NEW PRIMARY STANDARD FOR HYDROCARBON FLOWMETERS AT NMIJ
- INTERNATIONAL COMPARISON BETWEEN NMIJ AND SP -

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Abstract

A new primary standard for hydrocarbon flow measurements has been constructed at NMIJ, National Metrology Institute of Japan. The facility is designed for the calibration of hydrocarbon flowmeters in the flow rate range between 3 to 300 m^3/h with an expanded uncertainty better than 0.04 % for volumetric flow rates and 0.03 % for mass flow rates (coverage factor: k=2). The primary standard applies a static and gravimetric method with flying start and finish. The facility consists of two test rigs with kerosene and light oil as working fluid. The test lines for flowmeters are 50, 100 and 150 mm in diameter, and light oil and kerosene are used as the working fluids. A small volume prover and servo PD meters are used as working standards. This calibration facility has special features that enable highly accurate calibration. The uncertainty of calibration for flowmeters has been roughly estimated. As a result, the estimated uncertainty is shown to be less than the target uncertainty. The dominant sources of combined uncertainty of flow rate are uncertainties in the measurements of the mass of oil in the weighing tank and the density of oil through the flowmeter under test. To verify the performance of this oil calibration facility at NMIJ, an international comparison with SP, Swedish National Testing Research Institute, has been carried out. A screw-type positive displacement flowmeter was selected as the transfer standard and was calibrated at NMIJ and SP. The result shows that the two national standards at the two institutes agree within the quoted expanded uncertainties.

Introduction

There had been no national standard for hydrocarbon flow measurements used at industrial petroleum complexes in Japan. As a result, flowmeter manufacturers and users are forced to be responsible for the calibration of flowmeters. However, as the importance of measurement traceability is being recognized in the industry, measurement of flowrate at higher accuracy with certified uncertainty is seriously needed, especially for custody transfer. Accordingly, the Ministry of Economy Trade and Industry, Japan decided to construct a hydrocarbon flow calibration facility as a national primary standard at NIMJ, National Metrology Institute of Japan, which is responsible to establish the national measurement standard of Japan.

The new oil calibration facility is designed to calibrate hydrocarbon flowmeters in the flow rate range between 3 to 300 m^3/h with expanded uncertainty better than 0.04 % for volumetric flow rates and 0.03 % for mass flow rates (coverage factor: k=2). The new primary standard applies a static and gravimetric method with flying start and finish using the weighing tank and diverter. Such a calibration method with a diverter has been employed at many water calibration facilities, such as national standard facilities for the water meter [1,2]. This is because the diverter does not disturb the flow through the test line when it switches the flow at the beginning and at the end of the measurement. However the diverter has hardly been employed at oil calibration facilities.

In the present paper, first, an outline of the new oil calibration facility is described. A diverter system, a weighing system with dead weights, high stability of liquid temperature and test lines are major advantages of the facility that enable high-performance calibration. Secondarily, the uncertainty of calibration for the flowmeter is roughly estimated in accordance with the ISO Guide [3] in order to verify achievement of the target uncertainty of 0.04 % for volumetric flow rate. Finally, international comparison between measurements at NMIJ and Swedish National

Testing and Research Institute, SP, was carried out in order to verify the performance of the new oil calibration facility.

Primary standard for hydrocarbon flow measurement in Japan

A photograph and a schematic of the new primary standard for hydrocarbon flow are shown in Figure 1 and Figure 2. Light oil and kerosene are used as the working liquids; each oil has a separate test line. The flow rate range is from 3 to 300 m^3/h with expanded uncertainty of better than 0.04 % for volumetric flow rate and 0.03% for mass flow rate. This primary standard is based on static and gravimetric method with flying start and finish, i.e., the total mass of fluid passing through the flowmeter via the diverter is measured in a given time. Although the volumetric flow rate standard is fundamentally derived from mass, time and density standards, it is important to estimate other sources of measurement uncertainty and adopt suitable conditions for calibration.

The test rigs run through three rooms, a testing room, a weighing room and a pumps room. The temperature in the weighing room is air-conditioned between 18 °C and 23 °C. The air conditioner must be an all-fresh-air system in accordance with fire laws, so that conditioned air at 20 °C goes through the weighing room and the testing room out to the atmosphere. The fluctuation of temperature in the weighing room affects the uncertainty of buoyancy correction for mass, and it is controlled to be less than 1 °C daily. The temperature in the testing room is between 17 °C and 26 °C.

This facility is operational at pressures up to 0.8 MPa and temperatures from 15 to 40 °C. Each test rig has a 43 m^3 storage tanks to achieve better stability of the liquid temperature. The temperature stability of working fluids has a large effect on the uncertainty of density and hence, a sophisticated heat exchanger is installed in the test lines. Almost all the test lines and tanks are sufficiently covered by thermal insulator. Consequently, the fluctuation of temperature in the test line over 10 minutes is less than 0.03 °C. Highly accurate thermometers, the expanded uncertainty of which is 0.03 °C, are set upstream and downstream of the flowmeters. Also, thermometers, the uncertainty of which is better than 0.5 °C, are used for temperature control and environmental measurement. A small heat exchanger is provided to control the temperature in the storage tanks during night so that the adjusting time for temperature becomes shorter.

The flow rate through the test lines is basically regulated by a combination of several control valves. Each test line has six centrifugal pumps, which are driven by a 45 kW or 18.5 kW electric motor at constant speed, to deliver the test liquid. Three of them have a flow rate capacity of 100 m^3/h each and the other three have that of 10 m^3/h, at a 0.9 MPa pressure head. During operation, three pumps of the same capacity run to reduce the flow pulsation due to torque variation of the electric motor, while the other pumps remain at rest. In addition, when the working liquid flows into the weighing tank, the liquid in the 12 m^3 buffer tank is transferred to the storage tank to keep the liquid level in the storage tank constant, so that the pressure at the suction side of the pumps remains unchanged. As a result of those improvements, the flow rate through the test line fluctuates only 0.5% or less in 10 minutes.

Fine mesh screens in the storage tanks and buffer tanks are effective for removing fine bubbles caused at the diverter section. There are two mesh screens in the buffer tank to pre-remove larger bubbles. Three mesh screens, the spaces of which are 0.045, 0.035 and 0.028 mm respectively, are set at 30 degrees against the flow to remove the bubbles effectively. The void fraction in the storage tank was investigated by sampling the liquid and using a high-speed video camera during measurement. As a result, the void fraction of bubbles was measured to be less than 2×10^{-5} in storage tanks downstream of those screens.

The test lines for flowmeters are 50, 100 and 150 mm in diameter. The upstream straight pipe lengths for test flowmeters are more than 100 pipe diameters for each test line in order to generate the ideal velocity profile at the inlet of the flowmeter. There are trunnion-type valves, which are similar to block and bleed valves, in the branched pipes between the test meters and diverter in order to check the leakage from the valves.

A new diverter system [4,5] is designed to minimize the uncertainty of the collection time of hydrocarbon in the weighing tanks. The diverter has two wings that move at constant speed to cancel the effect of an asymmetric flow velocity profile of the liquid jet coming out of the nozzle.

The specifications of the diverters are listed in Table 1. There are large and small diverters for the 10,000 kg and 1,000 kg balances, respectively, and it is possible to change the nozzle width depending on the flow rate. A suitable nozzle width has been carefully decided, since a hydrocarbon jet at high speed is dangerous as it can explode due to oil mist and static electricity, while a narrow nozzle width is better to suppress regenerated bubbles. The wings move within the liquid jet at constant speed, driven by a ball screw and a servomotor.

A picture of the weighing system is shown in Figure 3. Each test line has a large weighing tank with a 10,000 kg balance and a small tank with a 1,000 kg balance, one of which is selected depending on the flow rates. The resolutions of 10,000 kg and 1,000 kg balances are 10 g and 1 g, respectively. These balances are equipped with standard dead weights, which are traceable to the national standard of mass of Japan. These dead weights and autoloading system enable the calibration of the balances automatically before and after the measurement, resulting in high reproducibility of the weight measurement. In addition, it is possible to automatically maintain 9,000-10,000 kg or 900-1,000 kg when supplying oil, in order to avoid impact of the falling liquid. Fin traps for oil mist are set between the diverter and the weighing tank to decrease the amount of evaporating oil and oil mist. The float in the tank reduces with evaporation and foaming.

Three servo PD flowmeters [6] are installed in the test rig as working standards. In a servo PD flowmeter, the spiral rotors are driven by a servomotor so that the differential pressure between the inlet and outlet of the flowmeter remains zero or a certain value that results in reduced differential pressure across the rotors. Thus, a wide range of flow rate can be measured at high accuracy. These flowmeters of 50, 100, and 150 mm diameter are set in the flow rate ranges from 3 to 30, 7.5 to 75, and 30 to 300 m^3/h, respectively. The long-stability of the servo PD flowmeter has been investigated by simultaneous calibration with a test meter. A small volume prover (SVP), standard volume of which was calibrated by the water draw method to be 85L, is installed downstream of the test meter in the light oil test rig. It is possible to compare the calibration results between the weighing system and SVP in order to investigate the effect of the sudden pressure change by proving with the SVP.

On-line oscillating density meters are installed upstream of the test line in order to measure the density of the working liquid on time. The flow rate through the density meter, which has an effect on the accuracy, is controlled at 0.3 m^3/h. At this moment, these on-line density meters are not in practical use because they have been found to be affected strongly by the liquid pressure. To solve this problem, pressure compensation function will be obtained experimentally or the pipe configuration will be changed so that the liquid pressure at the densitometer remains stable. Until then, the density is measured by off-line method.

Calibration procedure

The calibration procedure of the primary standard is similar to that of the large water facility at NMIJ [1]. The data acquisition system of the facility is shown in Figure 4. The flowmeters to be calibrated are restricted to the pulse-output type, which generate a pulse train at a frequency proportional to the flow rate. A double chronometric system is used in order to minimize uncertainty related to the time measurement. Figure 5 shows a diagram of the traceability system. The instruments that have a large effect on calibration, such as the weighing scales, thermometers, pressure gauges and so on, are calibratied traceable to national standards. The temperature of oil flowing through the flowmeter is measured every 15 seconds, and the pressure is measured every 2 seconds. The test meter and the reference meter, namely, the servo PD meter, can simultaneously be calibrated using the primary standard, in order to confirm the reproducibility of the calibration system by checking the K-factor of the servo PD meter.

Calculation of the calibration factor of the flowmeter (K-factor)

The calculation of the K-factor obtained at the oil calibration facility is based on the same concept as that of the large water facility at NMIJ, where static and gravimetric method with flying start and finish is applied [1]. However it must be taken into account that the thermal coefficient of

oil density is about three times that of water density. According to the specifications of the facility, the following conditions are satisfied.

(a) There is no leakage of oil and no generation of bubbles between the flowmeter under calibration and the nozzle of the diverter.

(b) The straight pipe upstream of the flowmeter is long enough to form an ideal flow at the entrance of the flowmeter.

By integrating the equation of mass conservation from the start of the measurement to the end of the measurement for the duration of diversion, the time-averaged volumetric flow rate through the flowmeter $\overline{q_{FM}}$ is obtained by

$$\overline{q_{FM}} = \frac{M_L}{\overline{r_{L,FM}} \cdot t_D} + \frac{\Delta M_{L,DV}}{\overline{r_{L,FM}} \cdot t_D} + \frac{\Delta\left(r_{L,FM} q_{FM}\right)}{\overline{r_{L,FM}}} \approx \frac{M_L}{\overline{r_{L,FM}} \cdot t_D} \quad (\mathrm{m^3/s}),$$

where M_L , $\Delta M_{L,DV}$ and $\Delta\left(r_{L,FM} q_{FM}\right)$ represent the mass of the oil discharged from the nozzle into the diverter, the error caused by dead volume, and the error correlated between the flow rate and the density in the flowmeter respectively. $\overline{r_{L,FM}}$ and t_D denote the density in the flowmeter and the diversion time, respectively. The mass of the oil discharged from the nozzle M_L is obtained as

$$M_L = \frac{k_S \cdot m_L}{\left(1 - r_G / r_{L,W}\right)} + \Delta M \approx \frac{k_S \cdot m_L}{\left(1 - r_G / r_{L,W}\right)} \quad (\mathrm{kg}),$$

where m_L , $r_{L,W}$ and r_G represent the reading from the weighing scale, the time-averaged density of the oil in the weighing tank and the density of the air around the weighing tank. The calibration factor of the weighing scale k_S , which corresponds to m_L , is calibrated by the dead weight. ΔM denotes the mass of the liquid that is discharged from the nozzle but not accumulated in the weighing tank caused by the mist, evaporation and remaining oil on the inside wall of the connecting duct.

The time-averaged density through the flowmeter $\overline{r_{L,FM}}$ is obtained from the density $r_{L,ref}$ measured by the off-line density meter at temperature T_{ref} and atmospheric pressure p_{ref} , as

$$\overline{r_{L,FM}} = \left\{r_{L,ref} + a_L\left(T_{TM} - T_{ref}\right)\right\}\left\{1 + F_L\left(p_{FM} - p_{ref}\right)\right\} \approx \left\{r_{L,ref} + a_L\left(T_m - T_{ref}\right)\right\}\left\{1 + F_L\left(p_m - p_{ref}\right)\right\},$$

where a_L and F_L represent the thermal coefficient of oil density in kg/(m^3·K) and compressibility factor in %/MPa. T_{TM} , p_{FM} , T_m and p_m denote the temperature and pressure at the flowmeter and the measured point, respectively.

The frequency of the pulse train from the flowmeter f_P is obtained as

$$f_P = \frac{I_P}{t_P} \quad (1/\mathrm{s}).$$

The K-factor of a flowmeter to be calibrated is defined by

$$K_f = \frac{f_P}{\overline{q_{FM}}} \quad (\mathrm{pulse/m^3}).$$

Finally, the K-factor is described by

$$K_f = \left\{r_{L,ref} + a_L\left(T_m - T_{ref}\right)\right\}\left\{1 + F_L\left(p_m - p_{ref}\right)\right\}\frac{\left(1 - r_G / r_{L,W}\right)}{k_S \cdot m_L}\frac{t_D}{t_P} I_P \quad (\mathrm{pulse/m^3}).$$

Uncertainty

The overall uncertainty is now under detailed estimation; here, the result of the last uncertainty analysis is described in the following.

The relative combined standard uncertainty of the K-factor $u_c(K_f)$ is expressed by

$$\left\{\frac{u_c(K_f)}{K_f}\right\}^2 = \left\{\frac{u(I_P)}{I_P}\right\}^2 + \left\{\frac{u(t_P)}{t_P}\right\}^2 + \left\{\frac{u(\Delta M_{L,DV})}{M_L}\right\}^2 + \left\{\frac{u(\Delta(r_{L,FM}\, q_{FM}))}{\overline{r_{L,FM}}\,\overline{q_{FM}}}\right\}^2 + \left\{\frac{u(M_L)}{M_L}\right\}^2 + \left\{\frac{u(\overline{r_{L,FM}})}{\overline{r_{L,FM}}}\right\}^2 + \left\{\frac{u(t_D)}{t_D}\right\}^2,$$

where $u(i)$ denotes the standard uncertainty of an uncertainty source i. The uncertainties of sources are estimated as follows.

(1) The number of pulses generated by the flowmeter.

Assuming that the number of pulses is not miscounted, the uncertainty of the number of pulses $u(I_P)$ is estimated to be zero.

(2) The duration for which flowmeter pulses are counted.

This uncertainty $u(t_P)$ is due to the timer, which was calibrated by a standard counter. According to the specifications of the timer, the stability of the timer is better than 25 ppm. Therefore, the relative standard uncertainty $u(t_P)/t_P$ is estimated to be 0.001 %.

(3) The effect of the dead volume

The dead volume means the volume between the test meter and the nozzle of the diverter. Since the thermal expansion of the pipe and the effect of the pressure difference are negligible, the mass difference in the dead volume between the start and the end of measurement is described as

$$\Delta M_{L,DV} = V_{DV} \cdot a_L \cdot \Delta T_{DV},$$

where V_{DV} represents the dead volume. ΔT_{DV} denotes the temperature difference in the dead volume between the start and end of measurement. When the maximum uncertainty is estimated using the 1,000 kg weighing scale, the relative standard uncertainty of the effect of the dead volume $u(\Delta M_{L,DV})/M_L$ is estimated to be less than 0.003 %.

(4) The effect of the correlation between mass flow rate and density in the flowmeter

The effect of the correlation between mass flow rate and density $\Delta(r_{L,FM}q_{FM})$ is described as

$$\Delta(r_{L,FM}q_{FM}) = \frac{\int_{t_D} r_{L,FM}q_{FM}\,dt}{t_D} - \overline{r_{L,FM}}\,\overline{q_{FM}} = \overline{r'_{L,FM}\,q'_{FM}},$$

where $\overline{r'_{L,FM}\,q'_{FM}}$ represents the correlation between the fluctuation of the density and the fluctuation of the mass flow rate. This effect is peculiar to the volumetric flowmeter, and it is not necessary to consider for the mass flowmeter. The density, which depends on the temperature and pressure, and mass flow rate are sufficiently stable in this facility. Therefore the relative uncertainty of the effect of the correlation between mass flow rate and density $u(\Delta(r_{L,FM}\, q_{FM}))/\overline{r_{L,FM}\, q_{FM}}$ is negligible.

(5) The mass of oil accumulating in the weighing tank

The uncertainty of the mass of oil in the weighing tank is expressed as

$$\left\{\frac{u(M_L)}{M_L}\right\}^2 = \left\{\frac{u(k_S)}{k_S}\right\}^2 + \left\{\frac{u(m_L)}{m_L}\right\}^2 + \left\{\frac{u(1-r_G/r_{L,W})}{1-r_G/r_{L,W}}\right\}^2 + \left\{\frac{u(\Delta M)}{M_L}\right\}^2,$$

where the terms on the right side of this equation represent the uncertainty of the calibration factor, resolution, buoyancy correction and the effect of oil mist, respectively. These terms is discussed below.

(a) Calibration factor of the weighing scale

The weighing scale is calibrated by dead weights, the expanded uncertainty (k=2) of which is 17 ppm, before and after calibration of the flowmeter. In addition, the following conditions and results for the weighing scale were experimentally investigated.

- ✓ The reproducibility of calibration factor is less than 20 ppm per day and 50 ppm per month.
- ✓ The repeatability of the calibration factor is less than 10 ppm.
- ✓ The weighing scale is used under a limited range from 9,000 kg to 10,000 kg, for the 10,000 kg weig hing scale.
- ✓ The temperture in the weighing room is maintaind at 20±3 °C.
- ✓ The weighing scale is an the electronic balance with levers, which is designed to load at the same point with calibration by dead weights and installation of oil. Reproducibility of an off-center loading experiment with the 1,000 kg weighing scale by using 200 kg dead weights is less than 20 ppm.

Although it is necessary to discuss the estimation of the weighing scale in more detail, the above results indicate that the relative standard uncertainty of the calibration factor $u(k_S)/k_S$ is estimated to be less than 0.010 %.

(b) Resolution of weighing scale

$u(m_L)$ is the standard uncertainty corresponding to the resolution of the weighing scale. The resolutions of 10,000 kg and 1,000 kg weighing scales are 10 g and 1 g, respectively. Thus the relative uncertainty of resolution is negligible.

(c) Buoyancy correction

The atmospheric pressure is measured using an absolute pressure gauge, the uncertainty of which is less than 1 %, and temperature in the room is maintained at 20±3 °C. Hence the uncertainty of air density in the weighing room $u(r_G)$ is less than 0.02 kg/m^3. Assuming the difference between the averaged temperature in the weighing tank and the measured value is less than 2 °C, the uncertainty of oil density in the weighing tank $u(r_{L,W})$ is less than 1 kg/m^3. The standard uncertainty of buoyancy correction is estimated to be 0.003 %.

(d) Effect of oil mist and evaporation

The difference between the mass of oil in the weighing tank and that passing through the nozzle is caused by oil mist and evaporation in the diverter and weighing tank. The effect of evaporation can be neglected at the experimental temperature, since the boiling points of kerosene and light oil are higher than that of water. Although error caused by oil mist is minimized, it is difficult to estimate the amount of oil mist generated. In order to investigate the effect of oil mist, the mass, which is installed in the weighing tank as oil mist, is measured while oil flows to a by-pass line. As a result, increased weight is found to be less than 1 g in one minute. Thus, the uncertainty due to oil mist before and after installation is less than 0.002 %.

According to the above discussion, the standard uncertainty of the mass of oil $u(M_L)/M_L$ is estimated to be less than 0.011 %.

(6) Time-averaged oil density through the flowmeter under calibration

The uncertainty of oil density consists of the uncertainty of the density measurement using the off-line density meter, the uncertainty of the thermal coefficient and compressibility factor of oil

and the uncertainty caused by temperature and pressure measurements at the flowmeter, and it is expressed as

$$\left\{\frac{u\left(\overline{r_{L,FM}}\right)}{r_{L,FM}}\right\}^2 = \left\{\frac{u\left(r_{L,ref}\right)}{r_{L,ref}}\right\}^2 + \left\{\frac{a_L}{r_{L,ref}}u\left(T_{ref}\right)\right\}^2 + \left\{F_L u\left(p_{ref}\right)\right\}^2$$
$$+ \left\{\frac{\left(T_{TM} - T_{ref}\right)}{r_{L,ref}}u\left(a_L\right)\right\}^2 + \left\{\frac{a_L}{r_{L,ref}}u\left(T_{FM}\right)\right\}^2 + \left\{\left(p_{FM} - p_{ref}\right)u\left(F_L\right)\right\}^2 + \left\{F_L u\left(p_{FM}\right)\right\}^2$$

The uncertainties of these sources are discussed belows.

(a) Density meter

The off-line density meter is adjusted by the density standard liquid of pure water, the expanded uncertainty of which is 30 ppm. In addition, the density meter is calibrated by an other density standard liquid, the density of which is similar to that of the working liquid. The specifications of the oscillating density meter are described as the uncertainty of density measurement and temperature of 0.001 kg/m^3 and 0.03 °C, respectively. The repeatability of density measurement is less than 5 ppm. These indicate that the relative standard uncertainty of the density meter, $\sqrt{\left\{u\left(r_{L,ref}\right)/r_{L,ref}\right\}^2 + \left\{a_L u\left(T_{ref}\right)/r_{L,ref}\right\}^2 + \left\{F_L u\left(p_{ref}\right)\right\}^2}$, is estimated to be less than 50 ppm.

(b) Thermal coefficient of oil density

The thermal coefficient of oil density is measured using the density meter thermometer. As a result, the thermal coefficient in kg/(m^3 °C) is found to be approximately constant against temperature although the density changes. The difference in temperature between the flowmeter and density meter is less than 0.5 °C, since the density is measured at a temperature similar to that downstream of the flowmeter. Therefore, the uncertainty of the thermal coefficient $\left|\left(T_{TM} - T_{ref}\right)u\left(a_L\right)/r_{L,ref}\right|$ is estimated to be less than 30 ppm.

(c) Measured temperature

The standard deviation of temperature downstream of the flowmeter measured using thermometer, the expanded uncertainty of which is 0.03 °C, is less than 0.03 °C. Furthermore the difference in temperature between the flowmeter and thermometer is estimated to be less than 0.03°C. Therefore, the standard uncertainty in relation to the measured temperature $\left|a_L/r_{L,ref}\,u\left(T_{TM}\right)\right|$ is estimated to be less than 50 ppm.

(d) Compressibility of oil

The compressibility factor of oil is approximately 0.1 %/MPa. Assuming that the uncertainty of the compressiblity of oil is 10 %, the standard uncertainty due to compresibility $\left(p_{FM} - p_{ref}\right)u\left(F_L\right)$ is estimated to be 50 ppm when the pressure at the flowmeter is 0.5 MPa.

(e) Measured pressure

The pressure at the flowmeter is calculated by averaging the pressures upstream and downstream of the flowmeter, measured by a pressure gauge with an accuracy of 0.001 MPa. The uncertainty of pressure measurement at the flowmeter is estimated to be less than 0.01 MPa, although it depends on the test meter used. Therefore, the standard uncertainty due to measured pressure $\left|F_L u\left(p_{FM}\right)\right|$ is estimated to be less than 10 ppm.

Considering all uncertainties in relation to the density, the standard uncertainty of the oil density through the flowmeter is estimated to be less than 0.010 %.

(7) Diversion time

The uncertainty of diversion time is dominated by the diverter timing error. The diverter timing error for large and small diverters has been evaluated by the experimental method described in ISO4185 [7]. The estimated error is shown in Figure 6. The diverter timing error is

shown to be less than 30ppm over the entire range of flow rate for test lines for both light oil and kerosene.

The uncertainty sources are listed in Table 2. Although it is necessary to perform estimations by more detailed analysis, the expanded uncertainty for volumetric flow rate is estimated to be less than the target uncertainty 0.04 %. Furthermore repeatability of the K-factor of a typical flowmeter, a turbine meter for example, is better than 0.01 %. These results indicate that the facility has an excellent calibration performance for flowmeters.

International comparison

To verify the performance of this facility, an international comparison with SP, Swedish National Testing Research Institute, was carried out. A screw-type positive displacement flowmeter, which is the same type as that used in the intercomparison in Europe [8], was selected as the transfer standard. This flowmeter was calibrated at SP and shipped to NMIJ. After calibration at NMIJ, it was returned to SP where it was calibrated again. The normally stated uncertainty for the equipment used at SP would be approximately ±0.1 %. In this case however, a smaller value can be achieved, due to the very good conditions (i.e., constant temperature) and use of special methods. This improved uncertainty is calculated as ±0.045 %. The experimental conditions are shown in Table 3. All results are shown as mean values of 2-8 individual test runs with a standard deviation of less than 0.01 %.

Figure 7 shows the results for the screw meter obtained at NMIJ and at SP. Since the calibration results obtained at SP changed about 0.04 % from the first measurement, “SP 1”, to the second measurement, “SP 2”, the uncertainty of the total intercomparison must be set to a similar value. Although the reason for the deviation in results before and after shipping are yet not known, possible reasons are transport damage, wear, meter malfunction or errors in test equipment. All plots in curve “SP 1” compared to curve “NMIJ” is within 0.05 % and all plots in curve “NMIJ” compared to curve “SP 2” are within 0.06 %. In addition, mean value of the difference among all flow rates is 0.02 %. These results show that the difference between the two standards, which were obtained using different calibration methods, is within the acceptable uncertainty.

Figure 8 shows the Youden plot with the relative K-factor calibrated at NMIJ to the average value between the servo PD meter and the screw meter at 120 m^3/h. All data are within ±0.006 % and the result does not show systematic effect due to the calibration facility. Furthermore, in order to confirm the performance of the weighing system with the diverter, the experiment at a flow rate of 30m^3/h was carried out using 10,000kg and 1,000 kg weighing system. The result is shown in figure 9 as a Youden plot. K-factors for both the 10,000 kg and the 1,000 kg weighing system are within ±0.006 %, and the difference between them is less than 0.003 %. These results indicate that the results for different weighing systems are insufficiently good agreement that the calibration is reliable.

Conclusions

A new primary standard for hydrocarbon flowmeters has been constructed at NMIJ. This calibration facility has special features that enable highly accurate calibration. It is clear that the target uncertainty 0.04% has already been achieved, by rough uncertainty analysis. The dominant uncertainty was shown to results from the measurement of the mass and density. It is necessary to estimate the uncertainty of calibration in more detail so that the uncertainty of the calibration facility will be improved. The international comparison experiment between NMIJ and SP was carried out. The results indicated that the calibration at NMIJ agrees with that at SP within the quoted expanded uncertainties for calibration at the two institutes.

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Table 1 Specifications of diverter

Diverter	Small	Large
Weighing scale [kg]	1,000	10,000
Flow rate range [m^3/h]	3 - 30	30 - 300
Nozzle width [mm]	2 - 30	2 - 40
Nozzle length [mm]	100	600
Maximum wing speed [m/s]	0.4	0.7

Table 2 Uncertainty sources and standard uncertainties.

Uncertainty sources	Standard uncertainty
Number of pulses	0
Duration of pulse counting	0.001%
Dead volume	0.003%
Fluctuations of flow rate and density	0.000%
Density of oil through the flowmeter	0.010%
Mass of oil in the weighing tank	0.011%
Duration of diversion	0.003%

Combined uncertainty	0.015%
Expanded uncertainty (k=2)	0.030%

Table 3 Experimental configuration for international comparison between NMIJ and SP.

	NMIJ	SP
Date	2002/5-8	2002/4, 2002/8
Method	Gravimetric flying s/s	Volumetric flying s/s
Reference	Weighing scale	Ball prover
Liquid used	Light oil	Exxsol D120
Viscosity@20°C	6.8 cSt	4.2 cSt
Density@20°C	830 kg/m^3	820 kg/m^3
Temperature	19.91-20.06 °C	19.46-21.42 °C
Test pressure	0.28-0.44 MPa	0.20-0.28 MPa
Flow rate	30-300 m^3/h	30-300 m^3/h

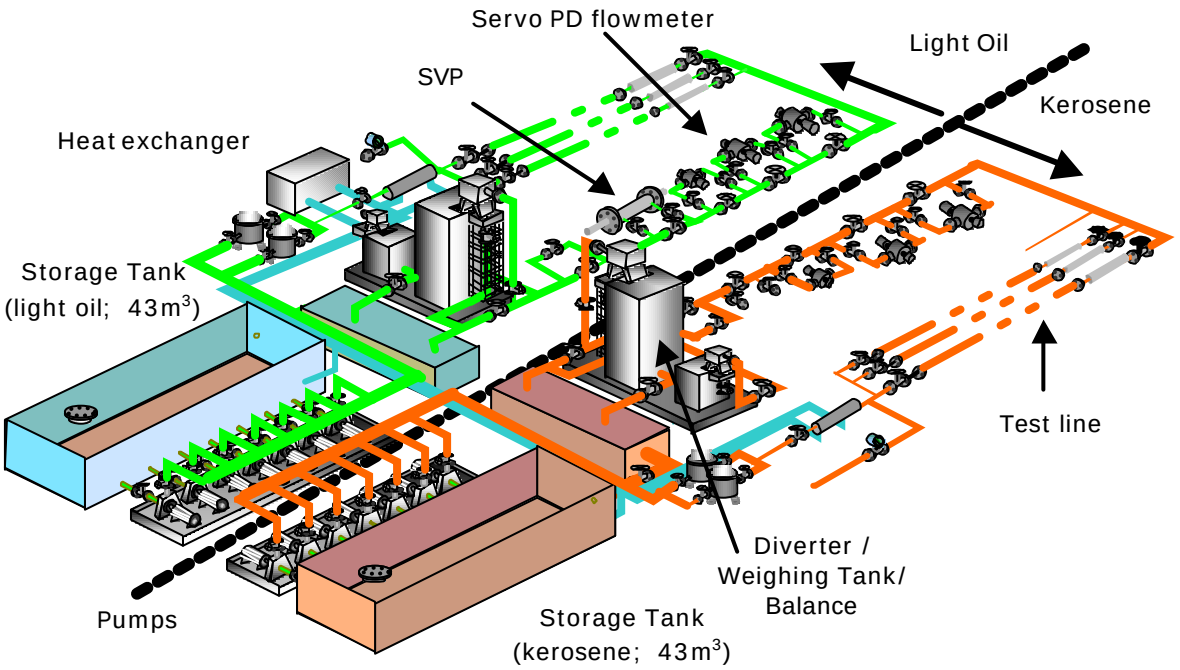


Figure 1 Schematic of the oil flow calibration facility.

Figure 2 Test lines in the facility.

Figure 3 Exteria of the weighing system.

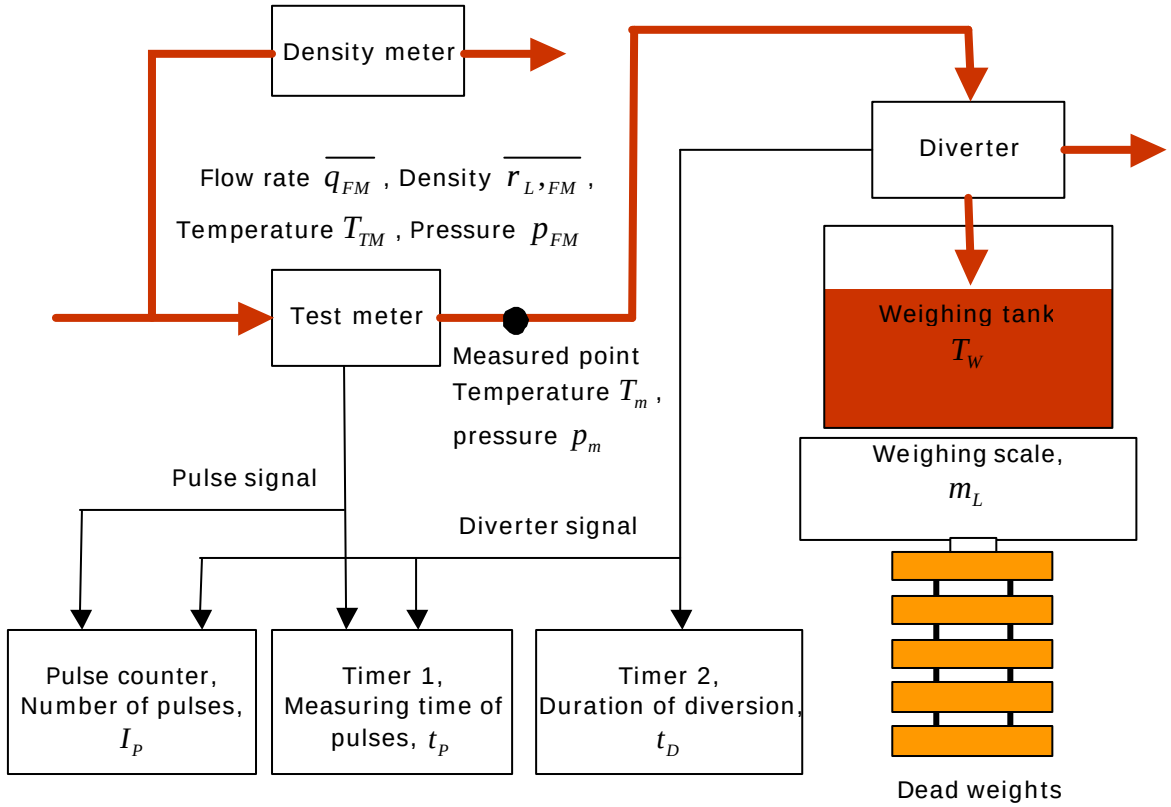


Figure 4 Data acquisition system of the facility.

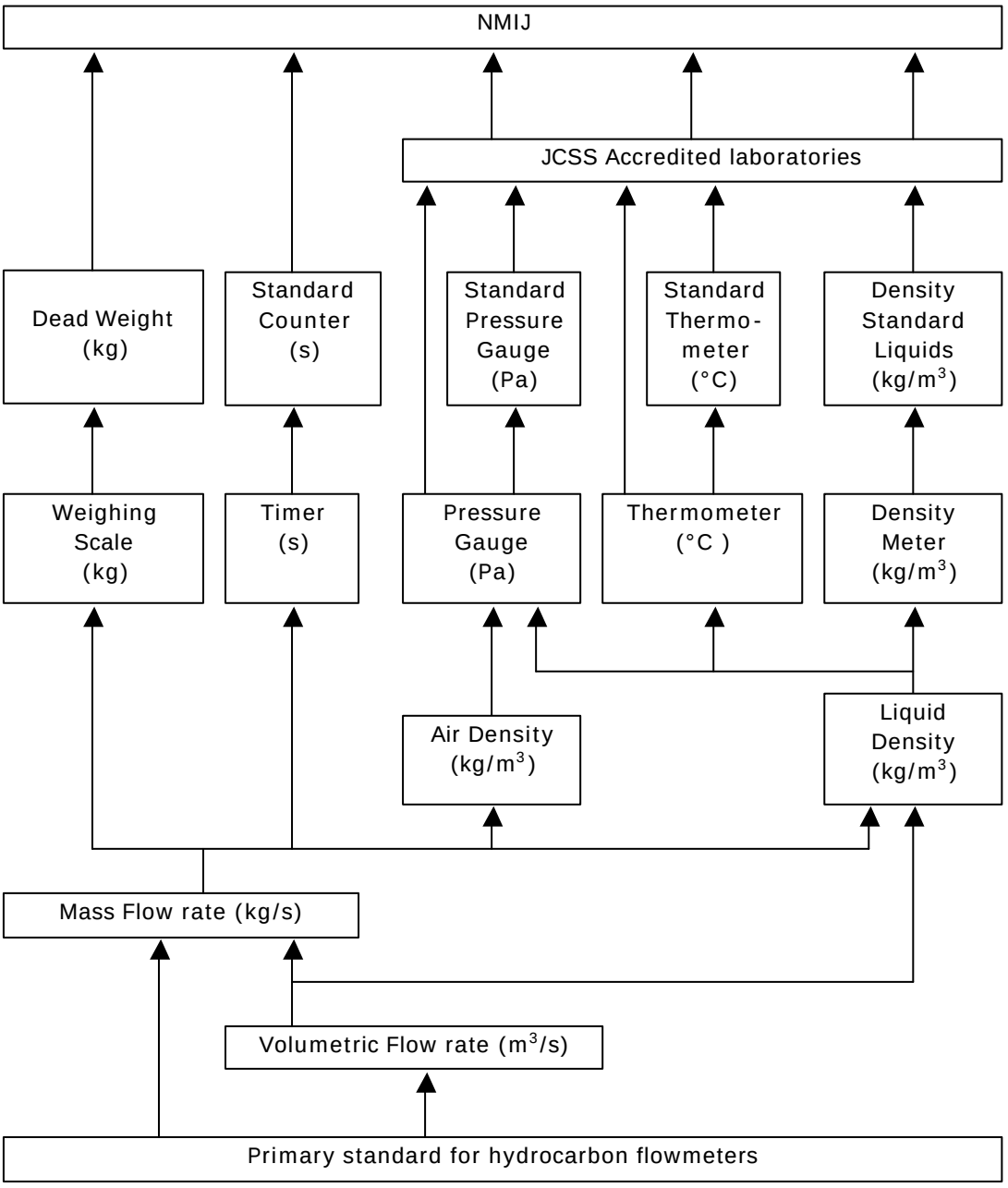
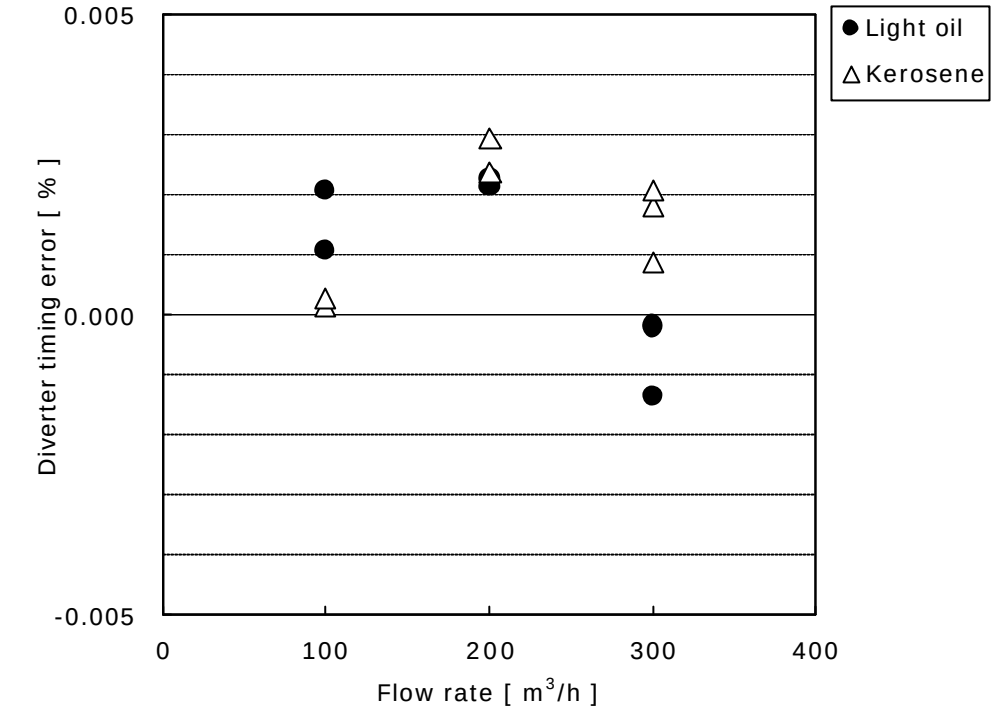
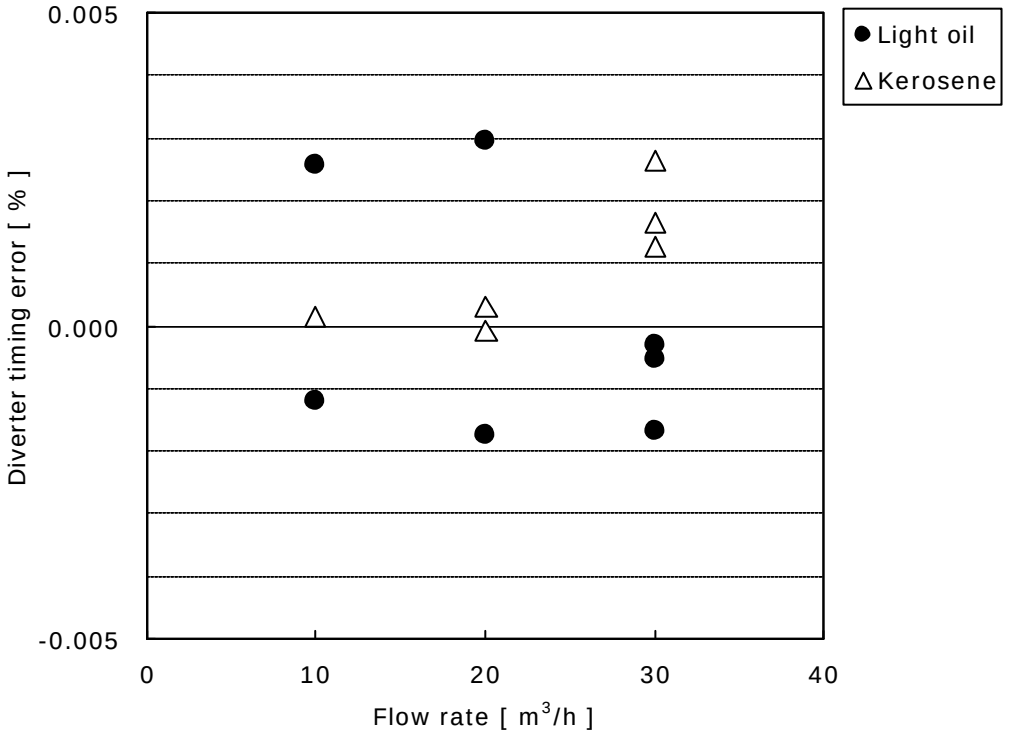


Figure 5 A diagram of traceability system.



(a)



(b)

Figure 6 Diverter timing error at the calibration facility for hydrocarbon flow measurement: (a) large diverter for 10,000 kg weighing system, (b) small diverter for 1,000 kg weighing system.

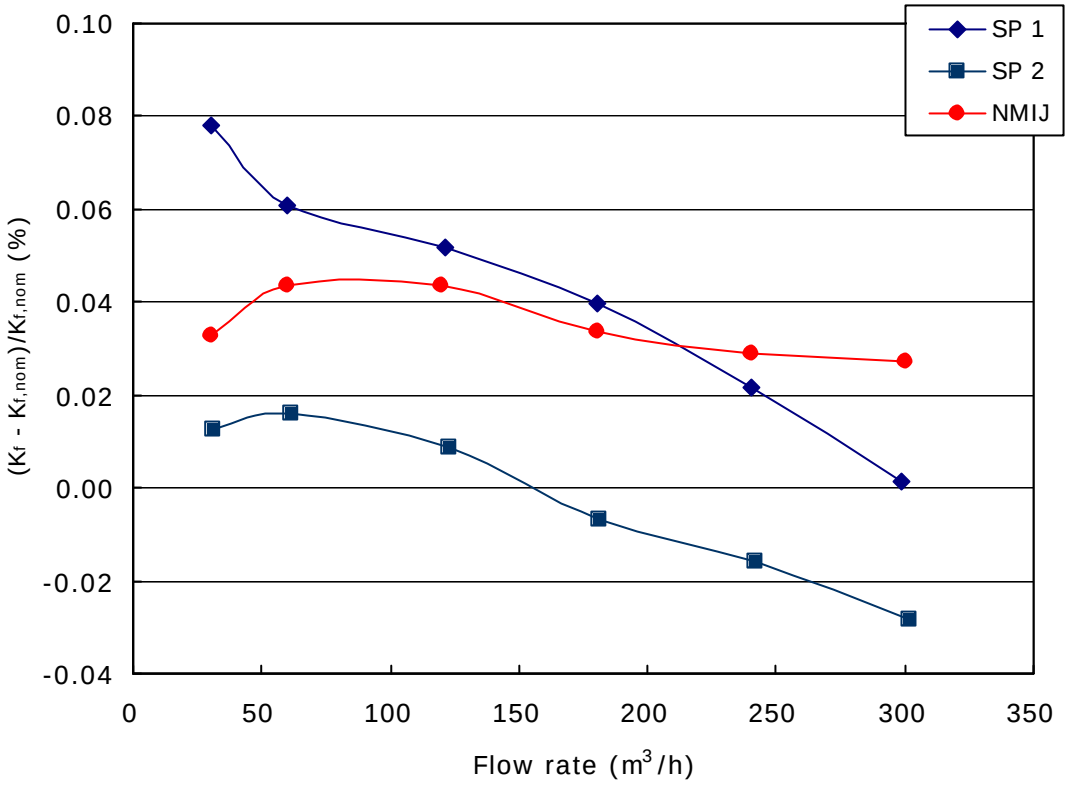


Figure 7 Results of international comparison at NMIJ and SP for screw meter.

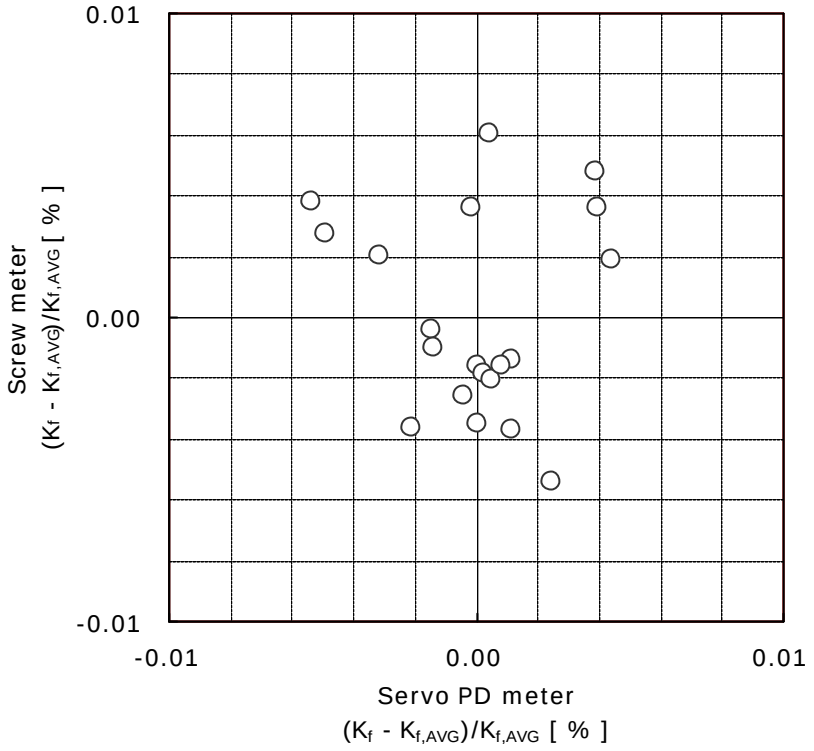


Figure 8 Youden plot of K-factor between screw meter and servo PD meter at NMIJ. Test flow rate was 120 m^3/h.

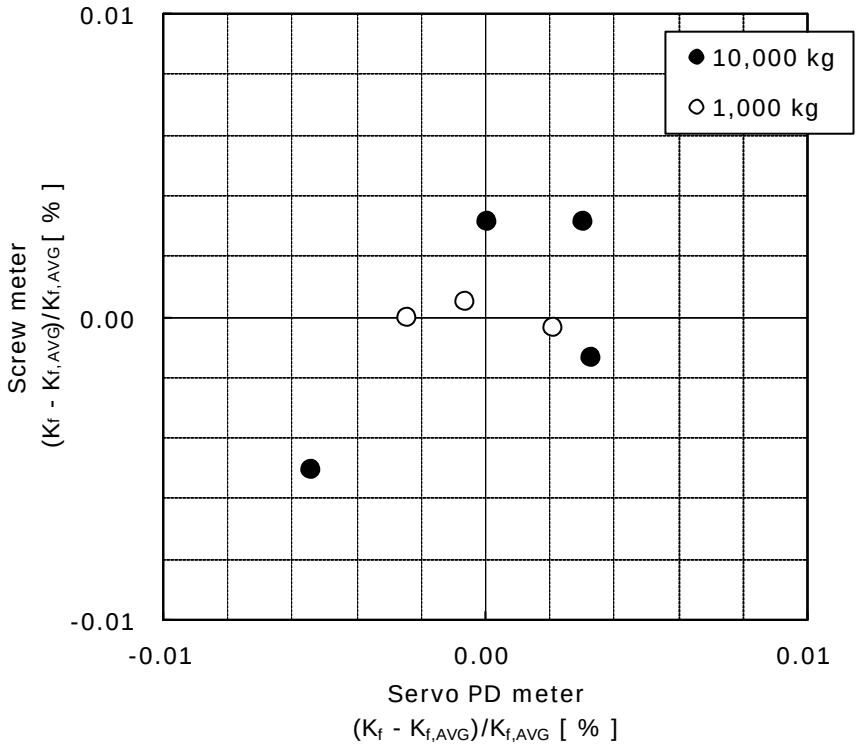


Figure 9 Youden plot of K-factor between screw meter and servo PD meter at NMIJ. Test flow rate was 30 m^3/h.