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

Fierce competition in fuel efficiency

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

Top 10 car models with best fuel efficiency in Japan

- Prius/Toyota: 40.8 km/L
- Aqua/Toyota: 38.0 km/L
- Fit Hybrid/Honda: 37.2 km/L
- Note/Nissan: 37.2 km/L
- Alto Lapin/Suzuki: 37.0 km/L
- Mira e5/Daihatsu: 35.6 km/L
- Grace Hybrid/Honda: 35.2 km/L
- Vitz Hybrid/Toyota: 34.8 km/L
- Corolla Sport/Toyota: 34.4 km/L
- mini / light vehicle

Source: http://e-nenpi.com
Background and Motivation

One example of the international regulations related to automobiles.

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

Flowrate (m³/h)

Viscosity (mPa·s)

Petroleum terminal
Petroleum refinery
Tanker
Chemical plant
Hydraulic machinery
Fuel efficiency measurement
Fuel mixer
Small Hydrocarbon Flow Facility
Primary standard for hydrocarbon

LPG
Gasoline
Kerosene
Light oil
Heavy oil

100 L/h
1 L/h
0.02 L/h
Calibration Facility

Weighing section (liquid collection)
Test section (DUT mounting)
Flow generation section (tank, pump)

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

thermostatic chamber
(for better stability of liquid temperature controllable at any value between 15°C~35°C)

100g weighing system using a pair of high-speed switching valves
(liquid collection for 0.02~1 L/h)

2kg weighing system using a conical rotating double-wing diverter
(liquid collection for 1~100 L/h)
Gravimetric system using a conical rotating double-wing diverter (CRDWD) for 1-100 L/h
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
A pair of switching valves as a flow diverter

Diaphragm valve
- Pneumatically actuated
- Short piston stroke to give fast working speed
- Long durable diaphragm (alloy)
- Built-in stroke positioning sensor

Diverting between two symmetrical flow paths
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

<table>
<thead>
<tr>
<th>Uncertainty sources</th>
<th>Light oil</th>
<th>Kerosene</th>
<th>Industrial Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse count</td>
<td>$8.2 \times 10^{-5}$</td>
<td>$8.2 \times 10^{-5}$</td>
<td>$8.2 \times 10^{-5}$</td>
</tr>
<tr>
<td>Time interval of pulse output</td>
<td>$1.4 \times 10^{-5}$</td>
<td>$1.4 \times 10^{-5}$</td>
<td>$1.4 \times 10^{-5}$</td>
</tr>
<tr>
<td>Liquid collection time</td>
<td>$8.1 \times 10^{-5}$</td>
<td>$8.1 \times 10^{-5}$</td>
<td>$8.1 \times 10^{-5}$</td>
</tr>
<tr>
<td>Measurement of liquid mass</td>
<td>$3.3 \times 10^{-5}$</td>
<td>$3.3 \times 10^{-5}$</td>
<td>$3.3 \times 10^{-5}$</td>
</tr>
<tr>
<td>Dead volume effect</td>
<td>$6.1 \times 10^{-6}$</td>
<td>$6.4 \times 10^{-6}$</td>
<td>$6.6 \times 10^{-6}$</td>
</tr>
<tr>
<td>Estimation of liquid density</td>
<td>$2.6 \times 10^{-4}$</td>
<td>$3.0 \times 10^{-4}$</td>
<td>$3.2 \times 10^{-4}$</td>
</tr>
<tr>
<td>Relative combined standard uncertainty</td>
<td>$2.8 \times 10^{-4}$</td>
<td>$3.2 \times 10^{-4}$</td>
<td>$3.4 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Uncertainty sources</th>
<th>Light oil</th>
<th>Kerosene</th>
<th>Industrial Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse count</td>
<td>$8.2 \times 10^{-5}$</td>
<td>$8.2 \times 10^{-5}$</td>
<td>$8.2 \times 10^{-5}$</td>
</tr>
<tr>
<td>Time interval of pulse output</td>
<td>$1.4 \times 10^{-5}$</td>
<td>$1.4 \times 10^{-5}$</td>
<td>$1.4 \times 10^{-5}$</td>
</tr>
<tr>
<td>Liquid collection time</td>
<td>$8.1 \times 10^{-5}$</td>
<td>$8.1 \times 10^{-5}$</td>
<td>$8.1 \times 10^{-5}$</td>
</tr>
<tr>
<td>Measurement of liquid mass</td>
<td>$1.8 \times 10^{-4}$</td>
<td>$1.8 \times 10^{-4}$</td>
<td>$1.8 \times 10^{-4}$</td>
</tr>
<tr>
<td>Dead volume effect</td>
<td>$1.2 \times 10^{-4}$</td>
<td>$1.3 \times 10^{-4}$</td>
<td>$1.3 \times 10^{-4}$</td>
</tr>
<tr>
<td>Estimation of liquid density</td>
<td>$2.6 \times 10^{-4}$</td>
<td>$3.0 \times 10^{-4}$</td>
<td>$3.2 \times 10^{-4}$</td>
</tr>
<tr>
<td>Relative combined standard uncertainty</td>
<td>$3.5 \times 10^{-4}$</td>
<td>$3.8 \times 10^{-4}$</td>
<td>$4.0 \times 10^{-4}$</td>
</tr>
</tbody>
</table>
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

- Estimation of liquid density: 0.032%
- Measurement of liquid mass: 0.018%
- Leakage possibility: 0.009%
- Liquid evaporation: 0.015%
- Correction factor of weighing scale: 0.003%
- Reading of weighing scale: 0.001%
- Buoyancy effect correction: 0.001%
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 $1.0 \times 10^{-4}$ in relative to 10 g of liquid collection.
Calibration and Measurement Capability

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

<table>
<thead>
<tr>
<th>Flow range, $Q$</th>
<th>Volumetric flowrate (%)</th>
<th>Mass flowrate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(1 \text{ L/h} \leq Q \leq 100 \text{ L/h}$) (2kg weighing system)</td>
<td>LO: 0.029 $(0.058)$ KE: 0.032 $(0.064)$ IGA: 0.034 $(0.068)$</td>
<td>LO, KE, IGA: 0.010 $(0.020)$</td>
</tr>
<tr>
<td>$(0.02 \text{ L/h} \leq Q \leq 1 \text{ L/h}$) (100 g weighing system)</td>
<td>LO: 0.036 $(0.072)$ KE: 0.039 $(0.078)$ IGA: 0.040 $(0.080)$</td>
<td>LO, KE, IGA: 0.025 $(0.050)$</td>
</tr>
</tbody>
</table>

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