# Evaluation of Coriolis Flowmeters for Hydrocarbon Volumetric Flow Measurement

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## Abstract

Some types of Coriolis flowmeters has been calibrated using the large and medium hydrocarbon flow calibration facilities at National Metrology Institute of Japan (NMIJ) in order to investigate the effect of the liquid pressure, temperature and properties, which are viscosity and density on volumetric and mass flow rate. Furthermore, the density measurement using the Coriolis flowmeters has been discussed in detail using these calibration results.

## Introduction

Coriolis flowmeters (CFMs) are widely used in oil industry due to good performance in mass flow measurement. CFMs can measure density and mass flow rate simultaneously. Therefore CFMs are often used for volumetric flow measurement in addition to mass flow measurement. However density measurement with CFMs have effects of temperature, pressure, flow rate, the properties of the fluid and environmental conditions on the stiffness[1] [2].

In this study, several kinds of commercial CFMs have been calibrated using the primary standards in order to investigate the effect of the liquid pressure, temperature and properties, that is viscosity and density on volumetric and mass flow rate. Furthermore, the density measurement using the CFMs has been discussed in detailed on the basis of calibration results.

## Experimental method

### Calibration facility

A schematic of the primary standard for large hydrocarbon flow measurements at NMIJ is shown in Fig. 1 [3] ~[5]. Light oil and kerosene are used as working liquids; each oil has a separate test line. The flow rate range is from 3 to 300 $m^3$/h. The expanded uncertainty has been evaluated experimentally and analytically to be 0.030 % for volumetric flow rate and 0.020 % for mass flow rate (coverage factor $k$ = 2). This primary standard is based on static and gravimetric methods with a flying start and finish; i.e., the total mass of fluid passing through the flowmeter via the diverter in a given period of time is measured. The facility consists of a 10 t weighing scale, a 1 t weighing scale, a density meter and the diverter system, which has double diverting wings[6]. The 1 t weighing scale is used when the flow rate is 3 ~ 30 $m^3$/h, and the 10 t weighing scale is selected at 30 ~ 300 $m^3$/h.

A schematic of the medium hydrocarbon flow calibration facility at NMIJ is shown in Fig. 2[7]. The flow rate range is from 0.1 to 15 $m^3$/h. Light oil, kerosene and spindle oil are used as working liquids; each oil is installed in a test line from storage tanks. The expanded uncertainty has been evaluated experimentally and analytically to be 0.030 % for volumetric flow rate and 0.020 % for mass flow rate (coverage factor $k$ = 2). This primary standard is based on static and gravimetric methods with a flying start and finish. The facility consists of a rotating double wing diverter[8] and a 60 kg weighing scale, which has a weighing tank of 32 kg.

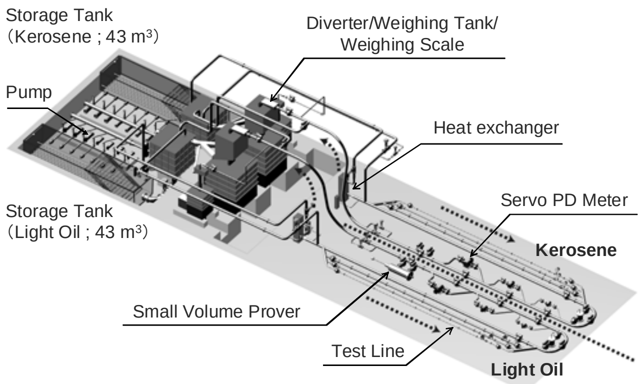


**Fig. 1 Large hydrocarbon flow calibration facility.**

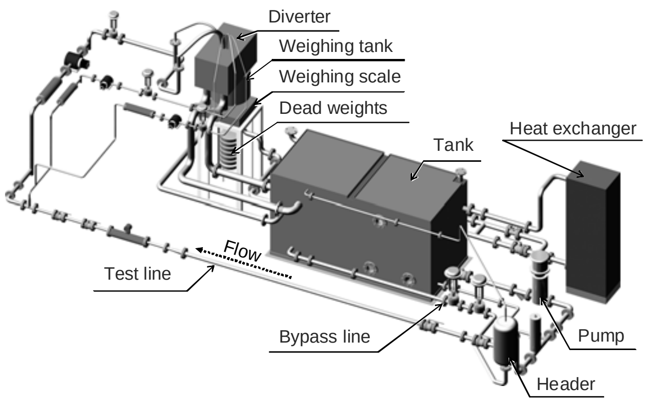


**Fig. 2 Medium hydrocarbon flow calibration facility.**

### Experimental method

A schematic diagram of calibration for commercial CFMs is shown in Fig. 3. The pulses of volumetric flow rates generated from the CFMs were obtained to pulse counters of the calibration facilities. The mass flow rate, volumetric flow rate, temperature and density outputted from the CFMs during calibration were obtained using PCs. The liquid temperature through the CFMs $T_L$ was measured at the downstream of the CFMs. The working liquid was sampled at a piping system branched out from the test line. Its density was measured with the density meter at the setting temperature under atmospheric pressure. The density of the working liquid in the CFMs under test was obtained by which the measured value was corrected using temperature and pressure. The standard mass flow rate and standard volumetric flow rate through the CFMs were estimated using the calibration facilities. The calibrated CFMs and the experimental condition are shown in Table 1 and Table 2. The ambient temperature around the CFMs was 20 ºC ±5 ºC. The pressure at the downstream of the CFMs was 0.40 MPa at normal calibration.

In CFMs, zero adjustment after installation in the test section is recommended since the zero point may change with each installation. Instead of this procedure, the flow rate readings of the CFMs for zero flow were measured before and after calibration without zero adjustment at the same pressure and temperature as those under the calibration conditions.

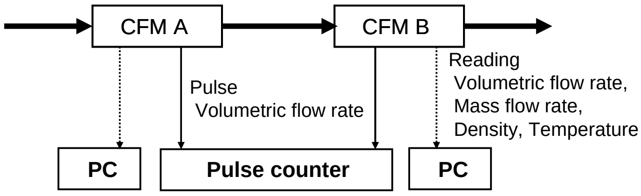


**Fig. 3 Schematic of calibration.**

**Table 1 Flowmeters.**

| CFM | Diameter | Calibration facility |
|---|---|---|
| A | 15 mm | Medium |
| B | 15 mm | |
| C | 100 mm | Large |
| D | 100 mm | |

**Table 2 Experimental condition.**

| Flowmeter | Flow rate | Liquid, Temperature, Viscosity, Density |
|---|---|---|
| A & B | 1.0, 2.0, 3.0 $m^3$/h | Kerosene<br>10 ºC, 2.6 cSt, 805 kg/$m^3$<br>20 ºC, 2.1 cSt, 798 kg/$m^3$<br>35 ºC, 1.6 cSt, 787 kg/$m^3$ |
| C & D | 100, 150, 200 $m^3$/h | Kerosene<br>20 ºC, 1.9 cSt, 793 kg/$m^3$<br>35 ºC, 1.5 cSt, 782 kg/$m^3$<br>Light oil<br>20 ºC, 6.9 cSt, 837 kg/$m^3$<br>35 ºC, 4.6 cSt, 827 kg/$m^3$ |

# Results and discussion

## Mass and volumetric flow rate

The both K factors for mass flow and volumetric flow of the CFMs $K_f$ were corrected to the corrected K factors $K_{fC}$ using (1) to compensate the effect of zero stability.

$$K_{fC} = K_f \left(1 - \frac{Q_{m0}}{Q_m}\right) \quad (1)$$

$Q_{m0}$ and $Q_m$ denote the mass flow rate reading for a zero flow and the actual mass flow rate, respectively. The differences of the K factors obtained using the pulse from those obtained by the flow rate reading were experimentally evaluated to be less than ±0.02 %, indicating that the K factors obtained by the flow rate reading using the PCs are suitable.

The relative corrected K factors of CFM A and CFM B against flow rates are shown in Fig. 4 and Fig. 5. The K factors for mass flow of CFM A show a good agreement within ±0.05 % at each temperature. However, the K factors for volumetric flow rates becomes larger as the temperature become higher, and the differences due to temperature are ±0.2 ~ 0.3 %. The deviation of the K factors for mass flow of CFM B due to temperature is shown to be less than ±0.02 % at each flow rate. The differences in the volumetric flow rates due to temperature is ±0.02 ~ 0.04 %, indicating that the temperature effect on the K factors for the volumetric flow rate is larger than that on mass flow rates.

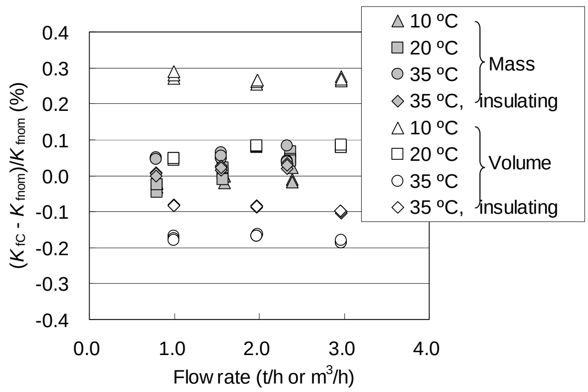


**Fig. 4 Relative K factors of CFM A.**

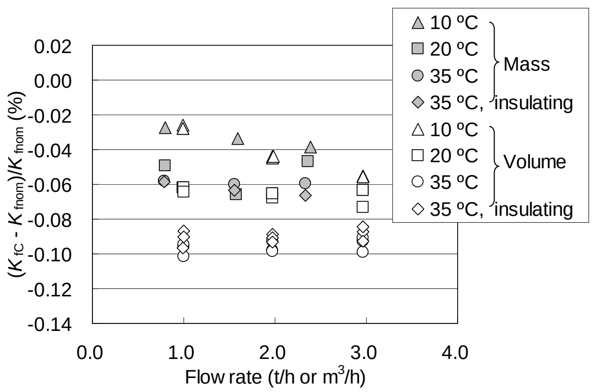


**Fig. 5 Relative K factors of CFM B.**

## Density measurement

In CFMs, the volumetric flow rate is calculated by dividing measured mass flow rate by density. The differeces of density reading from liquid density against differeces of the temperature reading of CFM A and CFM B $T_{CFM}$ from the actual liquid temperature $T_L$ are shown in Fig. 6 and Fig. 7, respectively. The differeces of temperature become lower as the liquid temperature becomes higher. These results indicate that the temprature reading is affected by ambient temperature of 20 ºC. Furthermore the temperature effect of density reading in CFM A is larger than that in CFM B, indicating that the effect of the differeces of liquid temperature from ambient temperature is dependent on each CFM. These results may be caused by measuring temperature on the vibrating tube in order to compensate the spring constant in CFMs.

Thermal insulators were set on the CFMs at liquid temperature of 35 ºC in order to avoid the effect of ambient temperature. As Fig. 6 and Fig. 7 shows, the temperature differeces are smaller when insulated, and the deviation of the K factors become smaller in Fig. 4 and Fig. 5, indicating that differences of liquid temperature from ambient temperature around the CFMs is one of important sources to achieve high accuracy for volumetric flow in CFMs.

The effects of liquid pressure and properties, that is viscosity and density on volumetric and mass flow rate will be presented in the conference.

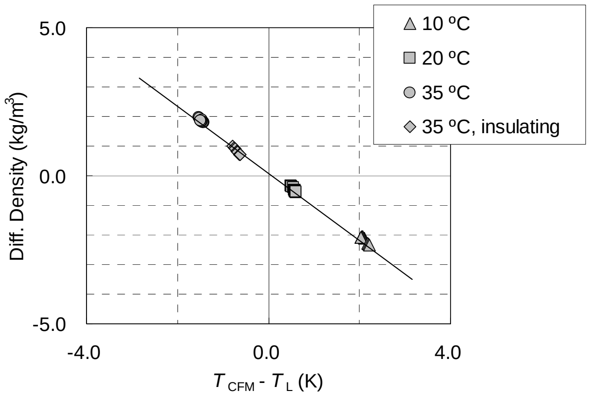


**Fig. 6 Relationship between differece of density and difference of temperature in CFM A.**

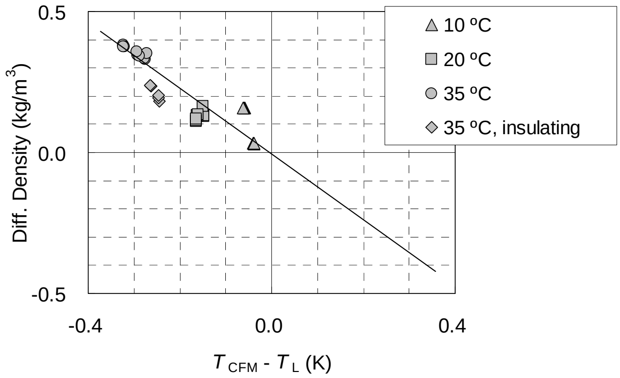


**Fig. 7 Relationship between differece of density and difference of temperature in CFM B.**

# Conclusions

Several kinds of CFMs were calibrated using the primary standard. As a result, volumetric flow measurement using some of the CFMs are affected by density measurement due to the difference of liquid temperature from the ambient temperature.

# References

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