The usual practice

Low flow rates: DW-FSS (dynamic weighing with flying-start-and-stop) with no diverters

Motivation

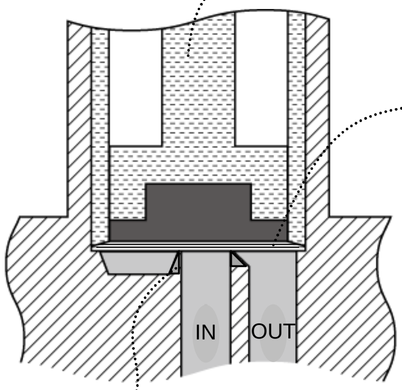
A challenge to test the limitation of SW-FSS at low flow rates, such as down to 0.02 L/h (0.33 mL/min).

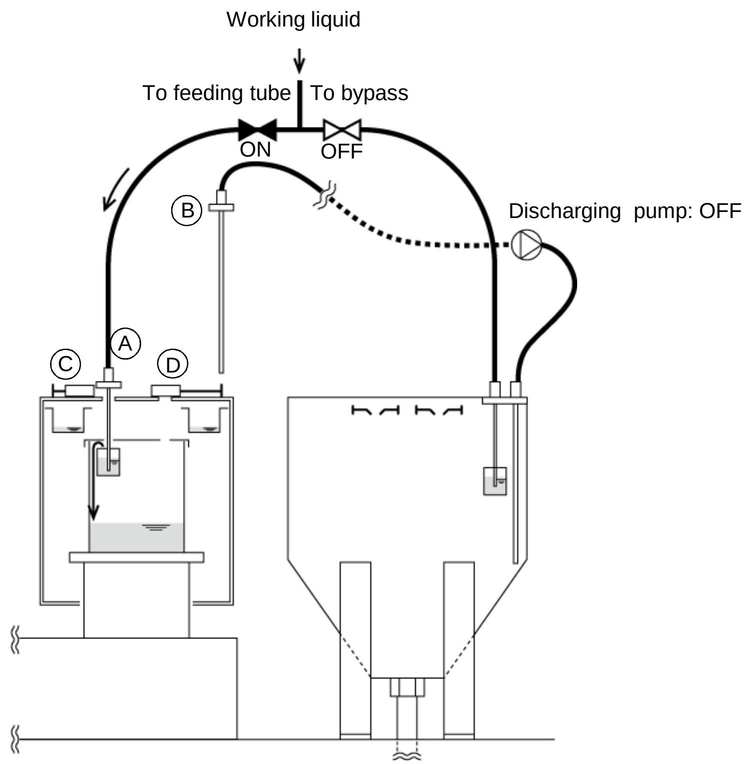
Gravimetric system using a pair of high-speed switching valves for 0.02 -1 L/h



Measurement Science and Technology, Vol. 29, 075304 (15 pp), 2018

A pair of switching valves as a flow diverter





<u>diaphragm valve</u>

- ●pneumatically actuated
- ●short piston stroke to give fast working speed
- ●long durable diaphragm (alloy)
- ●built-in stroke positioning sensor

<u>Diverting between two symmetrical flow paths</u>

Flow path to the feeding tube and flow path to the bypass line are symmetrical, so that flow rate is constant in both flow paths.

Uncertainty Budget

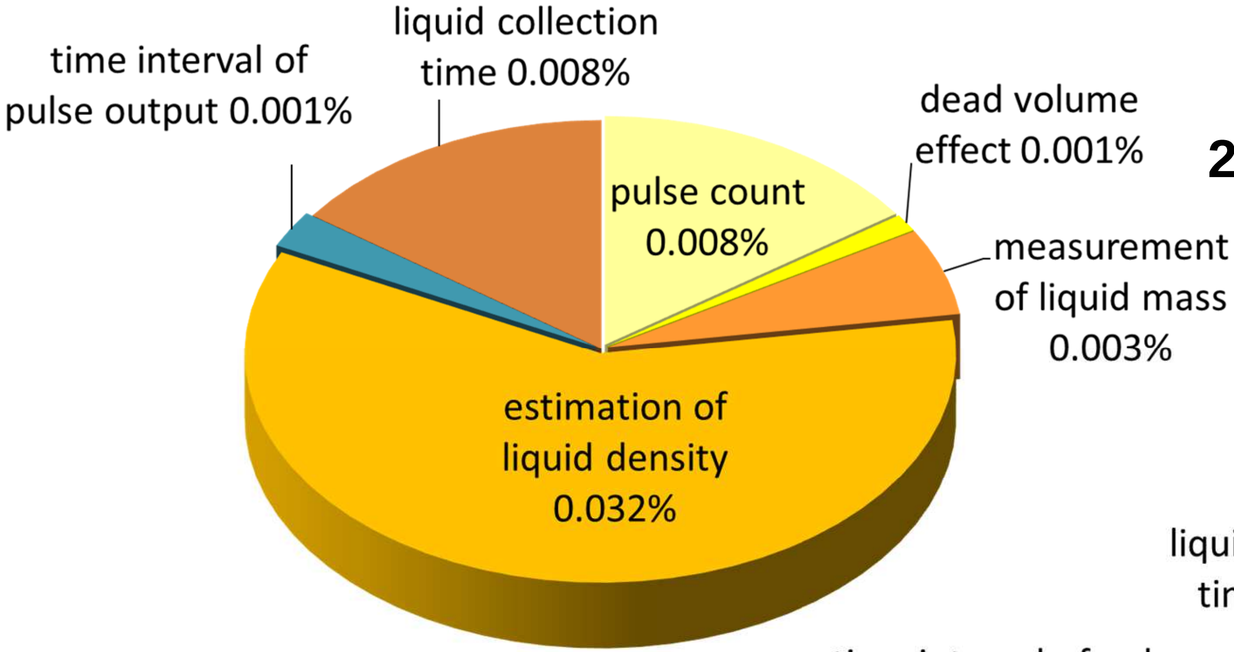
Uncertainty budget for 1 L/h ~ 100 L/h using 2 kg weighing system

Uncertainty sources	Light oil	Kerosene	Industrial Gasoline
Pulse count	8.2×10^{-5}	8.2×10^{-5}	8.2×10^{-5}
Time interval of pulse output	1.4×10^{-5}	1.4×10^{-5}	1.4×10^{-5}
Liquid collection time	8.1×10^{-5}	8.1×10^{-5}	8.1×10^{-5}
Measurement of liquid mass	3.3×10^{-5}	3.3×10^{-5}	3.3×10^{-5}
Dead volume effect	6.1×10^{-6}	6.4×10^{-6}	6.6×10^{-6}
Estimation of liquid density	2.6×10^{-4}	3.0×10^{-4}	3.2×10^{-4}
Relative combined standard uncertainty	2.8×10^{-4}	3.2×10^{-4}	3.4×10^{-4}

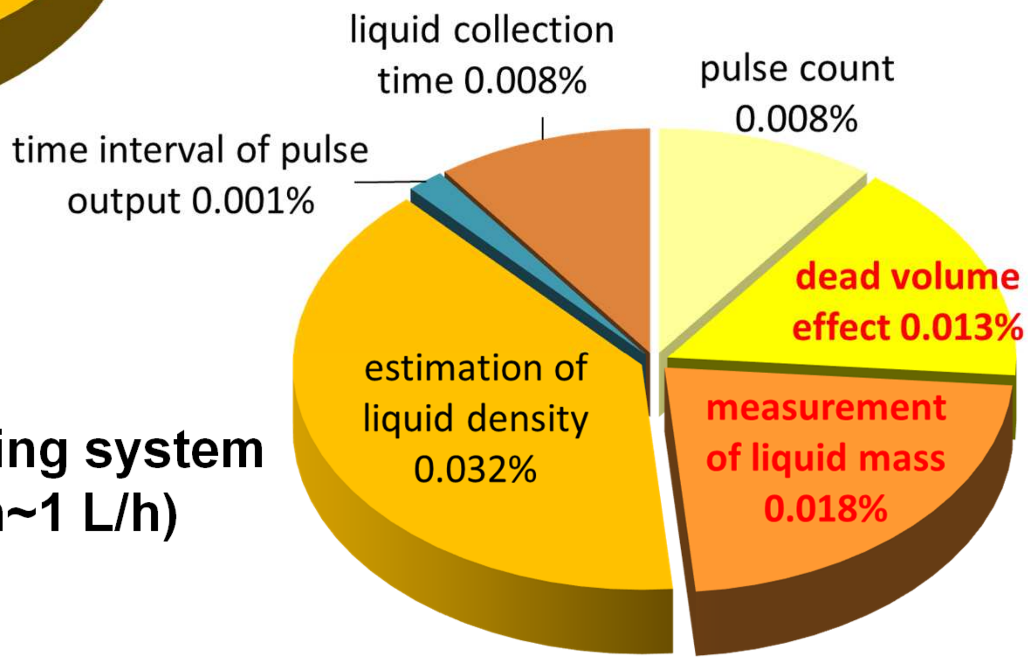
Uncertainty budget for 0.02 L/h ~ 1 L/h using 100 g weighing system

Uncertainty sources	Light oil	Kerosene	Industrial Gasoline
Pulse count	8.2×10^{-5}	8.2×10^{-5}	8.2×10^{-5}
Time interval of pulse output	1.4×10^{-5}	1.4×10^{-5}	1.4×10^{-5}
Liquid collection time	8.1×10^{-5}	8.1×10^{-5}	8.1×10^{-5}
Measurement of liquid mass	1.8×10^{-4}	1.8×10^{-4}	1.8×10^{-4}
Dead volume effect	1.2×10^{-4}	1.3×10^{-4}	1.3×10^{-4}
Estimation of liquid density	2.6×10^{-4}	3.0×10^{-4}	3.2×10^{-4}
Relative combined standard uncertainty	3.5×10^{-4}	3.8×10^{-4}	4.0×10^{-4}

Uncertainty Budget (Industrial Gasoline)

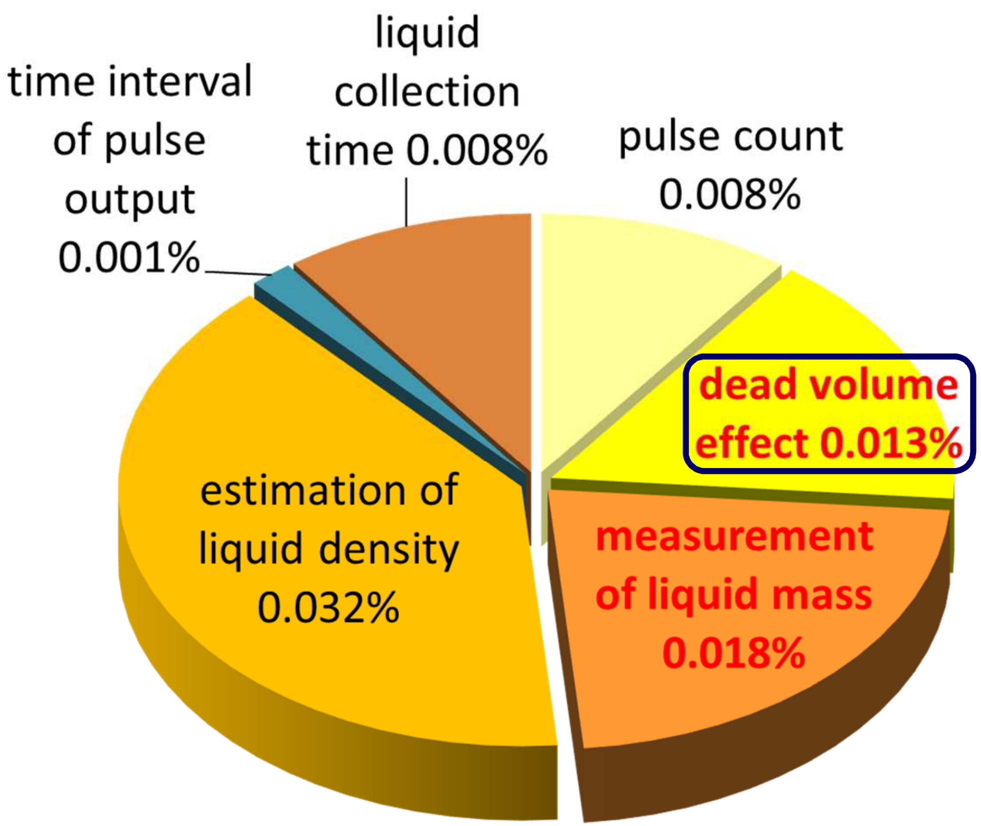


2 kg weighing system
(1 L/h~100 L/h)



100 g weighing system
(0.02 L/h~1 L/h)

Uncertainty budget for 0.02 L/h ~ 1 L/h using 100 g weighing system



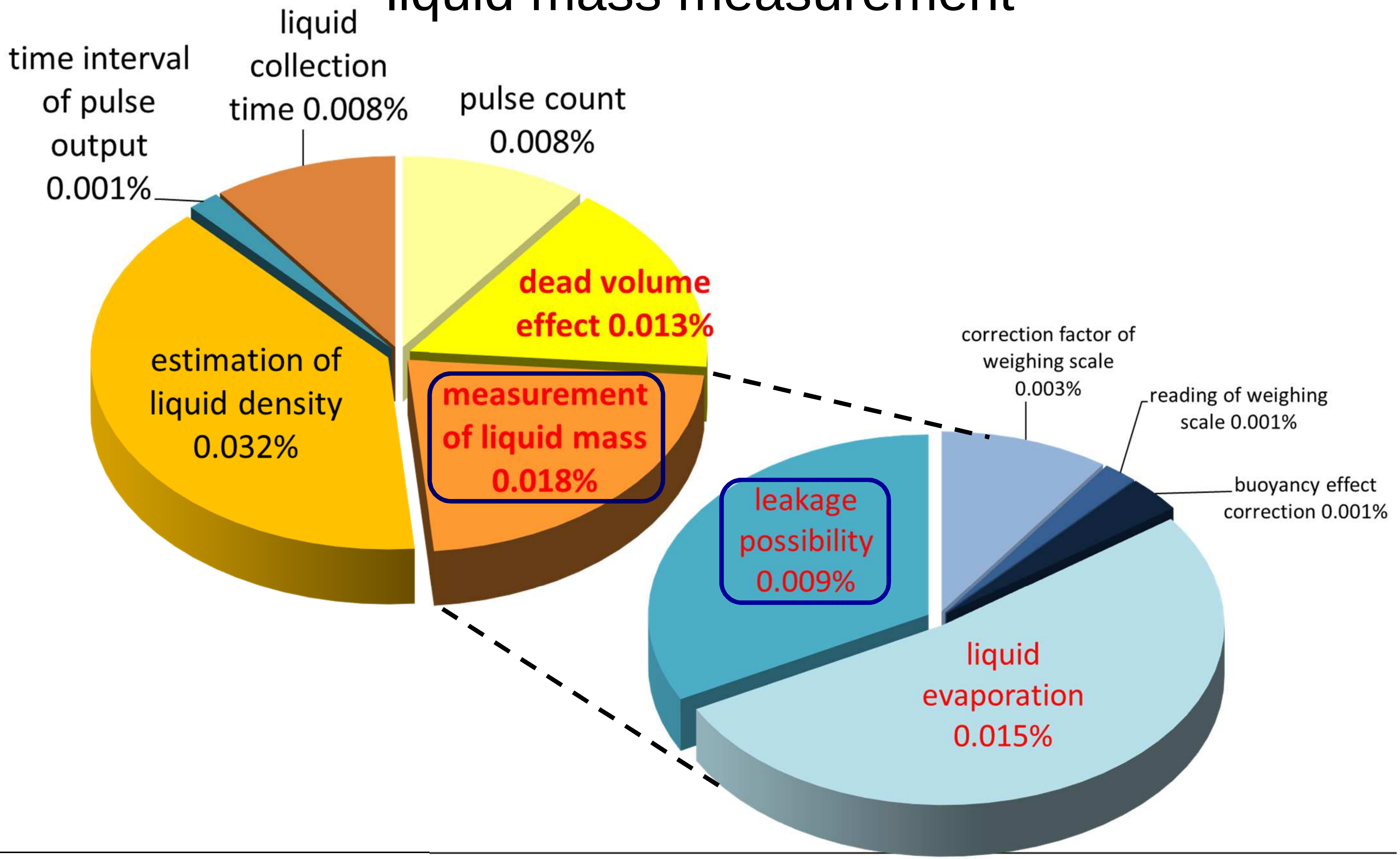
Dead volume effect

- The value is evaluated in relative to the smallest amount of liquid collection which is 10 g.
- 10 g of liquid collection is performed at 0.02 L/h and it takes about 40 minutes for one collection.

Some measures to cut down the dead volume effect:

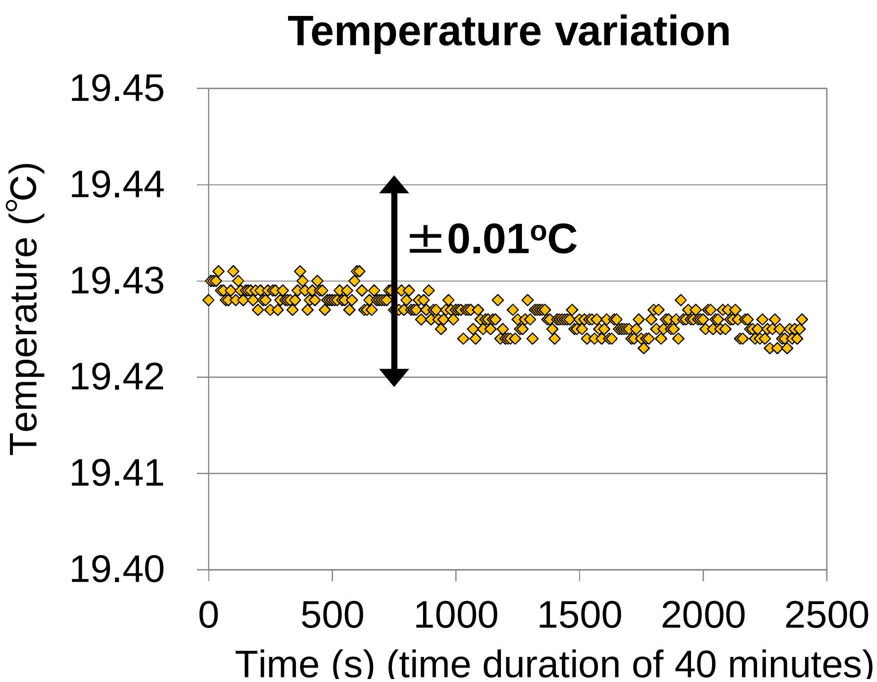
- Dead volume is made as small as possible.
- Temperature variation of liquid in the dead volume is controlled and stabilized (±0.025°C in one hour duration).

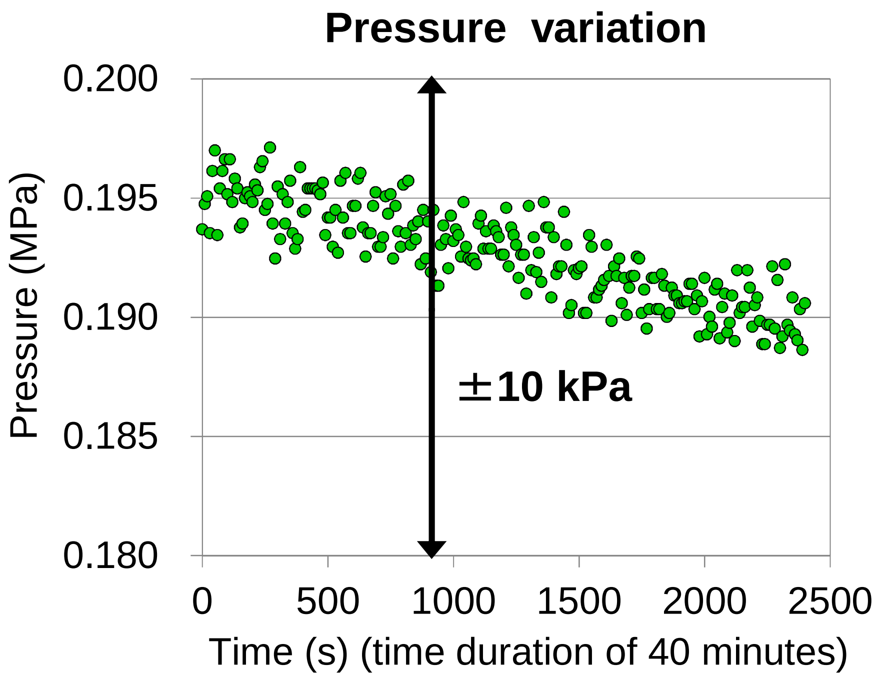
Contributing factors to uncertainty of liquid mass measurement



Check for leakage possibility

- Leakage check is performed by monitoring the pressure and temperature variation for the longest time of liquid collection (40 minutes).
- During this period, variation of pressure and temperature has to be maintained within ±10 kPa and ±0.01°C respectively.





- Leakage that is not detectable within ±10 kPa and ±0.01°C is treated as an uncertainty factor in liquid mass measurement and is estimated as 1.0×10^{-4} in relative to 10 g of liquid collection.

Calibration and Measurement Capability

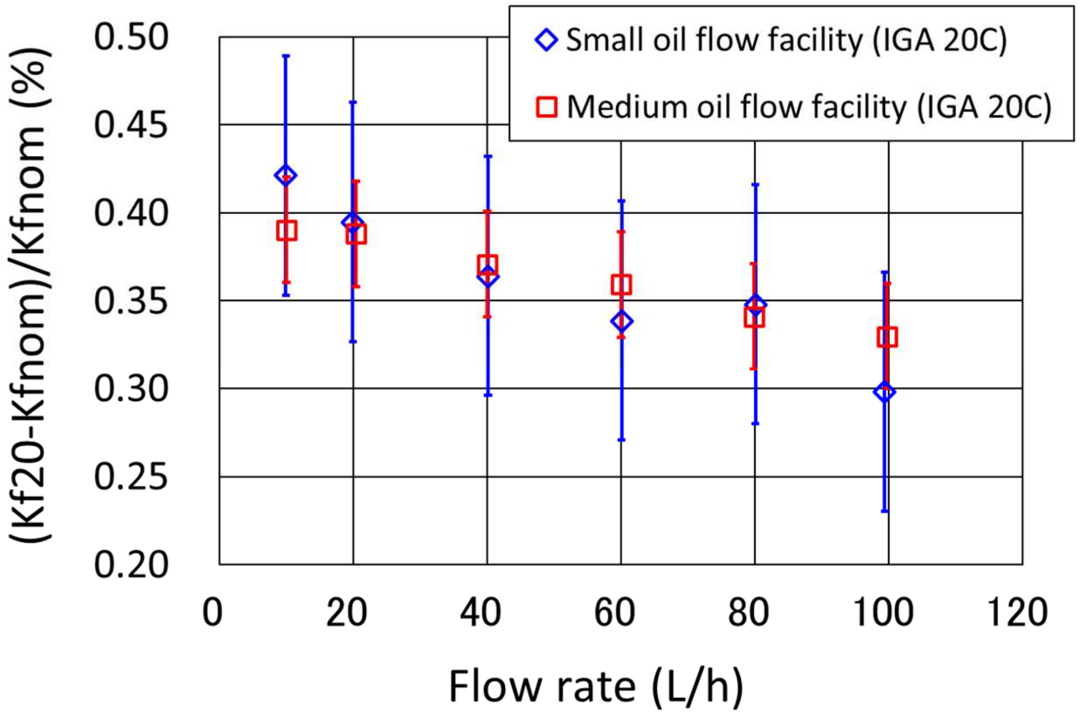
Ultimate uncertainty of calibration
(Calibration and measurement capability in italic, coverage factor: *k*=2)

Flow range, Q (Weighing system)	Volumetric flowrate (%)	Mass flowrate (%)
1 L/h ≤ Q ≤ 100 L/h (2kg weighing system)	LO: 0.029 *(0.058)* KE: 0.032 *(0.064)* IGA: 0.034 *(0.068)*	LO, KE, IGA: 0.010 *(0.020)*
0.02 L/h ≤ Q ≤ 1 L/h (100 g weighing system)	LO: 0.036 *(0.072)* KE: 0.039 *(0.078)* IGA: 0.040 *(0.080)*	LO, KE, IGA: 0.025 *(0.050)*

Note: LO: light oil, KE: kerosene, IGA: industrial gasoline

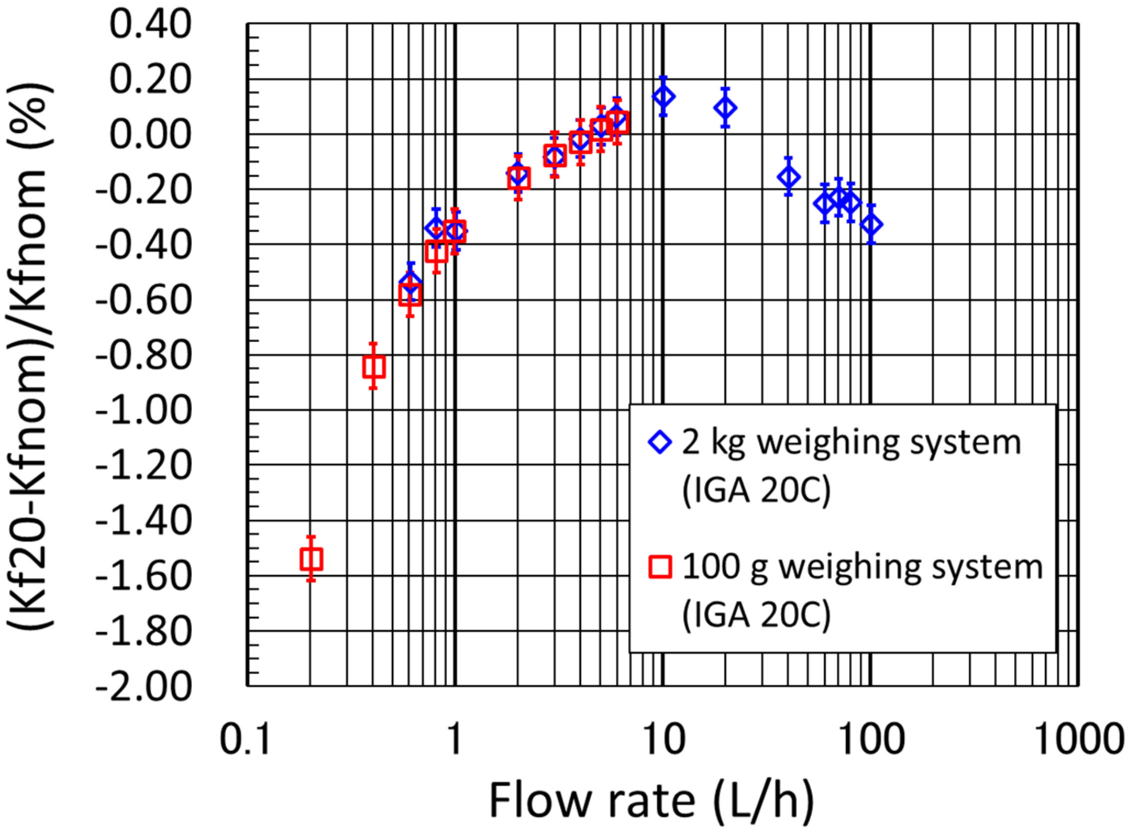
Validation of calibration and measurement capability (CMC) through intra-comparisons

- To justify the calibration capability of the facility, intra-comparisons with other primary standard facilities in NMIJ which are linked to international comparisons were performed.
- Intra-comparisons using light oil and kerosene have been reported in previous papers. In this paper, the intra-comparison conducted between the small oil flow facility (2 kg weighing system) and the medium oil flow facility using industrial gasoline is presented.



Comparison between weighing systems

- To justify the calibration capability for the flow range of 0.02 L/h ~ 1 L/h, a comparison was conducted between the 100 g and 2 kg weighing systems over an overlapping flow range using a volumetric flow meter as a transfer standard.
- The 2 kg weighing system was previously justified by intra-comparisons with other primary standards at NMIJ.



Summary and Conclusion

- NMIJ developed a primary standard for low liquid hydrocarbon flow rates that works on three common types of liquid fuels, namely light oil (diesel), kerosene and industrial gasoline.

- The primary standard comprises two gravimetric systems, one using a 2 kg weighing scale with a conical rotating double-wing diverter in the flow range of 1 L/h ~ 100 L/h, and the other using a 100 g weighing scale with a pair of high-speed switching valves as diverter in the flow range of 0.02 L/h ~ 1 L/h. Calibration method of static weighing with flying-start-and-finish is performed in both gravimetric systems.

- The expanded uncertainty of the 2 kg weighing system (1 L/h ~ 100 L/h) is estimated at 0.058 % (light oil), 0.064 % (kerosene) and 0.068 % (industrial gasoline) whereas the expanded uncertainty for the corresponding mass flow rates is estimated at 0.020 % for all working liquids.

- The expanded uncertainty of the 100 g weighing system (0.02 L/h ~ 1 L/h) is estimated at 0.072 % (light oil), 0.078 % (kerosene) and 0.080 % (industrial gasoline) whereas the expanded uncertainty for the corresponding mass flow rates is estimated at 0.050 % for all working liquids.

- Intra-comparisons with other primary standards in NMIJ that are linked to the international comparisons (CCM.FF.K1, CCM.FF.K2) show a good agreement between the facilities, hence justifying the CMC claimed by the primary standard (small oil flow facility).

Thank you for your attention.

mail: kh.cheong@aist.go.jp