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Investigation into calibration performance of small volume prover for hydrocarbon flow

Takashi Shimada*, Ryouji Doihara, Yoshiya Terao

National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology, Japan

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ABSTRACT

Several kinds of commercial flowmeters, namely, Coriolis flowmeters, turbine meters, ultrasonic flowmeters, and positive displacement flowmeters, have been calibrated using the primary standard for hydrocarbon flow measurement in Japan (which is based on static and gravimetric methods with a flying start and finish) and a small volume prover (SVP) at the same calibration condition in order to investigate the performance of the SVP. The differences in calibration results for the mechanical flowmeters between the primary standard and the SVP apparently depend on the flow rate, although the results show agreement within 0.04%. The computer-based flowmeters, which have a time delay in the output pulse signal, indicated larger differences due to the effect of the sudden flow rate change caused by the proving action of the SVP at larger flow damping times.

1. Introduction

Small volume provers (SVPs) [1] are generally used as calibration devices for gas and liquid flowmeters in many industrial companies because they can achieve high accuracy [2,3]. Furthermore, SVPs can be installed in a closed loop of a test rig, so they are useful for calibration at high volatilization and/or with toxic fluid. However, some SVPs exhibit a sudden flow rate change when their valves change the flow path of the liquid. The flow rate change has led computer-based flowmeters, which have a longer output response time, to has the potential to generate a wrong output signal [4–8]. Therefore, it is necessary to investigate the calibration uncertainty caused by SVPs in order to calibrate flowmeters at high accuracy.

The displacement volume in SVPs is normally applied as a constant value, which is determined by the waterdraw method [9], since the leakage from the gap between the displacement device and the cylinder is assumed to be zero or a constant for different liquids and flow rates. However, the effect of leakage in SVPs should be investigated in order to achieve high accuracy.

The large hydrocarbon flow calibration facility at the National Metrology Institute of Japan (NMIJ) is used as the primary standard in Japan [10–12]. This primary standard is based on static and gravimetric methods with a flying start and finish. 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 of $k=2$). Furthermore, an SVP is installed downstream of the test meter. It is easy to compare the calibration results obtained using the SVP with those obtained using the primary standard under the same calibration conditions.

In this article, several kinds of commercial flowmeters, namely, Coriolis flowmeters, turbine meters, ultrasonic flowmeters, and positive displacement flowmeters, are calibrated using the primary standard and the SVP in the same light oil test rigs in order to investigate the calibration performance of the SVP. Furthermore, the relationship between the type of flowmeter and the additional uncertainty due to the SVP are discussed in detail based on the calibration results.

2. Calibration facility

2.1. Large hydrocarbon flow calibration facility in Japan

Light oil and kerosene are used as the working fluids on two separate test lines in the large primary standard for hydrocarbon flow. The operational flow rate range of the facility is from 3 to 300 m^3/h. The facility is operational at pressures from 0.1 to 0.6 MPa at the test flowmeters, and it allows the temperatures of the liquids to be set from 15 to 35 °C. 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 through the diverter in a given period of time is measured. Each test line has a large weighing tank with a 10-ton weighing scale and a small tank with a 1-ton weighing scale. The 1-ton weighing

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* Correspondence to: 1-1-1 Umezono, Tsukuba, Ibaraki 305-8563, Japan. Tel.: +81 29 861 3816; fax: +81 29 861 4242.

E-mail address: t-shimada@aist.go.jp (T. Shimada).

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Nomenclature

I_P	Number of pulses accumulated by a pulse counter during measurement,t_P (pulses)
K_{fSVP}	K factor of a volumetric flowmeter calibrated using the SVP (pulses/L)
K_{fmSVP}	K factor of a mass flowmeter calibrated using the SVP (pulses/kg)
K_{fmnom}	Nominal K factor for a mass flowmeter (pulse/kg)
K_{fm0C}	Corrected K factor of a mass flowmeter (pulses/kg)
$K_{fm0CSVP}$	Corrected K factor of a mass flowmeter obtained using the SVP (pulse/kg)
K_{fm0CPS}	Corrected K factor of a mass flowmeter obtained using the primary standard (pulse/kg)
K_{fnom}	Nominal K factor for a volumetric flowmeter (pulse/L)
K_{fPS}	K factor of a volumetric flowmeter obtained using the primary standard (pulse/L)
K_{mSVP}	Relative difference of the K factor for a mass flowmeter obtained using the SVP from that obtained using the primary standard (-)
K_{SVP}	Relative difference of the K factor for a volumetric flowmeter obtained using the SVP from that obtained using the primary standard (-)
Q	Volumetric flow rate (m^3/h)
Q_{max}	Maximum volumetric flow rate in the flowmeters (m^3/h, tons/h)
Q_{m0}	Mass flow rate reading for zero flow (kg/s)
Q_{mFM}	Actual mass flow rate (kg/s)
t_D	Duration of measurement (s)
t_P	Time interval of pulse counting during measurement (s)
T_{SVP}	Temperature of the liquid at the SVP (°C)
$V_{SVP,nom}$	Displacement volume of the SVP at temperature of 15 °C under atmospheric pressure (L)
α_{SVP}	Thermal expansion coefficient of the cylinder material of the SVP ($=1.6\times10^{-5}\ K^{-1}$)
$\overline{\rho_{LFM}}$	Time-averaged density of the liquid through a flowmeter during the measurement (kg/m^3)
ρ_{SVP}	Density of the liquid in the displacement volume of the SVP at the end of the measurement (kg/m^3)

scale is used when the flow rate is 3–30 m^3/h, and the 10-ton weighing scale is selected at 30–300 m^3/h. The facility consists of a density meter and a diverter system with double diverting wings [13,14]. The test line diameters for the flowmeters are 50, 100, and 150 mm, and the upstream straight pipe lengths for the test flowmeters are more than 15 m in order to generate the ideal velocity profile at the inlet of the flowmeters. Detailed information, including the calibration procedure and the uncertainty analysis, can be found in our previous papers [10–12].

2.2. Small volume prover

The SVP is installed downstream of the test meter in the light oil test rig. A schematic of the SVP is shown in Fig. 1(a)–(e). The SVP consists of a measurement cylinder, a piston valve, a measurement piston, and a detecting system. The diameter of the measurement cylinder, the distance between the 1st and 2nd markers, and the distance between the return marker and the 1st marker are 381 mm, 745 mm, and 190 mm, respectively. The displacement volume of the SVP at the standard condition $V_{SVP,nom}$ (temperature of 15 °C under atmospheric pressure) was calibrated to be 84.914 L by the waterdraw method using a weighing scale before the SVP was set in the test rig. The double chronometry method with pulse interpolation is used for time measurement in order to eliminate the issue of pulse discretization error [15].

The effect of liquid pressure on the size of the measurement cylinder is negligible because of the pressure balance brought about by adopting a double-casing cylinder. Furthermore, better temperature uniformity in the measurement cylinder is achieved with this double casing.

The measurement piston is normally in the downstream position (Fig. 1(b)), and the piston valve is released and opened by the hydraulic pressure of its cylinder. The fluid flows along both the inner and outer side of the measurement cylinder. Before measurement, the measurement piston is returned to the upstream position by the hydraulic pressure of its cylinder (Fig. 1(c)). Then, the fluid flows along the outer side of the cylinder. The return speed of the measurement piston propelled by the hydraulic system is about 0.12 m/s. The piston valve is closed by the hydraulic pressure, and the hydraulic pressure for the measurement piston is released. Then, the piston moves downstream at a velocity corresponding to the flow rate of the fluid (Fig. 1(d)). As the measurement piston moves downstream, the return marker is detected and the 1st marker is detected, triggering the start signal. Then the 2nd marker is detected as the stop signal. The duration of the measurement is the time interval between the start and stop signals. After the 2nd marker is detected (Fig. 1(e)), the piston valve opens. The velocity of the measurement piston is 0.7 m/s at the maximum flow rate of 300 m^3/h. The minimum duration time for a pass is 1.0 s at this flow rate.

The K factor of the volumetric flowmeters calibrated using the SVP K_{fSVP} (pulses/L) is obtained using Eq. (1), assuming that the change in mass in the connecting volume between the SVP and the flowmeters is negligible.

$$K_{fSVP}=\frac{\overline{\rho_{LFM}}}{\rho_{SVP}}\frac{t_D}{t_P}\frac{I_P}{V_{SVP}} \tag{1}$$

Here, t_P (s), I_P (pulses), and t_D (s) represent the time interval from the rise of the pulses at the flowmeter right after the 1st signal of the SVP at the beginning of measurement to the rise of a pulse at the flowmeter right after the 2nd signal at the end of measurement, the number of pulses accumulated by a pulse counter during t_P, and the duration of the measurement, respectively. $\overline{\rho_{LFM}}$ (kg/m^3) and ρ_{SVP} (kg/m^3) denote the time-averaged density of the liquid through the flowmeter during the measurement and the density of the liquid in the displacement volume of the SVP at the end of the measurement, respectively.

The K factor of the mass flowmeters calibrated using the SVP K_{fmSVP} (pulses/kg) is obtained using Eq. (2).

$$K_{fmSVP}=\frac{1000}{\rho_{SVP}}\frac{t_D}{t_P}\frac{I_P}{V_{SVP}} \tag{2}$$

The 1st and 2nd markers for the displacement volume are set on the piston rod of the measurement piston. The piston rod is made of invar, of which thermal expansion is negligible. Therefore, the displacement volume of the SVP under the calibration condition V_{SVP} (L) is obtained as follows using the temperature of the liquid at the SVP T_{SVP} (°C) and the thermal expansion coefficient of the cylinder material α_{SVP} ($1.6\times10^{-5}\ K^{-1}$):

$$V_{SVP}=V_{SVP,nom}(1+2\alpha_{SVP}(T_{SVP}-15)) \tag{3}$$

The working liquid was sampled where the piping system branched out from the test line in order to estimate the density of the working liquid. Its density was measured with a density meter at the set temperature under atmospheric pressure. The density of the working liquid through the flowmeters during the