Establishment of Hydrocarbon Flow Traceability for a Large Ball Prover by Using Flowmeters installed in Parallel

T. Shimada[1], R. Doihara[1], Y. Terao[1], Y. Ito[2], S. Shiratori[2]

[1]*National Metrology Institute of Japan, AIST, 1-1-1 Umezono, Tsukuba, Japan*
[2] *OVAL Corporation, 3-10-8 Kamiochiai, Shinjuku-ku, Tokyo, Japan*
E-mail (corresponding author): t-shimada@aist.go.jp

Abstract

A large ball prover for hydrocarbon flow measurement has been calibrated over the actual operating flow rate range by using a standard flowmeter and a positive displacement flowmeter installed in parallel. The operating flow range of the ball prover is from 100 m^3/h to 1800 m^3/h, and its volume is 10 m^3. The standard flowmeter, of which maximum flow rate is 300 m^3/h, was calibrated at NMIJ in order to be traceable to national standard. The calibrated flow rates for the ball prover were expanded from 300 m^3/h to 1800 m^3/h by the standard flowmeter and the PD meter installed in parallel. As a results, the calibration factors for the ball prover were obtained at all operating flow range. The deviation of the calibration factors against flow rates was less than 0.04 %, indicating good linearity of the prover. The detailed uncertainty analysis was carried out, resulting the uncertainty of the calibration factors of the ball prover were evaluated to be less than 0.09 %. Furthermore the three flowmeters calibrated at NMIJ were mounted in parallel and calibrated by the ball prover simultaneously in order to confirm the calibration results.

1. Introduction

The measurement of hydrocarbon flow is important as a basis of quantity for the trade and taxation of petroleum products, and for the production control at the petrochemical plants. The accuracy of the flowmeter used in flow measurement is influenced by the property of liquids, the condition of flowmeter installation, and the condition of the flow. Therefore, it is necessary to calibrate the flowmeter periodically by standard flow of the operating liquid in according to the metrological traceability in order to achieve high accurate flow measurement.

Reference standard flowmeters, namely secondary standards, for accredited laboratories are calibrated by the national standard facilities for hydrocarbon flow in Japan according to the Japan Calibration Service System (JCSS) for hydrocarbon flow, which is an accreditation program for calibration laboratories in Japan [1][2]. However the flow rate range of the primary standard for hydrocarbon flow was limited to be up to 300 m^3/h and the required liquid type is not covered with it [3][4]. Therefore it is important to develop the technologies to expand the range of liquid types and flow rate range.

Some standard flowmeters mounted in parallel are often used for larger flow rate calibration in order to expand the standard flow. However it is necessary to calibrate each standard flowmeter against a superior reference and to install enough number of the standard flowmeters corresponding to the maximum flow rate for calibration. On the other hand, it is possible to expand the standard flow by using a larger flowmeter mounted in parallel and a larger prover or a larger flowmeter in series. In this case, a lot of calibrations should be carried out for the larger flowmeter and the prover in order to step up to the larger flow rates.

In this paper, a large ball prover for hydrocarbon flow measurement was calibrated over the actual operating flow rate range from 100 m^3/h to 1800 m^3/h by using a reference standard flowmeter and a large positive displacement flowmeter installed in parallel. The reference standard flowmeter, of which maximum flow rate is 300 m^3/h, was calibrated at NMIJ in order to be traceable to national standard. The calibrated flow rates for the ball prover were expanded from 100 m^3/h to 1800 m^3/h by using the reference standard flowmeter and the PD meter installed in parallel. Furthermore, the three PD meters calibrated at NMIJ were mounted in parallel and calibrated by the ball prover simultaneously in order to confirm the calibration results.

2. Calibration facility and equipment

2.1 Ball prover

A schematic of the ball prover (pipe prover) [5] used for calibration service of the flowmeters in OVAL is shown in Fig. 1. There are some calibration facilities for gasoline, kerosene and heavy oil at wide flow rate range in OVAL. In this study, it is focussed on the large calibration facility for kerosene. The operational flow rate range of the facility is from 100 m^3/h to 1800 m^3/h. The facility is operational at pressures from 0.1 to 0.4 MPa at the test flowmeters, and it allows the temperatures of the liquids to be set from 15 ºC to 30 ºC. The unidirectional ball prover has three spheres as displacers, and the displacement volume is 10 m^3. The minimum calibration time is approximately 30 s at the maximum flow rate of 1800 m^3/h. The two spheres are set in the valve section as a valve in order to stop the leakage between the upstream section and the downstream section during measurement. The double chronometry method with pulse interpolation is used for time measurement in order to eliminate the issue of pulse discretization error [6]. The temperature measured downstream of the flow meters and the pressure in the flow meters were estimated using the averaged pressure measured upstream and downstream of the flowmeters.

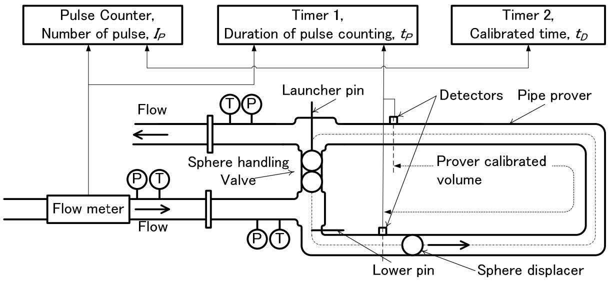

Figure 1: Schematic of large ball prover for hydrocarbon flow at OVAL.

2.2 Flowmeters

A spiral gear type positive displacement flowmeter, which is made by OVAL, was selected as a reference standard flowmeter in order to calibrate the ball prover. The diameter of the reference standard flowmeter is 150 mm and the maximum flow rate is 300 m^3/h. The reference standard flowmeter was calibrated at kerosene by the calibration facility for hydrocarbon flow measurement at NMIJ. The liquid, temperature and flow rate range at calibration were kerosene, 20 ºC and 35 ºC, and 70 m^3/h ~ 300 m^3/h, respectively. As a results, the expanded uncertainties of the calibration factors of the reference standard flowmeter, which are traceable to national standard, were 0.030 %(k=2). An oval gear type PD meter, which of diameter is 400 mm, was used in order to expand the standard flow to large flow rate range as accurately as possible. The maximum flow rate of the PD meter is 1800 m^3/h as same as that of the ball prover.

2.3 Calibration method

The schematic of the calibration for the ball prover (PP) is shown in Fig.2 and the calibration method of the ball prover by using the reference standard flowmeter (RSF) and the positive displacement meter (PDM) is shown in Table 1. Firstly, the PP was calibrated by the RSF at 100 m^3/h, 200 m^3/h and 250 m^3/h corresponding to the calibrated Re range at NMIJ, since the kinematic viscosity at calibration in the PP was different from that at the primary standard (#1 in Table 1). Secondly, the PDM was calibrated at 200 m^3/h and 250 m^3/h by the PP (#2). Thirdly, the PP was calibrated by the RSM and the PDM in parallel, resulting the standard flow of 400 m^3/h in the PP was estimated from the sum of the flow rate of 200 m^3/h through the RSF and the flow rate 200 m^3/h through the PDM (#3). Furthermore the RSF and the PDM were calibrated at 300 m^3/h by the PP, respectively (#4), and then the PP was calibrated at the total flow rate of 600 m^3/h through the RSF and PDM by the RSF and the PDM in parallel (#5). The standard flow for calibration of the PP was expanded to the larger flow rate by the sum of the flow rates through the RSF and the PDM in parallel (~#13).

The calibration was carried out at the stable condition as possible in order to avoid increasing the uncertainty due to a lot of calibration to expand the standard flow. The calibration was repeated 6 times under the same condition. The temperature of liquid was between 26.4 ºC and 29.6 ºC. The fluctuation in temperature during measurement was less than 0.2 ºC. The pressure upstream of the flowmeters and the pressure upstream of the PP were 0.29 MPa ~ 0.38 MPa and 0.19 MPa ~ 0.37 MPa, respectively. The kinematic viscosity and the density were 1.48 mm^2/s ~ 1.54 mm^2/s and 785.5 kg/m^3 ~ 787.9 kg/m^3.

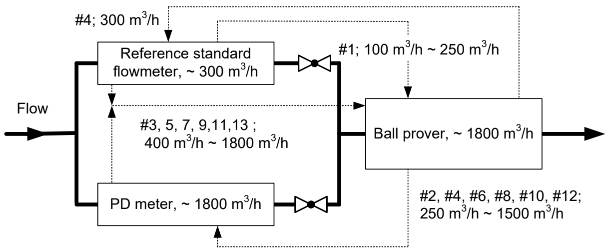

Figure 2: Schematic of calibration for ball prover.

Table 1: Calibration method.

No.	Measurement standard (calibrated flow rate range)	Device under test	Flow rate (m^3/h)
1	RSF (~ 265 m^3/h)	PP	100, 200, 250
2	PP	PDM	200, 250
3	RSF (~ 265 m^3/h) + PDM (~ 250 m^3/h)	PP	400, 500
4	PP	RSF & PDM	300
5	RSF (~ 300 m^3/h) + PDM (~ 300 m^3/h)	PP	600
6	PP	PDM	600
7	RSF (~ 300 m^3/h) + PDM (~ 600 m^3/h)	PP	900
8	PP	PDM	900
9	RSF (~ 300 m^3/h) + PDM (~ 900 m^3/h)	PP	1200
10	PP	PDM	1200
11	RSF (~ 300 m^3/h) + PDM (~ 1200 m^3/h)	PP	1500
12	PP	PDM	1500
13	RSF (~ 300 m^3/h) + PDM (~ 1500 m^3/h)	PP	1800

2.4 Calibration factor of ball prover

The calibration factor K_{PP} of the ball prover (PP) calibrated using the reference standard flowmeter and the PD meter in parallel is obtained using Eq. (1), assuming that the change in mass in the connecting volume between the ball prover and the flowmeters, the correlation between mass flow rate and density, and leakage and air between the ball prover and the flowmeters are negligible.

$$K_{PP} = \frac{1}{K_{f,RSF}} \frac{\rho_{RSF}}{\rho_{PP}} \frac{t_D}{t_{P,RSF}} \frac{I_{P,RSF}}{V_{PP}} + \frac{1}{K_{f,PDM}} \frac{\rho_{PDM}}{\rho_{PP}} \frac{t_D}{t_{P,PDM}} \frac{I_{P,PDM}}{V_{PP}} \quad (1)$$

Here, K_f (pulses/L), t_D (s), I_P (pulses), and t_P (s) represent the K factor of the flowmeter, the time interval from the rise of the pulses at the flowmeter right after the 1st signal of the PP 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, and the duration of the measurement, respectively. V_{PP} (m^3) denotes the displacement volume which is corrected the nominal volume by using the temperature and the pressure under the calibration condition. ρ (kg/m^3) and ρ_{PP} (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 PP at the end of the measurement, respectively.

The calibration factor K_f of the flowmeter calibrated using the PP is obtained using Eq. (2)

$$K_f = \frac{1}{K_{PP}} \frac{\rho_{FM}}{\rho_{PP}} \frac{t_D}{t_{P,FM}} \frac{I_{P,FM}}{V_{PP}} \quad (2)$$

3. Calibration results

3.1 Calibration result of reference standard flowmeter

The reference standard flowmeter was calibrated every year since 2009 by the national standard at NMIJ. The corrected K-factors $K_{f,RSF20}$ (pulse/L) of the reference standard flowmeter based on 20 ºC were calculated using the obtained K-factors $K_{f,RSFCAL}$ (pulse/L) by Eq.(3).

$$K_{f,RSF20} = K_{f,RSFCAL}\left(1 + 3\alpha_{RSF}\left(T_{RSFCAL} - 20\right)\right) \quad (3)$$

where α_{RSF} (K^{-1}), T_{RSFCAL} (ºC) denote the thermal expansion coefficients of the rotor, and the estimated temperature of liquid at the flowmeter, respectively.

The corrected K factors of the reference standard flowmeter obtained in 2009 to 2014 are shown in Fig.2. The K factors at the calibration of the PP were obtained by using the linear approximation equation $K_{f,RSFCAL,fit}$ against Re number with least square approximation. The deviations of the K factors from the linear approximation equation were less than ±0.02 %, indicating good long-term stability of the reference standard flowmeter over five years and good approximation equation.

3.2 Calibration result of ball prover

The calibration factor of the displacement volume in the ball prover at all operating flow range between 100 m^3/h and 1800 m^3/h is shown in Fig.3. The experimental standard deviation of the mean of the calibration factor at each flow rate was less than 0.01 %. The deviation of the calibration factors against flow rates was less than ±0.02 %, indicating good linearity of the prover. However, a small volume prover was calibrated in the more stable condition at NMIJ in order to investigate the flow rate dependency of the small volume prover, resulting that the calibration factor of a small volume prover has strong flow rate dependency and the deviation against flow rates was 0.04 % [7]. Therefore, further investigation is needed to consider the flow dependency of the PP in order to achieve a lower calibration uncertainty.

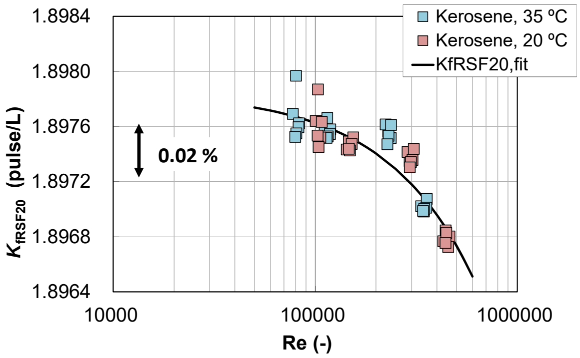

Figure 2: Corrected K factors of reference standard flowmeter obtained using the national standard at kerosene. The solid line indicates the fitting curve against the K factors at 20 ºC and 35 ºC.

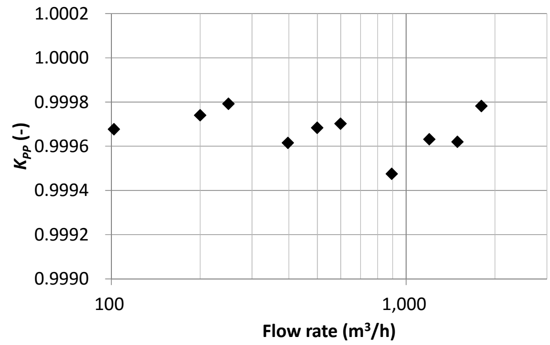

Figure 3: Calibration factor of the displacement volume in the ball prover.

4. Estimation of calibration uncertainty

The uncertainty of the calibration factor of the displacement volume in the ball prover (PP) were evaluated at the calibration condition. It is very difficult to verify all the uncertainty sources. For estimation of the calibration uncertainty of the ball prover, it was assumed that there was no leakage of test liquid in the test line between the flowmeters and the ball prover, and there was no vaporization in the test line.

The uncertainties due the reference standard flowmeter, the PD meter, the density measurement, the temperature and pressure correction in the displacement volume, the time measurement, the error correlated between the flow rate and the density in the flowmeter, the effect of change in mass within the connection pipe and the random effect of the flowmeters and the ball prover were estimated, taking the correlated measurement values in consideration. The correlation between the same measurement values during the calibration of the PP and the flowmeters is strong so that the uncertainty due to flow expansion is not so large. As a result, the expanded uncertainty (k=2) of the calibration factors of the ball prover in the flow rate range from 100 m^3/h to 1800 m^3/h were evaluated to be less than 0.09 %.

The expanded uncertainty of the calibration of flowmeters by using the PP is estimated to be 0.12 % by combining the uncertainty of the calibration factors of the displacement volume in the PP of 0.09 %.

5. Validation

A set of three PD meters, of which maximum flow rate is 300 m^3/h, were selected as a transfer standard in order to confirm the calibration results of the ball prover (PP). The each PD meter was calibrated in the flow rate rage from 100 m^3/h to 300 m^3/h by using the national standard at NMIJ before and after calibration by the ball prover. The PD meters mounted in parallel were calibrated in the flow rate range from 200 m^3/h to 850 m^3/h by the ball prover. The performance of the PD meters and their stability were evaluated at NMIJ, resulting that the standard uncertainty due to the transfer standard was estimated to be less than 0.02 %.

The En values between the calibration factors of the flowmeters obtained by the PP and the reference values by the national standard at NMIJ is shown in Fig. 4. The En values in the flow rate range from 200 to 850 m^3/h are less than 0.2, indicating that the calibration results obtained by the PP show good consistency with the reference values from NMIJ.

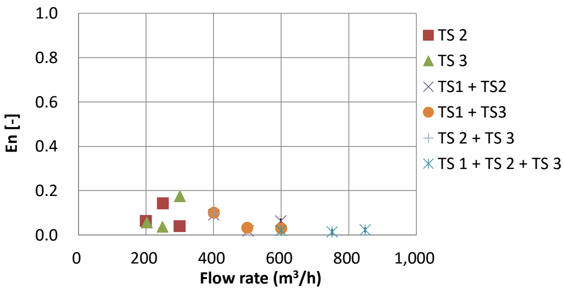

Figure 4: En values between the calibration factor by the PP and the reference values at NMIJ.

6. Conclusion

The large ball prover for hydrocarbon flow measurement was calibrated over the actual operating flow rate range from 100 m^3/h to 1800 m^3/h by using the reference standard flowmeter and the positive displacement flowmeter installed in parallel. As a results, the calibration factors for the ball prover were obtained at all operating flow range. The deviation of the calibration factors of the displacement volume in the ball prover against flow rates was less than 0.04 %, indicating good linearity of the prover. The uncertainty of the calibration factors of the ball prover were evaluated to be less than 0.09 %. Furthermore the calibration results obtained the ball prover show consistency with the reference values from NMIJ by using the transfer standard of the three PD meters calibrated at NMIJ.

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