APMP Key Comparison for Water Flow
5 kg/min to 60 kg/min
(APMP.M.FF.K1.1.2022)

Draft B Report

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1. Introduction

The key comparison, APMP.M.FF.K1.1.2022 for water flow measurement has been undertaken by APMP/TCFF, which is Technical Committee for Fluid Flow (TCFF) and was piloted by Center for Measurement Standards (CMS/ITRI) of Chinese Taipei. The purpose of this key comparison is to demonstrate the degree of equivalence of the water flow standard at the participating laboratories to the CCM.FF-K2.2011[1] key comparison reference value (KCRV) and to provide supporting evidence for the calibration and measurement capabilities (CMCs) claimed by the participating laboratories in the Asia-Pacific regions. CMS/ITRI and KRISS serve as the linking lab in this comparison.

Both Standing Start and Finish (SSF) and Flying Start and Finish (FSF) are allowed in this key comparison. It should be noted that when using the SSF method, each measurement should be at least one minute. At 5 kg/min this should be two minutes.

This document serves as the technical protocol for the comparison and includes e.g. specific instructions for calibrating the transfer standard and timetables for a successful and timely completion of the comparison.

1.1 Test liquid

Following the CCM.FF-K2.2011 key comparison project, the water is the test media.

2. Participants Information

There were 8 NMIs in APMP participated in this Key comparison. The 8 participants and the time schedule are shown in Table 1. The comparison measurements started in July 2022 and finished Aug. 2024. Each laboratory had several weeks for providing the measurements for sending the transfer standard to the next laboratory. Due to some problems with custom process, the transfer standard shipment was delayed several times. The transfer standard was calibrated and tested by the pilot laboratory before, during and after the comparison to assess its calibration stability.

2.1 Participants

The calibration system information of participates are presented in Appendix 1.

Table 1. Information of participants

NMI/DI	Contact	Test	Shipping	Remark
CMS/ITRI	Chun-Lin Chiang	2022/07/01-2022/07/22	2022/07/22-2022/08/01	First-round test by Pilot
KRISS	Sejong Chun	2022/08/01-2022/08/24	2022/08/25-2022/09/08	Linking Lab. (ATA Carnet)
NMIM	Ts. Mohd Noor bin Mohd Ghafar	2022/09/09-2022/09/30	2022/10/01-2022/11/17	(ATA Carnet)
NIMT	Theerarak Chinarak	2022/11/18-2022/12/01	2022/12/02-2022/12/13	(ATA Carnet)
AIST/NMIJ	Sanehiro Wada	2022/12/14-2023/01/28	2023/01/29-2023/03/03	(ATA Carnet) (Weighing system broken)
KRISS	Sejong Chun	-	2023/03/03-2023/03/10	(ATA Carnet) (Shipping)
CMS/ITRI	Chun-Lin Chiang	2023/03/11-2023/04/22	2023/04/23-2023/04/26	Second-round test by Pilot
NPLI	Shiv Kumar Jaiswal	2023/04/27-2023/06/10	2023/06/10-2023/06/20	
CMS/ITRI	Chun-Lin Chiang	-	2023/07/13-2023/07/18	(Shipping)
NMC	Zeng Yan	2023/07/19-2023/09/26	2023/09/27-2023/10/27	
CMS/ITRI	Chun-Lin Chiang	-	2023/11/14-2023/12/04	(Shipping)
NMLPHIL	Jose Marco D. Latosa	2023/12/05-2023/12/26	2023/12/27-2024/03/15	
CMS/ITRI	Chun-Lin Chiang	-	2024/03/15-2024/03/30	(Shipping) Payment not included in total
AIST/NMIJ	Sanehiro Wada	2024/03/30-2024/05/01	2024/05/01-2024/05/15	Second-time calibration, Payment not included in total
CMS/ITRI	Chun-Lin Chiang	2024/06/01-2024/08/04	-	Third-round test by Pilot

3. Description of the transfer standard

The transfer meter package made by aluminum extrusion is connected with one Coriolis flow meter (as Figure 1), stainless pipes, two on-off valves and hoses with quick coupling. The specification of the flange is ANSI #150 RF 1 inch. The flange connection will be connected with the NMI's test facility in the upstream and downstream. One absorbing pad can be placed under the transfer meter package to reduce the impact of the external vibration.

3.1 Description summary of the transfer standard

Skid

Maximum pressure   : 500 kPa gauge
Temperature range   : (20 to 30) °C
Mass flow rate   : (5 to 60) kg/min

Connection	: ANSI #150 RF 1 inch flange
Hose/quick coupling size	: DN25
Ball valve size	: DN15
Special adoptions	: One absorbing pad
	: two 2.5 m hoses

Coriolis flow meter (sensor)

Manufacturer	: ENDRESS + HAUSER
Type	: Promass F
Serial number	: S5128C02000
Size	: DN15
Output signal	: Frequency/Pulses
Pulse value	: 1000 pulses/kg

Coriolis flow meter(display)

Manufacturer	: ENDRESS + HAUSER
Type	: Promass 300
Serial number	: S5128C02000

Laptop computer

Manufacturer	: ASUS
Type	: ASUS X415
Serial number	: MCN0CV02P708483
Accessories	: a bag, a mouse, a laptop computer transformer with power cord suitable for 110 V_{AC}, two universal plugs A and two universal plugs B mentioned below
OS/Software	: Windows 11 / Microsoft office 2021

Power supply

Manufacturer	: MW
Type	: LPV-20-24
Input	: (100 to 240) V_{AC}
Output	: 24 V_{DC}

Universal plug A

Manufacturer	: SAMPO/LIBERTY
Type	: EP-UF1C(B)/LB-990B
Number	: 2 (for Coriolis flow meter and laptop respectively)
Input	: (100 to 240) V_{AC}
Area (~110 V, Type 1)	: Taiwan, Japan
Area (~220 V, Type 1)	: Philippines, China, Thailand, Vietnam

Area (~220 V, Type 2)	: China, Australia, New Zealand
Area (~220 V, Type 3)	: Hong Kong, U.A.E, Singapore, Malaysia
Area (~220 V, Type 4)	: China, Russia, U.A.E.
Area (~220 V, Type 5)	: U.A.E., Korea, Indonesia, Russia, Vietnam

Universal plug B

Manufacturer	: OWL
Type	: KWA-10
Number	: 2 (for Coriolis flow meter and laptop respectively)
Input	: (100 to 240) V_{AC}
Area	: India, Nepal, South Africa

We provide two ANSI #150 RF 1 inch flange connections in the upstream and downstream as shown in Figure 2. The participant also needs to take care of appropriate space for the placement of transfer standard package including the hoses in the upstream and downstream as Figure 3 showing. One 24 V_{DC} power supply, two waterproof terminal blocks and one 3 pin, 110 V_{AC} plug for the Coriolis mass flow meter are located on the aluminum extrusion as shown in Figure 4 and Figure 5. Please use the universal plug A or B placed in the laptop bag to connect the Coriolis flow meter to the appropriate V_{AC} power according to the power specifications of participants. Similarly, the plug of laptop can be changed and connected to the power of participants as shown in Figure 6. The input voltage ranges from (100 to 240) V_{AC}. Besides, the pin number of the laptop computer is "dannydanny25".

ANSI #150 RF 1 inch flange

Figure 1 Coriolis flow meter package   Figure 2 ANSI #150 RF 1 inch flange

Figure 3 The hose in the upstream and downstream

Figure 4 24 V_{DC} power supply   Figure 5 Plug and waterproof terminal block

Figure 6 Universal plug and electrical line of laptop computer and types of universal plug A

4. Measurement Procedure

These procedures are needed to be checked before the measurement for the KC. The transfer standard package is shipped in one transportation box, which is sufficiently robust to ensure safe transportation. The boxes should be opened by laboratory trained professional personnel upon receiving at the laboratory. Check the package casing for damage and the contents for missing against the Receiving Checklist Excel spreadsheet and send it to the pilot laboratory. "SHOCKWATCH" labels were given on box for damage check. If any of the "SHOCKWATCH"

labels are activated, note it on the Receiving Checklist and notify the pilot laboratory immediately.

4.1 Filling the transfer standard procedure

00   Make sure that all ball valves of the transfer package are closed.

01   Water fills the test facility upstream the transfer package according to the participants' own procedure.

02   Make sure that no leakage and no air inside the upstream pipe happens in the transfer standard and the participant's own facility.

03   Open the upstream ball valve and then downstream ball valve of the transfer package in order the let the flow passes through the mass flow meter.

04   Flow at least five minutes at 50 kg/min to bleed of air or vapors and make sure that the temperature is stable.

05   Slowly close the ball valve in the downstream.

06   Carry out the instrument health status check procedure and the zero adjustment procedure below before the measurement for the KC.

4.2 Instrument health status check procedure

The E+H Coriolis flow meter can be set as an wi-fi hotspot to let the laptop computer connect to the mass flow meter through the browser. This method can be used to carry out the health status check procedure.

00   Connect the power supply to the Coriolis flow meter. Find the wi-fi hotspot "EH_Promass 300 500_8C02000" in the wi-fi menu of the laptop and connect to it.

01   Open the chrome browser and enter the ip address: "192.168.1.212" to connect to the Coriolis meter login page. Make sure that the menu can be connected successfully. Enter the access code "0000" and click the "Login" button to go to the main menu.

02   The display language can be chosen according to your needs in the main menu. The default set is English. The information of the Coriolis flow meter including device name, device tag, flow rate and density are shown in the main menu. The "status signal" should presented "Device ok".

03   Click the "Instrument health status", "Diagnostics", "Heartbeat", and "Performing verification" button in order.

04   In the "Performing verification" menu, enter the Day, Hour and Minute term of the measuring time.

05   Change the "Cancel" status to the "Start" status in the "Start verification." term. It takes about few seconds to wait for the process till the progress bar reaches to the end.

4.3 Zero adjustment of mass flow meter

The zero adjustment is an important step before any measurement can take place for this KC. This procedure needs to be performed every time when the transfer standard is connected to another test facility. At the start of each day a zero check as described in will be sufficient. The zero adjustment procedures are presented below.

01 Click the "Setup", "Advanced setup", "Sensor adjustment", and "Zero point adjustment" button in order. It should be noted that the installation direction should not be changed in the "Sensor adjustment" menu and then click the "Zero point adjustment" button.

02 Click the "Zero point adjustment control" menu and change the "Cancel" status to the "Start" status. And then the zero adjustment procedure will start.

03 It takes about few minutes to wait for the zero adjustment procedure till the "Busy" status change to the "Cancel" status and the progress bar reaches to the end. Make sure that the valves in the upstream and downstream should be closed and the pipe is full and static before starting the zero adjustment procedure.

04 Back to the main menu, Check the zero point value in the menu.

4.4 Measurements procedures

The measurement process follows the contents in the CCM.FF-K2.2011 key comparison as shown in Table 1. The steps in Table 2 should be performed before the KC measurement.

Table 2. KC measurement procedure

Flow rate (kg/min)	Number of Repeats (n)	Remarks
5	3	Not in KCRV calculation
20	5	Not in KCRV calculation
40	10	
60	5	Not in KCRV calculation
50	5	
30	5	
10	5	Not in KCRV calculation
5	3	Not in KCRV calculation

5 Measurement Results

The data analysis follows the calculation method that determining the reference value at each flow rate will correspond to procedure presented by M. G. Cox[2] and the report for CCM.FF-K2.2011 key comparison Water flow (5 to 60) kg/min. Each flow rate includes (5, 10, 20, 30, 40, 50, 60) kg/min as shown in Table 2. The flow rate from 30 kg/min to 50 kg/min will

be determined to provide linkage to CCM.FF-K2.2011. CMS/ITRI and KRISS will serve as linking laboratories.

5.1 Method of measurement

The participating laboratories used their usual calibration procedure, that was described in their reports, as well as traceability to SI and to the independent realisation of the quantity.

The relative error of the transfer standard E_R in (%) is the quantity used to compare the participants' results. It is defined as the difference between the mass indicated by the transfer standard and the mass measured by the each participant's national standard divide by the mass measured by the each participant's national standard.

$$E_R = \frac{m_{TS} - m_s}{m_s} \times 100 \quad (\%) \tag{1}$$

where

E_R is the relative error of the transfer standard (%)

m_{TS} is the mass indicated by the transfer standard (kg)

m_s is the mass measured by the each participant's national standard (kg)

5.2 Stability of the transfer standard

The stability of the transfer standard was checked before starting the comparison by pilot laboratory-CMS/ITRI in 2022/07, 2023/04, 2024/07, during the comparison. The results of the relative errors of the transfer standard measured by the pilot laboratory are shown in Table 3 and Figure 7.

Table 3 Relative errors (%) of the transfer standard measured by the pilot laboratory

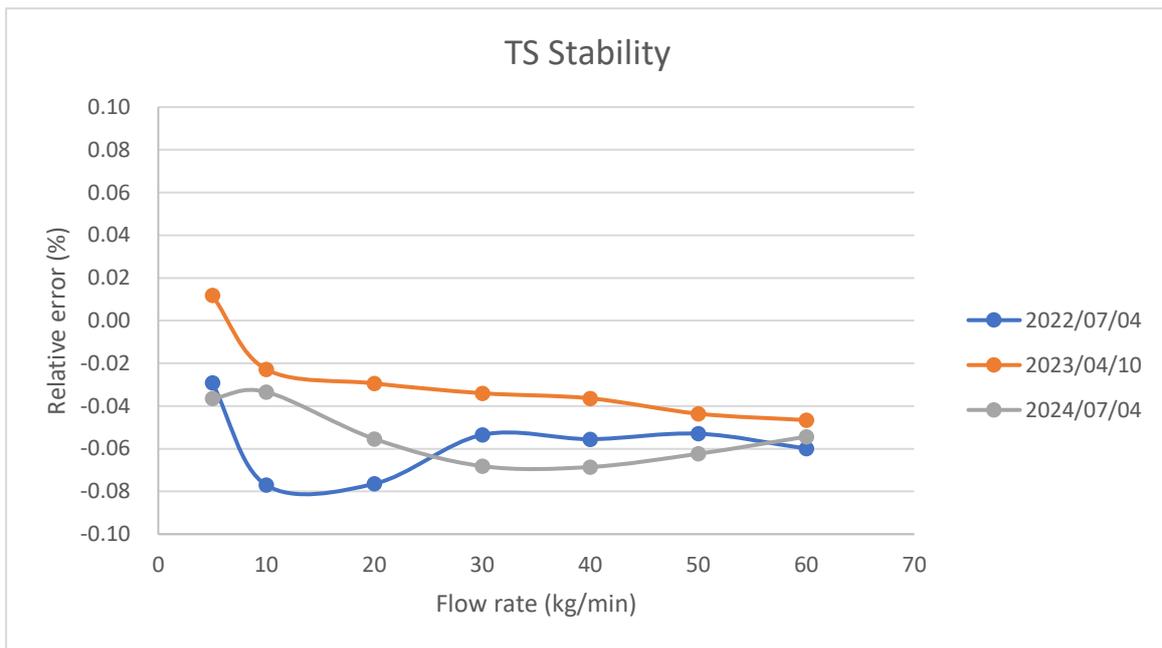| (kg/min)	Three times reproducibility data from Pilot		
	Relative error (%)		
	2022/07/04	2023/04/10	2024/07/04
5	-0.029	0.012	-0.036
10	-0.077	-0.023	-0.033
20	-0.076	-0.029	-0.055
30	-0.054	-0.034	-0.068
40	-0.056	-0.036	-0.069
50	-0.053	-0.044	-0.062
60	-0.060	-0.047	-0.054

Figure 7 Stability of the transfer standard

Considering the experimental data from the pilot lab and the claimed performance values of the flow meter provided by the transfer standard manufacturer, the measurement uncertainty derived from the stability of the transfer standard in this comparison will be based on the values in Table 4.

Table 4 The standard uncertainties of the transfer standard evaluated by the pilot laboratory

Set Point	Prior to Adjusting	After Adjusting
(kg/min)	u_{TS} (%)	u_{TS} (%)
5	0.014	0.016
10	0.016	0.016
20	0.014	0.016
30	0.010	0.010
40	0.009	0.010
50	0.005	0.010
60	0.004	0.010

Among them, u_{TS} in Table 4 represents the stability (reproducibility) of the transfer standard. u_{TS} is estimated standard uncertainty caused by the stability (reproducibility) of the transfer standard which was measured by the pilot laboratory.

$$u_{TS} = \max\left(\frac{\max(x_{TS,i1}, x_{TS,i2}, x_{TS,i3}) - \min(x_{TS,i1}, x_{TS,i2}, x_{TS,i3})}{2\sqrt{3}}\right) \qquad (2)$$

where

$x_{TS,i}$ is the relative error of the transfer standard; the subscript 1,2,3 represents the order of the sequence of the measurement of the pilot lab; the subscript i represents the calibration point corresponding to each flow rate; The uncertainty due to the stability of the transfer standard in this comparison was 0.01 % at (30 to 50) kg/min.

5.3 Laboratory results

All data collected from the participating laboratories are summarized in the following Tables 5 and Figure 8.

Table 5 Relative errors (%) of the transfer standard obtained by the participants

Flow rate	Relative error (%)							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
5	0.012	-0.025	[-]	-0.015	0.023	0.029	0.248	[-]
10	-0.023	-0.020	0.010	-0.005	-0.037	0.016	0.107	[-]
20	-0.029	-0.008	0.007	0.000	-0.044	-0.013	0.022	[-]
30	-0.034	-0.013	0.003	0.004	-0.043	0.023	-0.005	[-]
40	-0.036	-0.012	0.002	0.011	-0.047	0.025	-0.021	[-]
50	-0.044	-0.014	0.002	0.016	-0.049	0.031	-0.044	[-]
60	-0.047	-0.014	0.002	0.023	-0.049	0.026	-0.054	[-]

Note 1: NIMT requested for a withdrawal of their 5 kg/min result from this KC. Due to too short of collecting time (mass collection).

Note 2: NMIM requested for a withdrawal of all their results from this KC. Due to a faulty on their data acquisition system, they were unable to take the measurement data accurately during the calibration process. This has caused the reading was taken becomes less accurate and contributed to higher error in their measurement data. Their system also has limitation in terms of capturing analogue output signal from the meter under test. In addition, the instruction manual given did not suggest the use of additional equipment may be required to perform this calibration.
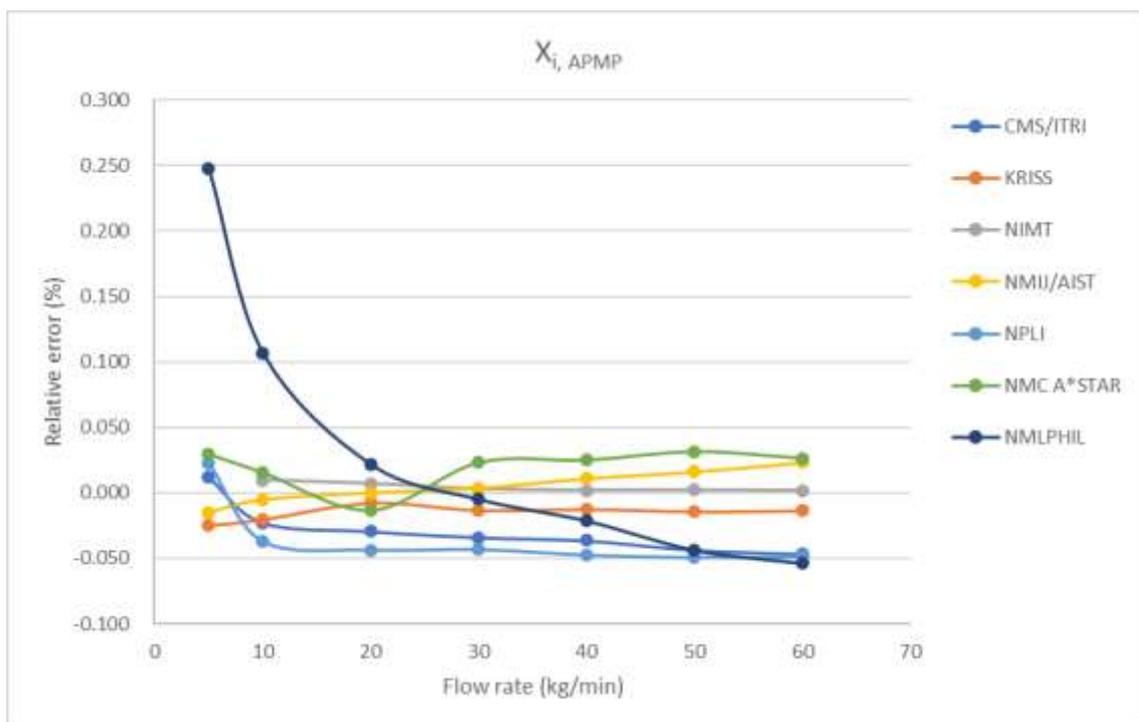
Figure 8 Relative errors of the participating laboratories

5.4 Laboratory uncertainty (U_{base})

The uncertainties are calculated according to the Evaluation of measurement data – Guide to the expression of uncertainty in measurement[3]. The expanded uncertainty U_{base} is obtained by multiplying the combined standard uncertainty u_{base} by coverage factor $k=2$ of participates for each flow rate are stated in Table 6.

Table 6 Expanded uncertainties (%) of measurements reported by participates

Flow rate	Expanded uncertainty (%), $k=2$							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
5	0.06	0.06	0.075	0.039	0.04	0.07	0.10	0.30
10	0.06	0.06	0.075	0.039	0.04	0.07	0.10	0.30
20	0.03	0.06	0.075	0.039	0.04	0.05	0.10	0.30
30	0.03	0.06	0.075	0.044	0.04	0.05	0.10	0.30
40	0.03	0.06	0.075	0.044	0.04	0.05	0.10	0.30
50	0.03	0.06	0.075	0.044	0.04	0.05	0.10	0.30
60	0.03	0.06	0.075	0.044	0.04	0.05	0.10	0.30

5.5 Uncertainty corrections and stability of the transfer standard

The standard uncertainties of the error in different laboratories u_{x1}, u_{x2} … u_{xn} include the uncertainty contributed by the transfer standard. This uncertainty was calculated according to the

following formula[4].

$$u_{xi} = \sqrt{\left(\frac{U_{\text{base},i}}{2}\right)^2 + u_{TS}^2} \qquad (3)$$

where

U_{base} is the expanded uncertainty($k=2$) determined by participating laboratory i and presented in results of laboratory i

u_{TS} is estimated standard uncertainty caused by the stability (reproducibility) of the transfer standard which was measured by the pilot laboratory. Its calculation method is described in Section 5.2. This transfer standard uncertainty component was combined by root-sum-of-squares with standard uncertainty provided by each participating laboratory (equation (3)).

6. Evaluations

6.1 Linkage to the CCM.FF-K2.2011

The APMP.M.FF.K1.1.2022 can be linked to the CCM.FF-K2.2011 results by correcting the results of link laboratories with the following procedures[5].

$$D = \sum w_i D_i \qquad (4)$$

Where

D_i is the correcting term calculated by the same link laboratory in CCM KC and APMP KC results. w_i is the weighting coefficient calculated by the equations below. And then the correcting term can be obtained in each flow rate condition.

$$D_i = x_{i,\text{CCM}} - x_{i,\text{APMP}} \qquad (5)$$

$$w_i = \frac{\frac{1}{u_{xi}^2}}{\sum \frac{1}{u_{xi}^2}} \qquad (6)$$

The measurement points of flow rates in the CCM.FF-K2.2011 were (30, 40, 50) kg/min. The KCRV (Key comparison reference value) and uncertainty of CCM.FF-K2.2011 in the flow range from 30 kg/min to 50 kg/min shown in Table 7 for the meter 1 and meter 2, respectively.

Table 7 The x_{KCRV} (Relative errors (%)) and uncertainty in the CCM.FF-K2.2011

Flow rate	Meter 1		Meter 2	
(kg/min)	x_{KCRV} (%)	Ux_{KCRV} (%)	x_{KCRV} (%)	Ux_{KCRV} (%)
30	-0.002	0.023	-0.021	0.035
40	-0.006	0.023	-0.017	0.037
50	-0.010	0.023	-0.012	0.036

These x_{KCRV} are used as the reference values after the results from APMP KC are corrected by D_i and w_i. Table 8 shows the results of CCM.FF-K2.2011 for two linking laboratories (KRISS

– Republic of Korea, CMS/ITRI – Chinese Taipei). In the flow rate set-points 30, 40, 50 kg/min.

Table 8 Relative errors (%) of linking laboratories of APMP in CCM.FF-K2.2011

| Flow rate | Meter 1-CCM.FF-K2.2011 | | | | Meter 2-CCM.FF-K2.2011 | | | |
| | CMS/ITRI | | KRISS | | CMS/ITRI | | KRISS | |
kg/min	$x_{i, CCM}$ (%)	$U_{base,CCM}$ (%)	$x_{i, CCM}$ (%)	$U_{base,CCM}$ (%)	$x_{i, CCM}$ (%)	$U_{base,CCM}$ (%)	$x_{i, CCM}$ (%)	$U_{base,CCM}$ (%)
30	-0.003	0.028	-0.002	0.06	-0.051	0.028	-0.005	0.06
40	-0.008	0.028	-0.005	0.06	-0.047	0.028	-0.007	0.06
50	-0.012	0.028	-0.008	0.06	-0.042	0.028	-0.005	0.06

For the correction between APMP.M.FF.K1.1.2022 and CCM.FF-K2.2011, the correction D were calculated by equation(4), (5) and (6). Table 9 shows the Correction D_i and its uncertainty of linking laboratories and Table 10 shows the correction D and its uncertainty applied to the results.

Table 9 Correction D_i and its uncertainty of linking laboratories

| Flow rate | Meter 1-CCM.FF-K2.2011 | | | | Meter 2-CCM.FF-K2.2011 | | | |
| | CMS/ITRI | | KRISS | | CMS/ITRI | | KRISS | |
kg/min	D_i	$u_{xi,APMP}$	D_i	$u_{xi,APMP}$	D_i	$u_{xi,APMP}$	D_i	$u_{xi,APMP}$
30	0.031	0.018	0.011	0.032	-0.017	0.018	0.008	0.032
40	0.028	0.018	0.007	0.032	-0.011	0.018	0.005	0.032
50	0.032	0.018	0.006	0.032	0.002	0.018	0.009	0.032

Table 10 Correction D and its uncertainty

| Flow Rate | D_{meter1} | $u_{D,meter1}$ | D_{meter2} | $u_{D,meter2}$ |
kg/min	(%)	(%)	(%)	(%)
30	0.026	0.016	-0.011	0.016
40	0.023	0.016	-0.007	0.016
50	0.025	0.016	0.003	0.016

The corrected value x_i' for each flow rate and each participant of APMP was calculated as

$$x_i' = x_{i,APMP} + D \qquad (7)$$

where $x_1, x_2, \dots x_n$ are relative errors of the transfer standard in one flow rate in different laboratories $i=1, 2, \dots$ n.

This correction D provide an estimate of what would have been the results from the

APMP.M.FF.K1.1.2022 participants, if they had actually participated in CCM.FF-K2.2011.

The corrected relative error (%) of participating laboratory and KCRV of CCM.FF-K2.2011 was shown in Table 11.

Table 11 Corrected relative errors of the participating laboratories by linking with CCM.FF-K2.2011

Relative errors (%) of the transfer standard obtained by the participants @Corrected by meter1								
Flow rate	Relative error (%)							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
30	-0.008	0.013	0.029	0.030	-0.017	0.049	0.021	[-]
40	-0.013	0.011	0.025	0.034	-0.024	0.048	0.002	[-]
50	-0.018	0.011	0.028	0.042	-0.024	0.057	-0.018	[-]
Relative errors (%) of the transfer standard obtained by the participants @Corrected by meter2								
Flow rate	Relative error (%)							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
30	-0.045	-0.024	-0.008	-0.007	-0.054	0.012	-0.016	[-]
40	-0.043	-0.019	-0.005	0.004	-0.054	0.018	-0.028	[-]
50	-0.040	-0.011	0.006	0.020	-0.046	0.035	-0.040	[-]

6.2 Degree of Equivalence to KCRV

The KC Reference value (x_{KCRV}) and the expanded uncertainty of the x_{KCRV} of the APMP KC can be obtained by the equation (8). When the x_{KCRV} will be determined, the differences between the x_{KCRV} and the participating laboratories will be calculated according to

$$di = x_i + D - x_{KCRV} \tag{8}$$

Based on these differences, the Degree of Equivalence (DoE) will be calculated according to equation (9):

$$E_{n_i} = \left| \frac{di}{U(di)} \right| \tag{9}$$

The DoE is a measure for the equivalence of the results of any laboratory with the x_{KCRV} or with any other laboratory, respectively. The results of a laboratory will be equivalent (passed) if $E_{ni} \leq 1$. The laboratory will be determined as not equivalent (failed) if $E_{ni} > 1.2$. For values of DoE in the range $1 < E_{ni} \leq 1.2$ the "warning level" is defined. In this case some actions to check are recommended to the laboratory. The standard uncertainty and the expanded uncertainty can be calculated as follows[6][7].

Independent laboratories without contribution to the KCRV as equation (10)

$$u(di) = \sqrt{u_{xi}^2 + u_{x_{KCRV}}^2 + u_D^2} \tag{10}$$

Independent laboratories with contribution to the KCRV as equation (11)

$$u(di) = \sqrt{u_{xi}^2 + u_{x_{KCRV}}^2 + u_D^2 - 2u_{KCRV}^2} \qquad (11)$$

Then,

$$U(di) = 2u(di) \qquad (12)$$

The expanded uncertainty $U(di)$ is determined by equation (12). Degree of Equivalence (DoE) to x_{KCRV} of each participating laboratory was calculated according to equation (9) as shown in Table 12, Table 13 and Table 14.

Table 12 d_i of participating laboratories to x_{KCRV}

d_i (%) to $x_{KCRV,meter1}$								
Flow rate	Relative error (%)							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
30	-0.006	0.015	0.031	0.032	-0.015	0.051	0.023	[-]
40	-0.007	0.017	0.031	0.040	-0.018	0.054	0.008	[-]
50	-0.008	0.021	0.038	0.052	-0.014	0.067	-0.008	[-]
d_i (%) to $x_{KCRV,meter2}$								
Flow rate	Relative error (%)							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
30	-0.024	-0.003	0.013	0.014	-0.033	0.033	0.005	[-]
40	-0.026	-0.002	0.012	0.021	-0.037	0.035	-0.011	[-]
50	-0.028	0.001	0.018	0.032	-0.034	0.047	-0.028	[-]

Table 13 $u(d_i)$ of participating laboratories to x_{KCRV}

$u(d_i)$ (%) of $d_{i,meter\ 1}$								
Flow rate	$u(d_i)$ (%)							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
30	0.021	0.033	0.043	0.031	0.030	0.033	0.055	[-]
40	0.021	0.033	0.043	0.031	0.030	0.033	0.055	[-]
50	0.021	0.033	0.040	0.027	0.025	0.033	0.052	[-]
$u(d_i)$ (%) of $d_{i,meter\ 2}$								
Flow rate	$u(d_i)$ (%)							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
30	0.016	0.031	0.045	0.034	0.032	0.036	0.056	[-]
40	0.015	0.030	0.046	0.034	0.033	0.036	0.056	[-]
50	0.016	0.030	0.046	0.034	0.033	0.036	0.056	[-]

Table 14 Degree of equivalence (DoE) of participating laboratories to x_{KCRV}

Degree of equivalence (DoE) of participating laboratories to $x_{KCRV,meter\ 1}$								
Flow rate	Degree of Equivalence							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
30	0.14	0.22	0.36	0.52	0.25	0.77	0.21	[-]
40	0.17	0.25	0.36	0.65	0.31	0.82	0.07	[-]
50	0.20	0.32	0.46	0.97	0.28	1.01	0.08	[-]
Degree of equivalence (DoE) of participating laboratories to $x_{KCRV,meter\ 2}$								
Flow rate	Degree of Equivalence							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
30	0.74	0.05	0.14	0.21	0.51	0.47	0.05	[-]
40	0.87	0.04	0.13	0.31	0.56	0.49	0.10	[-]
50	0.91	0.02	0.19	0.47	0.52	0.65	0.25	[-]

7. Conclusion

There 8 NMIs participated in APMP.M.FF.K1.1.2022 for the linkage to key comparison reference value (x_{KCRV}) in CIPM key comparison CCM.FF-K2.2011. CMS/ITRI coordinated the comparison and acted as a pilot laboratory. A Coriolis mass flow meter had been circulated as a transfer standard. The stability of transfer standard was checked during the comparison by pilot laboratory. The results of each participating laboratory were linked to x_{KCRV} of CCM.FF-K2.2011 by correcting the results of linking laboratories, KRISS and CMS/ITRI, which participated in CCM.FF-K2.2011. Degree of Equivalence (DoE) to x_{KCRV} of 7 participating laboratory shows equivalent and consistent with KCRV. The results of this comparison will be used for supporting evidence for the calibration and measurement capabilities (CMCs) claimed by the participating laboratories.

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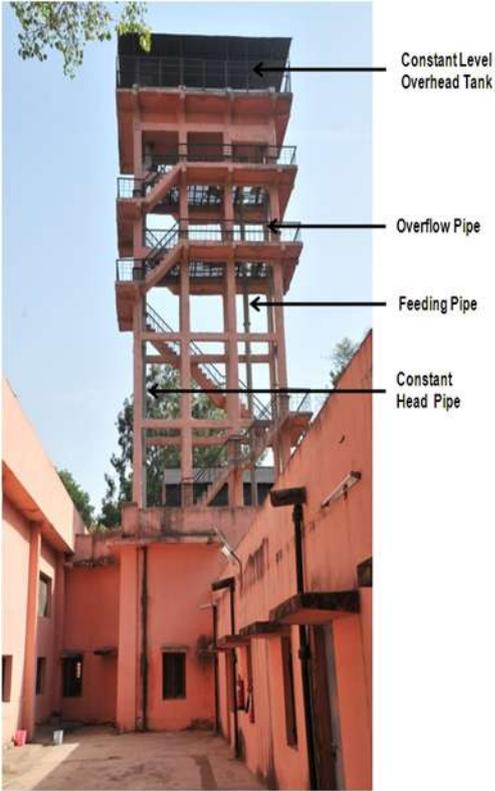
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Appendix 1 The calibration system information of participates

Chinese Taipei	**CMS/ITRI** Contact: Chun-Lin Chiang **address:** Center for Measurement Standards, ITRI 30 Ta Hsueh Road, Hsinchu 300065. Chinese Taipei
	System Description: The calibration method for water flowmeters is static weighing coupled with the flying start and finish mode. The system uses a diverter to manipulate flow along its bypass loop or towards the weighing tank. Then the quantity of water accumulated in the tank is compared with that measured by the meter under test. Both quantity-type and rate-type flowmeters could be calibrated by the system. The output of flowmeters could be volume, mass, volume flowrate, mass flowrate, or velocity. The parameter used to express the calibration result could be relative error, error, meter factor, K-factor, converting factor for electrical current to flow. The measurement range is defined as follows: Temperature: 10 °C to 45 °C; Pressure: 0 kPa to 500 kPa (gauge); Accumulated volume: 0.02 m^3 to 0.6 m^3; Accumulated mass: 20 kg to 550 kg; Volume flow rate: 0.3 m^3/h to 33 m^3/h; Mass flow rate: 300 kg/h to 33000 kg/h;
South Korea	**KRISS** Contact**:** Sejong Chun **Shipping address:** Korea Research Institute of Standards and Science Thermometry and Fluid Flow Metrology Group Division of Physical Metrology 205-dong 101-ho, Gajeong-ro 267, Yuseong-gu, Daejeon (zip 34113) South Korea
	System Description The water flow standard system at KRISS consists of a constant-level head tank, five weighing tanks, a reservoir, three pumps, six flow control units, six flow diverters, six weigh-bridges, ten test pipe lines, and ten reference flow meters. The constant-level head tank is located at 20 m high from the ground level. Its height is 3 m. Thus, water pressure can be maintained at 230 kPa (gauge). The weight-bridges can collect water into the weighing tanks depending on the weighing capacity of 25 000 kg, 5 000, 1 000 kg, 100 kg, 64 kg and 6 kg. The straight pipelines have diameters from 10 mm to 400 mm. The biggest pipeline (400 mm) is directly connected from the head tank. A header is connected to the other pipelines (10 mm to 250

mm) to supply water from the head tank to the pipelines. The flow diverters are operated by the flying-start-and-finish method according to ISO 4185:1980.

Range of flowrate	10 L/h … 2 000 m³/h
Fluid temperature	10 ºC … 40 ºC
Line pressure	230 kPa (gauge) (Constant head tank) 300 kPa (gauge) (Direct pumping)
Uncertainty ($k = 2$)	0.06 % (Volume flow, Mass flow)
Reference	Gravimetric
Operating method	Constant head tank, Direct pumping, Flying-start-and-finish (Standing-start-and-finish possible, but not used)
Calibration line diameter	10 mm … 400 mm
Test fluid	water

Malaysia

NMIM
Contact: Ts. Mohd Noor bin Mohd Ghafar
Shipping address:
National Metrology Institute of Malaysia (NMIM)
Lot PT 4803, Bandar Baru Salak Tinggi
43900 Sepang
Selangor Darul Ehsan
Malaysia

System Description
NMIM calibration facility used a static-gravimetric technique. The calibration of flowrate is determined by collecting a prescribed mass of steadily flowing water over a measured time interval.
The system uses a diverter to manipulate flow along its bypass loop or towards the weighing tank. Then the quantity of water accumulated in the tank is compared with that measured by the meter under test.
The measurement range is defined as follows:
- 2 test line (tested meter size DN15 to DN50)
- maximum flow rate : up to 40 m³/hr.
- 4 units master meter :
- Line 1 : 1 unit DN4 (range 0 ~ 0.5 m³/hr)
    1 unit DN20 (range 1 ~ 12 m³/hr)
- Line 2 : 1 unit DN6 (range 0 ~ 1 m³/hr)
    1 unit DN32 (range 1 ~ 40 m³/hr)
- 2 units Weighing Scale :
    Line 1 : 60 kg (resolution 1 g)
    Line 2 : 600 kg (resolution 50 g)

Thailand

NIMT
Contact: Theerarak Chinarak
Shipping address:
National Institute of Metrology
3/4-5 Moo 3, Klong 5, Klong Luang
Pathumthani 12120
Thailand

System Description
There are two piston provers for water flow calibration at

NIMT. Smaller piston prover has about 5 litres capacity while a larger piston has about 60 litres capacity. The quantity of water is measured by the linear encoder and verified by water draw method. The output of flow meters could be volume, volumetric flow rate or mass flow rate.

Description	Small prover	Large prover
Range of flow rate	(0.20-120) L/min	(2 – 1,500) L/min
Fluid temperature	(15 - 30) °C	(10 – 40) °C
Line pressure	(1 – 5) bar gauge	(0.5 – 8) bar gauge
Uncertainty (k =2)	0.075%	0.075%
Volume	5 litres	(2 – 60) litres
Meter size	(0.5 – 1.5) inch	(0.5 – 3) inch
Medium	RO water	DI water

Japan

NMIJ/AIST
Contact: Sanehiro Wada
Shipping address:
National Metrology Institute of Japan
National Institute of Advanced Industrial Science and Technology(AIST)
Liquid Flow Standards Section, Fluid Flow Division
North site 14, 1497-1 Teragu, Tsukuba, Ibaraki, 300-4201 Japan

System Description
NMIJ provides calibration services for water flowmeters with four calibration facilities as national standards. The water flow calibration facilities cover the range from 2 L/h to 12 000 m³/h with uncertainties from 0.039% to 0.081%. The calibration method for water flowmeters is the static and gravimetric method with flying start and stop method.

The measurement conditions are as follows:
Flow rate: 2 L/h to 12 000 m³/h
Temperature: 5℃ to 70℃
Pressure: up to 0.23 MPa (gauge, using head tank)
Uncertainty: 0.039 to 0.081 (k=2)

India

NPLI
Contact: Shiv Kumar Jaiswal
Shipping address:

New SS Pipe lines (DN25, 50, 100 ,150 & 200)

Constant Head Tank of Primary

CSIR-National Physical Laboratory
Dr KS Krishnan Marg, Pusa
New Delhi, Delhi 110012
India

System Description

The upgraded NPLI Primary Water Flow Calibration Facility is used for calibration of different types of flowmeters of sizes DN2 to DN200 in the flow range upto 650 m^3/h using weighing method as per ISO 4185 Standard. In this system, five pipe lines (DN25, DN50, DN100, DN150 and DN200) have been installed and connected to 3 nos. of high accuracy weighing systems (300 kg, 3000 kg and 6000 kg capacities) through fishtail, nozzle and diverter systems. A separate line of DN15 size has been also derived for calibration of DN2 to DN4 size mass flowmeters using 12 kg weighing scale employing standing start and standing finish method in the flow range 10 L/h to 500 L/h. These weighing systems are of electromagnetic force compensation type. The facility uses overhead tank at the height of 25 m having capacity of 21 m^3, thus giving water pressure of 250 kPa (gauge). The sump tank size is 30 m $\times$ 3 m $\times$ 3 m, thus having capacity of 270 m^3. A new direct pumping header of DN150 size was added using 3 HP, 5 HP and 10 HP pumps for calibration of flowmeters upto DN100 size in the flow range upto 175 m^3/h with maximum water pressure of 300 kPa. These pumps were integrated with variable frequency drives (VFDs) for flow control and energy saving. Out of 3 nos. of 50 HP pumps, 1 no. of 50 HP pump was integrated with VFD for flow control and energy saving. In this intercomparison, DN25 line and 300 kg weighing system was used. The 300 kg weighing system works in the flow range 0.1 m^3/h to 20 m^3/h with expanded uncertainty of 0.04% at k=2 for mass flow rate and volume flow rate.

Singapore

(a) NMC Liquid Flow Calibration System, (b) the Primary Standard, and (c) TS setup in the comparison

NMC A*STAR
Contact: Zeng Yan
Shipping address:
National Metrology Centre, 8 CleanTech Loop, Unit 01-20
Singapore, 637145.

System Description

The water flow measurement is realised by deriving collected water weight in a time interval (t) based on the static gravimetric method to establish the measurement traceability to SI unit. The water flow measurement system is based on the standing start and stop gravimetric method. The measurement configuration is shown in Figure 1. Water is pumped from water tank by a centrifugal pump in different flow rates. Water flow is metered by Coriolis flow meters with totalizer mass and then collected by weighing tank KCS600. After completed the sampling

	batch, the totalized mass collected by flow meters and weighing balance, and other relative parameters will be recorded	
	Range of flowrate	5 kg/min to 600 kg/min
	Fluid temperature	17 ºC to 23 ºC
	Line pressure	(1 to 4) bar gauge
	Uncertainty (k =2)	0.1% for (5 to 60) kg/min 0.05% for (60 to 600) kg/min
	Reference	Gravimetric
Philippines 	**NMLPHIL** Contact: Jose Marco D. Latosa **Shipping address:** F3Q2+W7F, Metrology Building, Industrial Technology Development Institute, DOST Compound, General Santos Avenue, Saliksik St, Taguig, Kalakhang Maynila, Philippines	
	System Description The Water Flow Calibration Facility at the ITDI–National Metrology Laboratory of the Philippines is designed for the calibration of liquid flow meters using the gravimetric static weighing flying-start-and-stop method. It is equipped with two parallel test lines, DN100 and DN50, to accommodate a range of flow meter sizes. The facility includes two weighing systems with capacities of 150 kg and 1500 kg, supporting 120 L and 1200 L collection tanks, respectively.	

Appendix 2 Mean of KCRV to evaluation

Based on the CCM.FF-K2.2011 comparison, the dual-meter method was adopted. Two independent values of KCRV and their relative expanded uncertainties were defined at 30 kg/min, 40 kg/min, and 50 kg/min, respectively.

The measurement values of CMS/ITRI and KRISS, which served as linkage laboratories for the APMP.M.FF.K1.1.2022, showed discrepancies in the Degree of Equivalence (DoE) with the two KCRV, indicating that the derived D and u_D from the linkage laboratories vary depending on the different KCRV values.

Therefore, when independent calculations are performed, some laboratories may have an En value greater than 1 at certain flow rates. As the results, the Pilot Lab. recommends using the average D_i approach, along with the uncertainty derived from the average, and then applying a weighted average method for the evaluation of D and u_D.

A2-Table 1 Mean of KCRV from CCM.FF-K2.2011 and its uncertainty

The KCRV (Relative errors (%)) and uncertainty in the CCM.FF-K2.2011						
Flow rate	Meter 1		Meter 2		Mean	
(kg/min)	x_{KCRV} (%)	Ux_{KCRV} (%)	x_{KCRV} (%)	Ux_{KCRV} (%)	x_{KCRV} (%)	Ux_{KCRV} (%)
30	-0.002	0.023	-0.021	0.035	-0.012	0.030
40	-0.006	0.023	-0.017	0.037	-0.012	0.031
50	-0.010	0.023	-0.012	0.036	-0.011	0.030

A2-Table 2 Correction average D_i and its uncertainty of linking laboratories

Flow rate	CMS/ITRI				KRISS			
kg/min	$D_{CMS,average}$	$u_{base,APMP}$	$u_{TS,APMP}$	$u_{average,CCM}$	$D_{KRISS,average}$	$u_{base,APMP}$	$u_{TS,APMP}$	$u_{average,CCM}$
30	0.007	0.015	0.010	0.016	0.010	0.030	0.010	0.002
40	0.009	0.015	0.010	0.016	0.006	0.030	0.010	0.003
50	0.017	0.015	0.010	0.016	0.008	0.030	0.010	0.004

A2-Table 3 Correction w_i of linking laboratories

Flow rate	CMS/ITRI			KRISS		
kg/min	$D_{CMS,average}$	$u_{average,APMP}$	w_{CMS}	$D_{KRISS,average}$	$u_{average,APMP}$	w_{KRISS}
30	0.007	0.024	0.639	0.010	0.032	0.361
40	0.009	0.024	0.637	0.006	0.032	0.363
50	0.017	0.024	0.641	0.008	0.032	0.359

A2-Table 4 Correction D and its uncertainty

$D_{average}$ (%)	$u_{Daverage}$ (%)
0.008	0.019
0.008	0.019
0.013	0.019

A2-Table 5 Corrected relative errors of the participating laboratories by linking with CCM.FF-K2.2011

Relative errors (%) of the transfer standard obtained by the participants @ Corrected by average

Flow rate	Relative error (%)							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
30	-0.026	-0.005	0.011	0.012	-0.035	0.031	0.003	[-]
40	-0.028	-0.004	0.010	0.019	-0.039	0.033	-0.013	[-]
50	-0.030	-0.001	0.016	0.030	-0.036	0.045	-0.030	[-]

A2-Table 6 d_i of participating laboratories to x_{KCRV}

d_i (%) to x_{KCRV}								
Flow rate	Relative error (%)							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
30	-0.015	0.006	0.022	0.023	-0.024	0.043	0.014	[-]
40	-0.017	0.007	0.021	0.031	-0.028	0.045	-0.002	[-]
50	-0.019	0.010	0.027	0.041	-0.025	0.056	-0.019	[-]

A2-Table 7 $u(d_i)$ of participating laboratories to x_{KCRV}

$u(d_i)$ (%) of $d_{i,average}$								
Flow rate	$u(d_i)$ (%)							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
30	0.022	0.034	0.046	0.034	0.033	0.036	0.056	[-]
40	0.021	0.034	0.046	0.034	0.033	0.036	0.057	[-]
50	0.021	0.034	0.046	0.034	0.033	0.036	0.056	[-]

A2-Table 8 Degree of equivalence (DoE) of participating laboratories to x_{KCRV}

Degree of equivalence (DoE) of participating laboratories to x_{KCRV}								
Flow rate	Degree of Equivalence							
(kg/min)	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
30	0.34	0.09	0.25	0.34	0.36	0.59	0.13	[-]
40	0.40	0.11	0.23	0.44	0.42	0.61	0.02	[-]
50	0.45	0.15	0.29	0.59	0.38	0.77	0.17	[-]

Appendix 3 Consistency check

In this comparison, measurements were conducted not only at flow rates of 30 to 50 kg/min but also at 5, 10, 20, and 60 kg/min. However, since the CCM.FF-K2.2011 did not provide relevant KCRV values, the consistency assessment method used in the CCM comparison was also adopted. This ensured the consistency of data among the participating laboratories and served as a reference for future studies.

The chi-squared test for the consistency check was performed using values of relative errors of the transfer standard at each flow rate.

At first the chi-squared value χ^2_{obs} was calculated by

$$\chi^2_{\text{obs}} = \frac{(x_1 - x_{\text{ref}})^2}{u^2(x_1)} + \frac{(x_2 - x_{\text{ref}})^2}{u^2(x_2)} + \ldots\ldots\ldots + \frac{(x_n - x_{\text{ref}})^2}{u^2(x_n)} \qquad \text{(A3-1)}$$

The degrees of freedom v were assigned

$$v = n - 1 \qquad \text{(A3-2)}$$

where n is the number of evaluated laboratories.

The consistency check failed if

$$P_r\{\chi^2_v > \chi^2_{\text{obs}}\} < 0.05 \qquad \text{(A3-3)}$$

The function CHIINV(0.05; v) in Excel was used.

The consistency check failed if CHIINV(0.05; v) $< \chi^2_{\text{obs}}$

If the consistency check passed, then x_{ref} and $U(x_{\text{ref}})$ were accepted as the key comparison reference value x_{ref} and the expanded uncertainty of the key comparison reference value $U(x_{\text{ref}})$, respectively.

If the consistency check failed, then the laboratory with the highest value of $(x_i - x_{\text{ref}})^2/u^2(x_i)$ was excluded for the next round of evaluation and the new reference value y (WME), the new standard uncertainty of the reference value $u(x_{\text{ref}})$ and the chi-squared value χ^2_{obs} was calculated again without the values of the excluded laboratory. The consistency check was calculated again, too. This procedure was repeated until the consistency check passed.

To pass the consistency check, we excluded some laboratory data of the consistency check. After the data points are excluded, we get the reference value of APMP, the standard uncertainty of the reference value $u(x_{\text{ref}})$ and the chi-squared value χ^2_{obs} without the values of excluded laboratory. The reference values and their uncertainties are listed in A3-Table 1.

A3-Table 1 The calculated values of the reference values and their uncertainties of consistency check

Flow Rate	x_{ref}	$u(x_{ref})$	$U(x_{ref})$	Consistency Check	
(kg/min)	(%)	($k = 1$, %)	($k = 2$, %)	CHIINV(0.05,n-1)	Okay! / OOPs
5	0.004	0.014	0.028	9.488	Okay!
10	-0.014	0.014	0.028	11.070	Okay!
20	-0.017	0.011	0.022	12.592	Okay!
30	-0.016	0.010	0.020	12.592	Okay!
40	-0.017	0.010	0.020	12.592	Okay!
50	-0.019	0.010	0.020	12.592	Okay!
60	-0.019	0.010	0.020	12.592	Okay!

Note: At a flow rate of 5 kg/min, excluded data from three laboratories; at a flow rate of 10 kg/min and 50 kg/min, excluded data from two laboratories; for the remaining flow rates, excluded data from one laboratory.

Appendix 4 Comparison criterion pass/fail/inconclusive

The definitions and the results of the presently used comparison criterion pass/fail/inconclusive [5] are listed as follows:

- Criterion A: Participant i passes if $|E_n| \leq 1$ and fails if $|E_n| > 1$.
  - Pass : $|E_n| \leq 1$
  - Fail(X) : $|E_n| > 1$

  Note: In criterion A, the results of a laboratory will be equivalent (passed) if $|E_n| \leq 1$. The laboratory will be determined as not equivalent (failed) if $|E_n| > 1$. But, for values of DoE in the range $1 < |E_n| \leq 1.2$. the "warning level" is defined in "Review Protocol for Fluid Flow Calibration and Measurement Capabilities (CMCs), December 2022, WGFF Guideline" .

- Criterion B:
  - Pass : $|E_n| \leq 1$ and $\left| \dfrac{U_{TS}}{U_{\text{base},i}} \right| \leq 2$
  - Fail(X) : $|E_n| > 1$ and $\left| \dfrac{U_{TS}}{U_{\text{base},i}} \right| \leq 2$
  - ? : Inconclusive

- Criterion D:
  - Pass : $|E_n| \leq 1$ and $P_i \geq 0.35$
  - Fail(X) : $|E_n| > 1$ and $P_i \geq 0.35$
  - ? : Inconclusive

Flow Rate	Lab							
5 kg/min	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
A) $\|E_{ni}\| \leq 1$	Pass	Pass	X	Pass	Pass	Pass	X	X
B) $u_{TS}/u_{\text{base},i} \leq 2$, $\|E_{ni}\| \leq 1$	Pass	Pass	X	Pass	Pass	Pass	X	X
D) $\|E_n\| \leq 1$ and $P_i \geq 0.35$	pass	pass	X	pass	pass	pass	X	X

Flow Rate	Lab							
10 kg/min	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
A) $\|E_{ni}\| \leq 1$	Pass	Pass	Pass	Pass	Pass	Pass	X	X
B) $u_{TS}/u_{\text{base},i} \leq 2$, $\|E_{ni}\| \leq 1$	Pass	Pass	Pass	Pass	Pass	Pass	X	X
D) $\|E_n\| \leq 1$ and $P_i \geq 0.35$	pass	pass	pass	pass	pass	pass	X	X

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Water flow 5 kg/min to 60 kg/min (1st version)

Flow Rate	Lab							
20 kg/min	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
A) $\lvert E_{ni}\rvert \leq 1$	Pass	Pass	Pass	Pass	Pass	Pass	Pass	X
B) $u_{TS}/u_{\text{base},i} \leq 2$, $\lvert E_{ni}\rvert \leq 1$	Pass	Pass	Pass	Pass	Pass	Pass	Pass	X
D) $\lvert E_n\rvert \leq 1$ and $P_i \geq 0.35$	pass	pass	pass	pass	pass	pass	pass	X

Flow Rate	Lab							
30 kg/min	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
A) $\lvert E_{ni}\rvert \leq 1$	Pass	Pass	Pass	Pass	Pass	Pass	Pass	X
B) $u_{TS}/u_{\text{base},i} \leq 2$, $\lvert E_{ni}\rvert \leq 1$	Pass	Pass	Pass	Pass	Pass	Pass	Pass	X
D) $\lvert E_n\rvert \leq 1$ and $P_i \geq 0.35$	pass	pass	pass	pass	pass	pass	pass	X

Flow Rate	Lab							
40 kg/min	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
A) $\lvert E_{ni}\rvert \leq 1$	Pass	Pass	Pass	Pass	Pass	Pass	Pass	X
B) $u_{TS}/u_{\text{base},i} \leq 2$, $\lvert E_{ni}\rvert \leq 1$	Pass	Pass	Pass	Pass	Pass	Pass	Pass	X
D) $\lvert E_n\rvert \leq 1$ and $P_i \geq 0.35$	pass	pass	pass	pass	pass	pass	pass	X

Flow Rate	Lab							
50 kg/min	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
A) $\lvert E_{ni}\rvert \leq 1$	Pass	Pass	Pass	Pass	Pass	X	Pass	X
B) $u_{TS}/u_{\text{base},i} \leq 2$, $\lvert E_{ni}\rvert \leq 1$	Pass	Pass	Pass	Pass	Pass	X	Pass	X
D) $\lvert E_n\rvert \leq 1$ and $P_i \geq 0.35$	pass	pass	pass	pass	pass	X	pass	X

Flow Rate	Lab							
60 kg/min	CMS/ITRI	KRISS	NIMT	NMIJ/AIST	NPLI	NMC A*STAR	NMLPHIL	NMIM
A) $\lvert E_{ni}\rvert \leq 1$	Pass	Pass	Pass	Pass	Pass	Pass	Pass	X
B) $u_{TS}/u_{\text{base},i} \leq 2$, $\lvert E_{ni}\rvert \leq 1$	Pass	Pass	Pass	Pass	Pass	Pass	Pass	X
D) $\lvert E_n\rvert \leq 1$ and $P_i \geq 0.35$	pass	pass	pass	pass	pass	pass	pass	X