ILC Euramet report #1361 Water flow

Bilateral Comparison between Metrologi-LIPI and LNE-CETIAT

Final report

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SOMMAIRE

1. INTRODUCTION

The metrological equivalence of national measurement standards and of calibration certificates issued by national metrology institutes is established by a set of key and supplementary comparisons chosen and organized by the Consultative Committees of the CIPM or by the regional metrology organizations in collaboration with the Consultative Committees.

The comparison is organized within the EU-Indonesia Trade Support Programme II, Sub-project Number APE12-06b, “Improvement of traceability of Metrology and Calibration measurements of RCM- LIPI”.

Two National Metrology Institutes take part in this comparison: LNE through CETIAT as Designated Institute (France) and Metrologi-LIPI (Indonesia).

LNE-CETIAT is acting as the pilot laboratory and in this function is responsible for writing the protocole, evaluating the measurement results and writing the final report.

The comparison will be accomplished in accordance with the EURAMET Guidelines on Conducting Comparisons and BIPM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons.

The comparison was registered by EURAMET as project #1361; artifacts circulation started in March 2015 and was completed in September 2015.

2. ORGANIZATION

2.1. Participants

Table 1 - List of participant’s laboratories and their contacts

Laboratory Code	Contact Person, Laboratory	Phone, email
LNE-CETIAT	Ms Isabelle CARE CETIAT Domaine scientifique de la Doua 25, avenue des Arts 69100 Villeurbanne France	Tel. +33 4 72 44 49 92 e-mail : isabelle.care@cetiat.fr
Metrologi-LIPI	Mr. Bernadus Herdi Sirenden Pusat Penelitian RCM- Lembaga Ilmu Pengetahuan Indonesia (Puslit RCM--LIPI) Kompleks PUSPIPTEK Gedung 420 Tangerang Selatan Banten Indonesia	Tel. +62-21-7560533 e-mail: ben@kim.lipi.go.id

2.2. Schedule

Table 2 - Schedule of the comparison

RMO	Laboratory	Original schedule	Date of measurement	Results received
APMP	RCM- LIPI	April 2015	May 2015	June 2015
EURAMET	LNE-CETIAT	May 2015	July 2015	August 2015
APMP	RCM- LIPI	June 2015	September 2015	October 2015

3. ARTEFACTS

3.1. Description of the artefacts

The travelling standards are two turbines provided by RCM--LIPI covering the range of 0.5 $m^3.h^{-1}$ to 30 $m^3.h^{-1}$ (about 8 $dm^3.min^{-1}$ to 500 $dm^3.min^{-1}$).

Their specifications are as the following:

Table 3 - List of artefacts

Name	FT-12	FT-24
Manufacturer	FTI	FTI
Model	FT-12AEU3-LEA-0	FT-24AEU3-LEA-0
SN	12013288	2407168
Nominal range	7.57 – 75.71 dm^3/min	56.78 – 567.81 dm^3/min
Output	Pulses	Pulses

3.2. Stability of artifacts

As the owner of the artifacts, Metrologi-LIPI has measured the standard according to the technical protocol twice. First, measurements were performed in April (labeled #1), the second measurements were performed in September (labeled #2).

3.2.1. Artifact FT-12

During the measurement at LNE-CETIAT, the ball bearings of the FT-12 turbine broke as shown on the photos below.

Figure 1 - Photos of the broken FT-12 turbine

The comparison was, as a consequence, stopped for this turbine.

3.2.2. Artifact FT-24

Table 4 - Stability measurements done by Metrologi-LIPI on artifact FT-24 at the beginning (#1) and the end (#2) of the comparison

May 2015 (#1)				September 2015 (#2)			
Q_{ref} ($l.min^{-1}$)	K factor ($pulse.l^{-1}$)	s ($pulse.l^{-1}$)	u ($pulse.l^{-1}$)	Q_{ref} ($l.min^{-1}$)	K factor ($pulse.l^{-1}$)	s ($pulse.l^{-1}$)	u ($pulse.l^{-1}$)
58.2	147.4	0.12	0.18	58.1	147.5	0.13	0.19
75.0	147.2	0.07	0.10	75.2	147.2	0.15	0.22
168.8	146.3	0.20	0.31	166.8	146.4	0.12	0.18
332.6	146.0	0.15	0.23	336.4	144.9	0.67	1.02
500.9	145.6	0.45	1.68	512.8	145.2	0.78	1.19

In the table above, the following notations are used:

- Qref, reference flow rate measured by the reference test rig (described in Annex)
- K factor of the turbine, calculated from the measurements of pulses and time
- s, repeatability observed during the tests
- u, standard uncertainty of the K factor

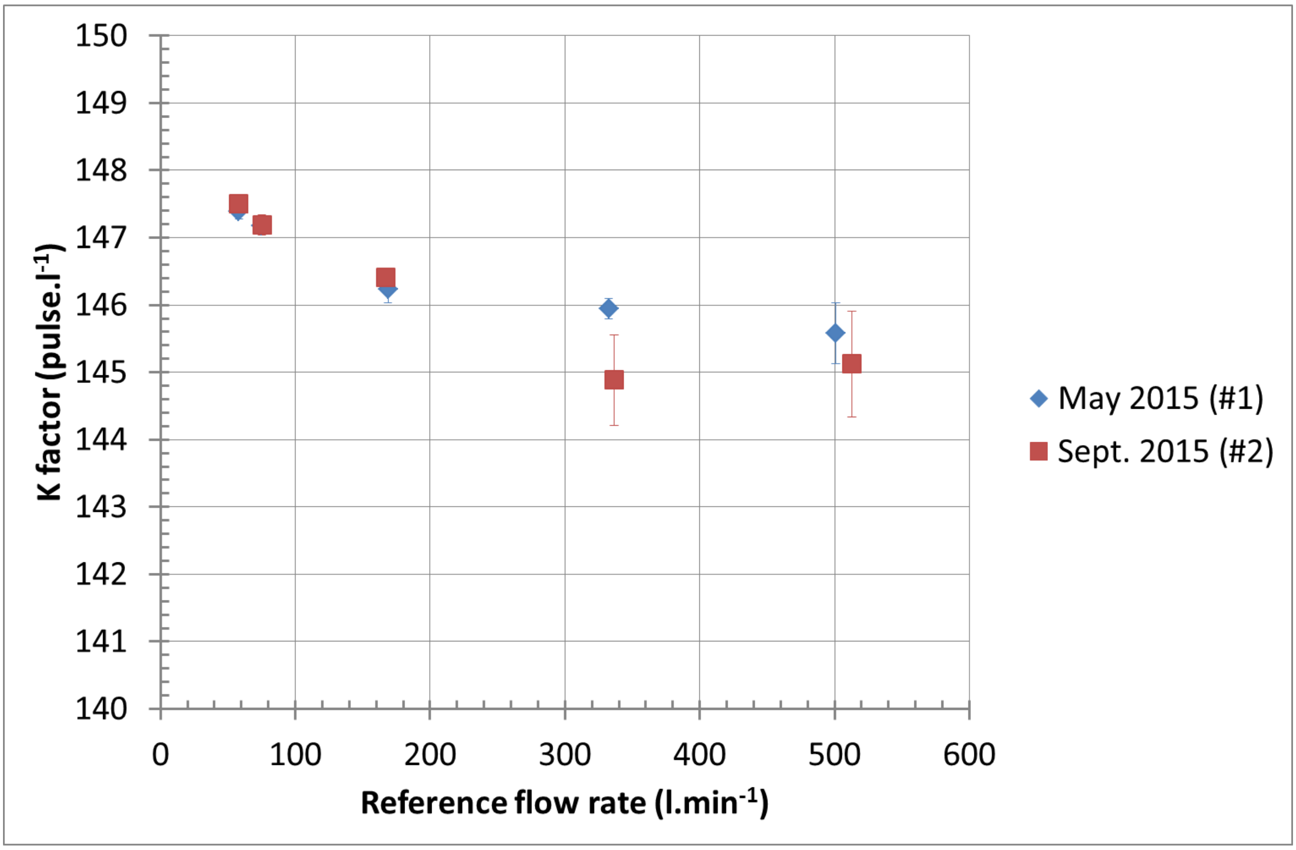


Figure 2 - Stability of the artefact FT-24

The differences between second measurements and first ones are plotted in the figure above, where the errors bars represent the expanded uncertainties (k=2).

For flow rates equal or higher than 332 $l.min^{-1}$, during the final tests, at the end of the comparison, the repeatability of the calibration of the turbine was poor. As a consequence, a deviation is observed on the K-factor value of the turbine for these flow rates. No significant drift is observed within the reported uncertainties at 95% confidence level (k=2) for the flow rates below 170 $l.min^{-1}$.

4. Measurement instructions

The K-factor of the turbines had to be determined under the following conditions:

- Pressure: 1 bar abs
- Water temperature: 23°C ± 2°C
- Ambient temperature: 23°C ± 2°C

at the following flow rates:

- Turbine FT-12
    - 0.5, 1, 2, 3.5 and 4.5 $m^3.h^{-1}$(8.3, 16.7, 33.3, 58.3, 75 $dm^3.min^{-1}$)
- Turbine FT-24
    - 3.5, 4.5, 10, 20 and 30 $m^3.h^{-1}$(58.3, 75, 166.7, 333.3, 500 $dm^3.min^{-1}$)

The measurements were repeated at least five times.

5. Results and analysis

5.1. Results

5.1.1. Artifact FT-12

As already mentioned, this turbine broke during the tests at LNE-CETIAT. The comparison stopped at this stage for this turbine since no data are available.

5.1.2. Artifact FT-24

During the 1st step, Metrologi- LIPI used a RF pickoff to measure the output of the turbine. This RF pickoff wasn't sent with the turbines at LNE-CETIAT.

During the tests at LNE-CETIAT, an amplified pickoff, with a supply voltage of 9V was used instead of the RF one.

During the last step of the comparison, Metrologi-LIPI performed the tests twice. The first time, the RF pickoff was used to estimate the stability of the artefact during the comparison process; the second time, the same amplified pickoff as the one used during the tests at LNE-CETIAT (with the same supply voltage of 9V) was used.

The comparison between the two laboratories is done with the results obtained with the amplified pickoff.

	LNE-CETIAT			Metrologi-LIPI		
Flowrate $l.min^{-1}$	K-factor $pulse.l^{-1}$	σ $pulse.l^{-1}$	U $pulse.l^{-1}$	K-factor $pulse.l^{-1}$	σ $pulse.l^{-1}$	U $pulse.l^{-1}$
58	146.59	0.05	0.16	147.26	0.08	0.21
75	146.47	0.08	0.18	147.14	0.04	0.11
167	146.07	0.03	0.15	145.24	0.79	2.04
333	145.54	0.01	0.15	145.57	0.29	0.75
500	145.91	0.01	0.15	146.16	0.04	0.11

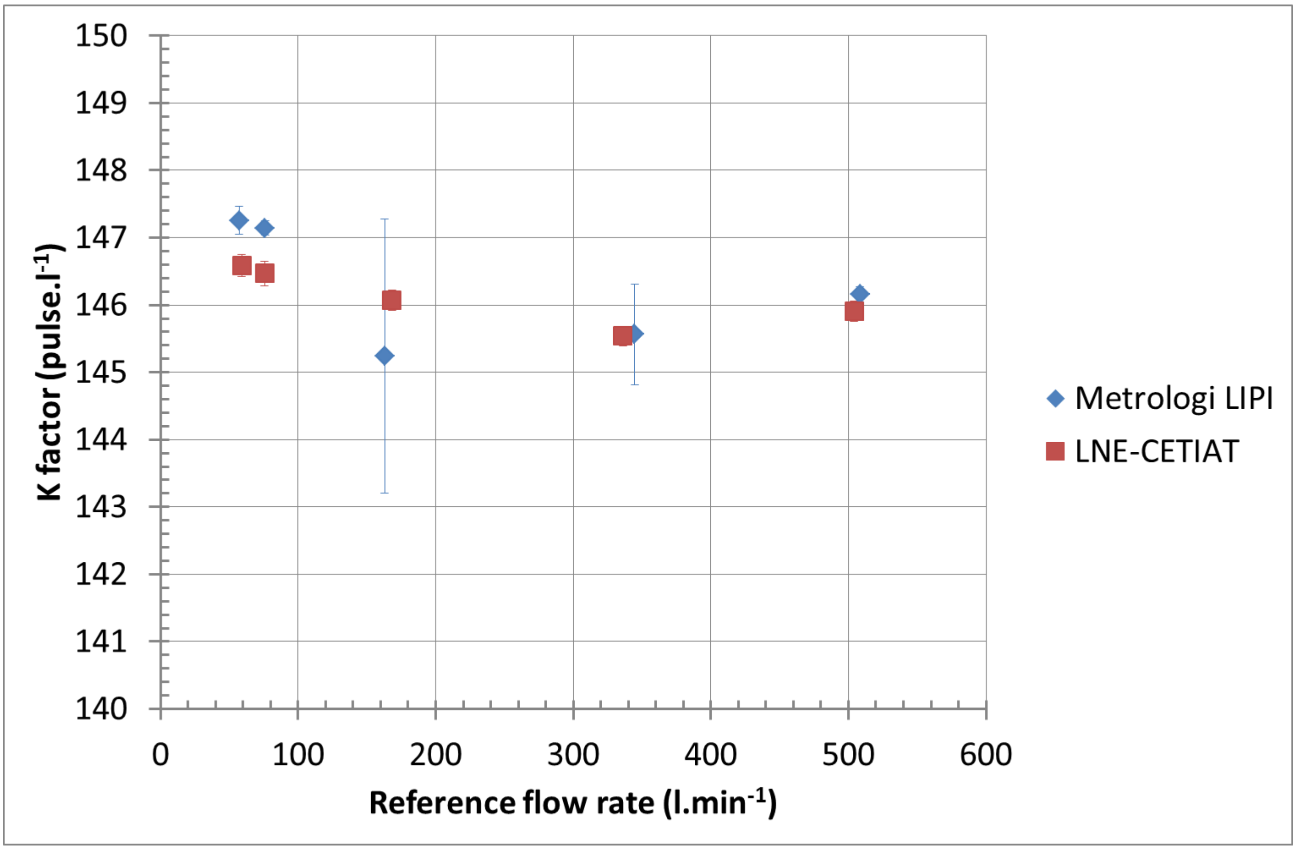


Figure 3 - Comparison of the results for the FT-24 turbine

5.2. Analysis

To evaluate the comparison, the calculation of the normalized error, En, is used with the following equation:

$$En = \frac{X_{lab} - X_{ref}}{\sqrt{U_{lab}^2 + U_{ref}^2}}$$

with:

- X_i, the K-factor obtained by the lab I (in pulse.l^{-1})
- U_i, the expanded uncertainty associated to the X_i value (in pulse.l^{-1})

The following judgement criterion is used:

- $|En| \leq 1$, pass
- $|En| > 1$, fail

Table 1 - Comparison results for te FT-24 turbine

	LNE-CETIAT		RCM- LIPI			
Flowrate l.min^{-1}	K-factor pulse.l^{-1}	U pulse.l^{-1}	K-factor pulse.l^{-1}	U pulse.l^{-1}	En -	Result
58	146.59	0.16	147.26	0.21	2.5	Fail
75	146.47	0.18	147.14	0.11	3.2	Fail
167	146.07	0.15	145.24	2.04	-0.4	Pass
333	145.54	0.15	145.57	0.75	-	-
500	145.91	0.15	146.16	0.11	-	-

The En criterion fails for two of the three points. The third one passes because the expanded uncertainty of Metrologi-LIPI is higher.

5.3. Discussion of results and conclusion of EURAMET 1361 bilateral comparison

From the results, this bilateral comparison is not successful.

The comparison with the FT-12 turbine was not completed because of the breakage of the turbine during the comparison.

Because of some drift in the K-factor value for the FT-24 turbine, the measurements at flow rates larger than 170 l.min^{-1} cannot be used. At lower flow rates, the En criterion failed. The results are not consistent within the associated uncertainties. Metrologi- LIPI has to identify the causes of this discrepancy.

5.4. Metrologi-LIPI comments

The result from bilateral comparison between LNE-CETIAT and Metrologi-LIPI shows bad result, with only one point passes with very high uncertainty. This result gives Metrologi-LIPI a reason to examine the performance of Piston-Prover.

The stability test of FT-24 turbine shows there is a significant drift for flow rate higher than 332 $l.min^{-1}$. After having carefully examined the test data, it was found that for this flow rate, the time to take data is lower than16 seconds, since the elementary volume of the Piston-Prover is only 92.15 liters. Metrologi-LIPI suspected that this duration is not enough to reach a stabilized flow. This instability was detected by the turbine and produced a K-factor drift. For this reason, it is suspected that the Piston-Prover performance is instable for flow rates higher than 332 $l.min^{-1}$.

The flow rates below 332 $l.min^{-1}$ show consistent result of K-factor, but fail to match with LNE-CETIAT results. Metrologi-LIPI examined the method to determine the elementary volume of the Piston-Prover. It was found that there was a mistake in the calculation formula of the density of the flowing water. With this mistake the elementary volume of the Piston Prover was 92.15 liters. This value was used to determine the turbine K-factor.

After having corrected the density formula using the appropriate Tanaka formula, it was found that the elementary volume of the Piston Prover became 92.61 liters. This new value was used to recalculate the K-factor of the turbine. The results are presented below and show that the En value is lower than 1.

Table 2 – Comparison results for the FT-24 turbine after METROLOGI-LIPI included the underestimated uncertainty contribution

	LNE-CETIAT		METROLOGI-LIPI		
Flowrate $l.min^{-1}$	K-factor $pulse.l^{-1}$	U $pulse.l^{-1}$	K-factor $pulse.l^{-1}$	U $pulse.l^{-1}$	En -
58	146.59	0.16	146.5	0.21	0.26
75	146.47	0.18	146.4	0.11	0.29
167	146.07	0.15	144.5	2.03	0.77

With the comparison results, new CMC will be issued

Table 2 – New CMC for METROLOGI-LIPI Liquid Flow Measurement

Calibration or Measurement Service			Measurand Level or Range			Measurement Conditions/Independent Variable		Expanded Uncertainty			Reference Standard used in calibration		List of Comparisons supporting this measurement/ calibration service
Quantity/ Class	Instrument or Artifact	Instrument Type or Method	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Standard	Source of traceability	
Water Flow	Turbine	Volumetric	4	167	dm^3/min	Ambient Temperature	(21.0-26.0) ºC	1.4	%	2	Piston Prover	METROLOGI-LIPI	EURAMET-1361_FLOW
Water Flow	Positive Displacement	Volumetric	4	167	dm^3/min	Ambient Temperature	(21.0-26.0) ºC	0.8	%	2	Piston Prover	METROLOGI-LIPI	EURAMET-1361_FLOW
Water Flow	Ultrasonic	Volumetric	4	167	dm^3/min	Ambient Temperature	(21.0-26.0) ºC	5.0	%	2	Piston Prover	METROLOGI-LIPI	EURAMET-1361_FLOW
Water Flow	Rotameter	Volumetric	4	167	dm^3/min	Ambient Temperature	(21.0-26.0) ºC	1.2	%	2	Piston Prover	METROLOGI-LIPI	EURAMET-1361_FLOW
Water Flow	Electromagnetic	Comparison	4	167	dm^3/min			1.6	%	2	Turbine Flowmeter	METROLOGI-LIPI	EURAMET-1361_FLOW

Annexe A

DESCRITION OF THE TEST RIGS OF THE LABORATORIES

A.1. METROLOGI- LIPI

The calibration method pertains to any type flow meter in any liquid medium, which indicates unit of volume and/or volumetric flow rate. In measuring range (3.7 – 1365.9)lpm, with best measurement capability 0.12% at actual conditions of calibration.

For laboratory calibration, the temperature of the instruments, master meter and test meter, or the ambient temperature, should be in between (21,0 - 26,0)"C during calibration.

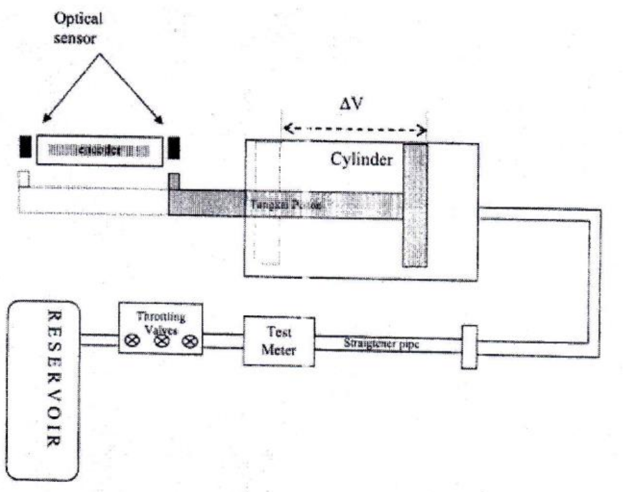


Figure 4 – Schematic diagram of the facility

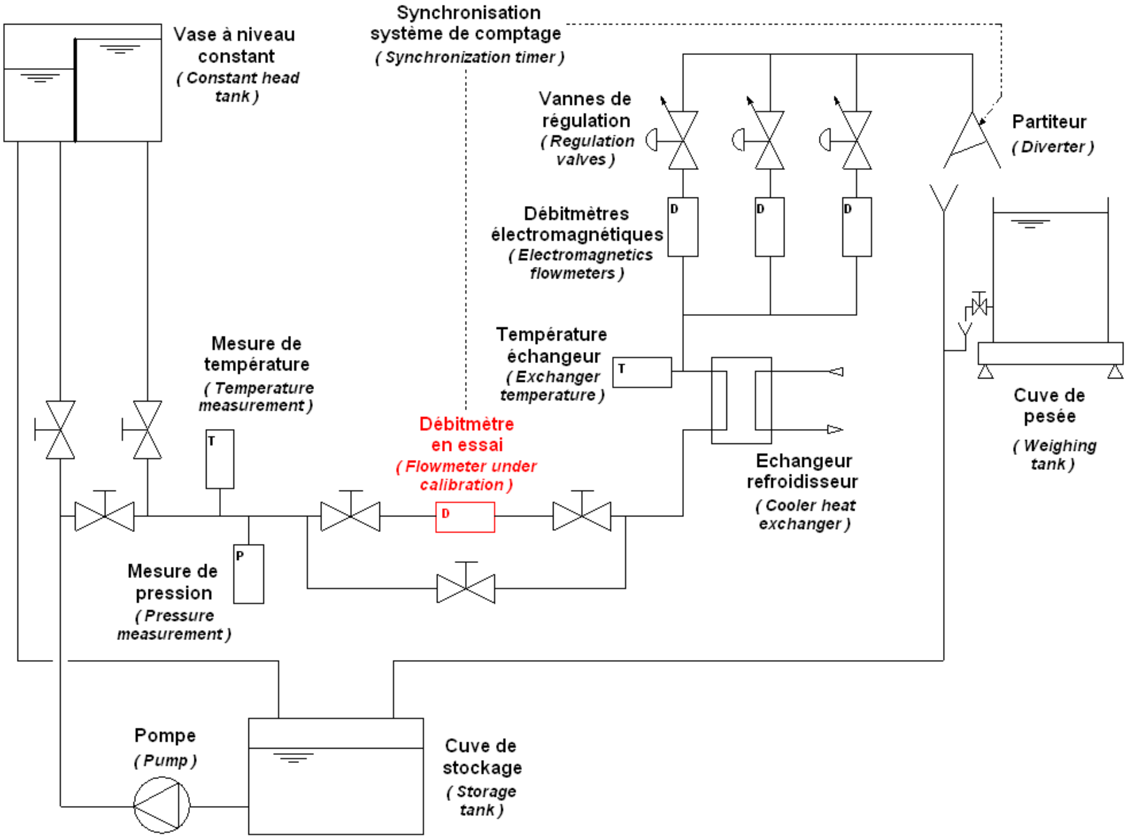
A.2. LNE-CETIAT

CETIAT facility was created in 1980 for industrial purpose and became the French designated institute for water flow measurements in 2002 (LNE – CETIAT). This gravimetric test rig uses a start/stop method to measure the water flow reference. Calibration can be done on delivered mass or mass flow measurements using three Sartorius balances. Delivered volume and volume flow rates can also be obtained using the same protocol and water density. One of the main advantages of this calibration rig is the possibility to change the temperature of water easily.

The temperature regulated water in the storage tank is sent to the constant head tank which discharges at constant pressure (1 bar) through the flow meter under calibration. The liquid flows permanently through the flowmeter and is switched either to the weighing tank or to the storage tank. This switching is controlled by an electronic circuit which detects electrical pulses sent by the flowmeter.

A first pulse generated by the flowmeter control the diverter switching to the weighing tank. At the moment of switch, a stopwatch and an external electronic counter used to obtain the number of pulses totalized are started simultaneously. After a certain amount of pulses set on the external counter and which corresponds to the filling of the weighing tank, the diverter switches back to the storage tank and both the stopwatch and the counter stop.

Flow rate	0.008 $m^3.h^{-1}$ to 36 $m^3.h^{-1}$
Fluid	Water
Pipe diameter	DN 1 to DN 100
Pressure range	1 bar to 4 bar
Water temperature	15°C to 90°C
Method of measurement	Gravimetric
Expanded uncertainty	0.05 % to 0.16 %


Synchronisation
système de comptage
(Synchronization timer)
Vase à niveau
constant
(Constant head
tank)
Vannes de
régulation
(Regulation
valves)
Partiteur
(Diverter)
Débitmètres
électromagnétiques
(Electromagnetics
flowmeters)
D
Température
échangeur
(Exchanger
temperature)
T
Mesure de
température
(Temperature
measurement)
Cuve de
pesée
(Weighing
tank)
Débitmètre
en essai
(Flowmeter under
calibration)
Echangeur
refroidisseur
(Cooler heat
exchanger)
Mesure de
pression
(Pressure
measurement)
P
Pompe
(Pump)
Cuve de
stockage
(Storage
tank)

Annexe B

UNCERTAINTY BUDGET FOR EACH LABORATORY

B.1. METROLOGI-LIPI

LIPI

Lembaga Ilmu Pengetahuan Indonesia
Indonesian Institute of Sciences
Pusat Penelitian Metrologi
Research Center for Metrology
Bidang Metrologi Mekanik
Mechanical Metrology Division

Auxiliary Technical Quality Document

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Disahkan: *Authorization:*	Nama: Ghufron Zaid Posisi: Kepala Bidang Metrologi Mekanik	Tanda tangan: *Signature:*

Budget ketidakpastian pengukuran volume dasar actual
Uncertainty budget of actual basic volume

Quantity : liquid flow rate
Type of Artfact : flow rate measuring system
Refference Standard : volumetric prover system

Mathematical Model :
$$\Delta V_T = \Delta V_p = \frac{\Delta V_{p20}}{\left[1 - \alpha_c\left(T_p - 20\ °C\right)\right]}$$

Uncertainty equation :
$$u(\Delta V_P) = \sqrt{\left(\frac{\partial \Delta V_P(\Delta V_{20})}{\partial \Delta V_{20}}.u(\Delta V_{20})\right)^2 + \left(\frac{\partial \Delta V_P(T_P)}{\partial T_P}.u(T_P)\right)^2}$$

Uncertainty source	Unit	Distr.	Symbol	U	Divisor	vi	ui	ci	ci.ui	(ci.ui)²	(ci.ui)/vi
unc.due to basic volume at standard condition	dm^3	Normal	ΔV_p	0,03	2,1	21	$1,3 \times 10^{-2}$	1,0	$1,3 \times 10^{-2}$	$1,6 \times 10^{-4}$	$1,2 \times 10^{-9}$
unc.due to piston temperature cert	°C	Normal	T_p	0,11	2,0	60	$5,5 \times 10^{-2}$	0,005	$2,6 \times 10^{-4}$	$6,9 \times 10^{-8}$	$8,0 \times 10^{-17}$
Sums										$1,6 \times 10^{-4}$	$1,2 \times 10^{-9}$
Combined uncertainty										0,01	
Effective degree of freedom, veff										22	
Coverage factor for CL = 95%										2,1	
Expanded uncertainty, U (in dm^3)										0,03	

Budget ketidakpastian pengukuran koreksi volume tipe B
Uncertainty budget of measurement of volume correction type B

Uncertainty of flowmeter

Quantity : liquid flow rate
Type of Artfact : flow rate measuring system
Refference Standard : volumetric prover system

Mathematical Model : $K_V = \Delta V_T - \Delta V_I$

Uncertainty equation : $$u(K_V) = \sqrt{\left(\frac{\partial K_V(\Delta V_T)}{\partial \Delta V_T}.u(\Delta V_T)\right)^2 + \left(\frac{\partial K_V(\Delta V_{IR})}{\partial \Delta V_{IR}}.u(\Delta V_{IR})\right)^2}$$

Uncertainty source	Unit	Distr.	Symbol	U	Divisor	vi	ui	ci	ci.ui	(ci.ui)²	(ci.ui)/vi
unc.due to actual basic volume	dm^3	normal	ΔV_T	0,03	2,1	22	$1,3 \times 10^{-2}$	1	$1,3 \times 10^{-2}$	$1,6 \times 10^{-4}$	$1,2 \times 10^{-9}$
unc.due to UUT indication of volume	dm^3	rectanggular	ΔV_{IR}	0,01	1,7	1×10^{10}	$2,9 \times 10^{-3}$	1	$2,9 \times 10^{-3}$	$8,3 \times 10^{-6}$	$6,9 \times 10^{-21}$
Sums										$1,7 \times 10^{-4}$	$1,2 \times 10^{-9}$
Combined uncertainty										0,01	
Effective degree of freedom, veff										23	
Coverage factor for CL = 95%										2,1	
Expanded uncertainty, U (in dm^3)										0,03	

Budget ketidakpastian terbentang pengukuran koreksi volume
Extended Uncertainty budget of measurement of volume correction

Uncertainty of Flowmeter

Quantity : liquid flow rate
Type of Artfact : flow rate measuring system
Refference Standard : volumetric prover system

Mathematical Model : $\overline{K_V} = \frac{\sum_{i=1}^{n} K_{Vi}}{n}$

Uncertainty equation : $u(\overline{K_V}) = \sqrt{(u_A(\overline{K_V}))^2 + (u(K_V))^2}$

Uncertainty source	Unit	Distr.	Symbol	U	Divisor	vi	ui	ci	ci.ui	(ci.ui)²	(ci.ui)/vi
unc.due to volume correction type A	dm^3	student T	K_V	0,06	2,0	11	$3{,}04 \times 10^{-2}$	1	$3{,}04 \times 10^{-2}$	$9{,}3 \times 10^{-4}$	$7{,}8 \times 10^{-8}$
unc.due to volume correction type B	dm^3	Normal	K_V	0,03	2,1	23	$1{,}3 \times 10^{-2}$	1	$1{,}3 \times 10^{-2}$	$1{,}7 \times 10^{-4}$	$1{,}2 \times 10^{-9}$
Sums										$1{,}1 \times 10^{-3}$	$7{,}9 \times 10^{-8}$
Combined uncertainty										0,03	
Effective degree of freedom, veff										15	
Coverage factor for CL = 95%										2,1	
Expanded uncertainty, U (in dm^3)										0,07	

Budget ketidakpastian laju alir actual
Uncertainty budget of actual flow rate

Uncertainty of Flowmeter

Quantity : liquid flow rate
Type of Artfact : flow rate measuring system
Refference Standard : volumetric prover system

Mathematical Model : $Q_T = \frac{\Delta V_T}{\Delta t}$

Uncertainty equation : $u(Q_T) = \sqrt{\left(\frac{\partial Q_T(\Delta V_T)}{\partial \Delta V_T}.u(\Delta V_T)\right)^2 + \left(\frac{\partial Q_T(\Delta t)}{\partial \Delta t}.u(\Delta t)\right)^2}$

Uncertainty source	Unit	Distr.	Symbol	U	Divisor	vi	ui	ci	ci.ui	(ci.ui)²	(ci.ui)/vi
unc.due to timer	s	Normal	Δt	0,06	2,5	63	$2,5 \times 10^{-2}$	0,01	$3,3 \times 10^{-4}$	$1,1 \times 10^{-7}$	$1,9 \times 10^{-16}$
unc.due to Actual Volume	dm^3	Normal	ΔVact	0,03	2,1	21	$1,3 \times 10^{-2}$	3,0	$3,8 \times 10^{-2}$	$1,5 \times 10^{-3}$	$1,03 \times 10^{-7}$
Sums										$1,5 \times 10^{-3}$	$1,03 \times 10^{-7}$
Combined uncertainty										0,04	
Effective degree of freedom, veff										21	
Coverage factor for CL = 95%										2,1	
Expanded uncertainty, U (in dm^3/min)										0,08	

Budget ketidakpastian pengukuran koreksi laju alir tipe B
Uncertainty budget of measurement of flow rate correction type B

Uncertainty of flowmeter

Quantity : liquid flow rate
Type of Artfact : flow rate measuring system
Refference Standard : volumetric prover system
Mathematical Model : $K_Q = Q_T - Q_I$

Uncertainty equation : $u(K_Q) = \sqrt{\left(\frac{\partial K_Q(Q_T)}{\partial Q_T}.u(Q_T)\right)^2 + \left(\frac{\partial K_Q(Q_{IR})}{\partial Q_{IR}}.u(Q_{IR})\right)^2}$

Uncertainty source	Unit	Distr.	Symbol	U	Divisor	vi	ui	ci	ci.ui	$(ci.ui)^2$	(ci.ui)/vi
unc.due to actual flow rate	dm^3/min	normal	Q_T	0,08	2,1	21	$3,8 \times 10^{-2}$	1	$3,8 \times 10^{-2}$	$1,5 \times 10^{-3}$	$1,03 \times 10^{-7}$
unc.due to UUT indication of flow	dm^3/min	rectanggular	Q_{IR}	0,01	1,7	1×10^{10}	$2,9 \times 10^{-3}$	1	$2,9 \times 10^{-3}$	$8,3 \times 10^{-6}$	$6,9 \times 10^{-21}$
Sums										$1,5 \times 10^{-3}$	$1,01 \times 10^{-7}$
Combined uncertainty										0,04	
Effective degree of freedom, veff										21	
Coverage factor for CL = 95%										2,1	
Expanded uncertainty, U (in dm^3)										0,08	

Budget ketidakpastian terbentang pengukuran koreksi laju alir
Extended Uncertainty budget of measurement of flow rate correction

Uncertainty of Flowmeter

Quantity : liquid flow rate
Type of Artfact : flow rate measuring system
Refference Standard : volumetric prover system

Mathematical Model :

$$\overline{K_Q} = \frac{\sum_{i=1}^{n} K_{Qi}}{n}$$

Uncertainty equation :

$$u(\overline{K_Q}) = \sqrt{\left(u_A(\overline{K_Q})\right)^2 + \left(u(K_Q)\right)^2}$$

Uncertainty source	Unit	Distr.	Symbol	U	Divisor	vi	ui	ci	ci.ui	(ci.ui)²	(ci.ui)/vi
unc.due to flow rate correction type A	dm^3	student T	K_Q	0,002	2,0	12	$9,2 \times 10^{-4}$	1	$9,2 \times 10^{-4}$	$8,5 \times 10^{-7}$	$6,01 \times 10^{-14}$
unc.due to flow rate correction type B	dm^3	Normal	K_Q	0,08	2,1	21	$3,8 \times 10^{-2}$	1	$3,9 \times 10^{-2}$	$1,5 \times 10^{-3}$	$1,03 \times 10^{-7}$
Sums										$1,5 \times 10^{-3}$	$1,03 \times 10^{-7}$
Combined uncertainty										0,04	
Effective degree of freedom, veff										21	
Coverage factor for CL = 95%										2,1	
Expanded uncertainty, U (in dm^3)										0,08	

Budget ketidakpastian pengukuran K-faktor tipe B
Uncertainty budget of measurement of K-factor type B

Uncertainty of Flowmeter

Quantity : liquid flow rate
Type of Artfact : flow rate measuring system
Refference Standard : volumetric prover system

Mathematical Model : $$K_f = \frac{N_T}{\Delta V_T}$$

Uncertainty equation : $$u(K_f) = \sqrt{\left(\frac{\partial K_f(\Delta V_T)}{\partial \Delta V_T}.u(\Delta V_T)\right)^2 + \left(\frac{\partial K_f(N_{TR})}{\partial N_{TR}}.u(N_{TR})\right)^2}$$

Uncertainty source	Unit	Distr.	Symbol	U	Divisor	vi	ui	ci	ci.ui	(ci.ui)²	(ci.ui)/vi
unc.due to actual volume	dm³	normal	ΔV_T	0,03	2,1	22	$1,3 \times 10^{-2}$	1	$1,3 \times 10^{-2}$	$1,6 \times 10^{-4}$	$1,2 \times 10^{-9}$
unc.due to UUT indication of pulse	pulse	rectangular	N_{TR}	0,5	1,7	1×10^{10}	$2,9 \times 10^{-1}$	17	4,9	24	$5,8 \times 10^{-8}$
Sums										24	$5,8 \times 10^{-8}$
Combined uncertainty										4,9	
Effective degree of freedom, veff										1×10^{10}	
Coverage factor for CL = 95%										2,0	
Expanded uncertainty, U (in pulse/dm³)										9,6	

Budget ketidakpastian terbentang pengukuran K-faktor
Extended Uncertainty budget of measurement of K-factor

Uncertainty of Flowmter

Quantity : liquid flow rate
Type of Artfact : flow rate measuring system
Refference Standard : volumetric prover system

Mathematical Model :

$$\overline{K_f} = \frac{\sum_{i=1}^{n} K_{fi}}{n}$$

Uncertainty equation :

$$u\left(\overline{K_f}\right) = \sqrt{\left(u_A\left(\overline{K_f}\right)\right)^2 + \left(u\left(K_f\right)\right)^2}$$

Uncertainty source	Unit	Distr.	Symbol	U	Divisor	vi	ui	ci	ci.ui	(ci.ui)²	(ci.ui)/vi
unc.due to k-factor type A	pulse/dm³	student T	K_f	1,0	2,0	12,0	0,5	1	0,5	0,25	$5{,}2 \times 10^{-3}$
unc.due to k-factor type B	pulse/dm³	Normal	K_f	9,6	2,0	1×10^{10}	4,9	1	4,9	24	$5{,}8 \times 10^{-8}$
Sums										24	$5{,}2 \times 10^{-2}$
Combined uncertainty										4,9	
Effective degree of freedom, veff										1×10^5	
Coverage factor for CL = 95%										2,0	
Expanded uncertainty, U (in pulse/dm³)										9,7	

B.2. LNE-CETIAT

Hot water (30°C < t ≤ 90°C)

Quantity	Standard uncertainty (in quantity unit)
K	$5{,}8.10^{-5}$
M [kg]	$(2{,}55.10^{-5}+6{,}3.10^{-6}.M^2/\tau^2+8{,}4.10^{-8}.M^2)^{1/2}$
ρ [kg.m^{-3}]	0,35
τ [s]	$8{,}5.10^{-4}$

Cold water (15°C ≤ t ≤ 30°C)

Quantity	Standard uncertainty (in quantity unit)
K	$5{,}8.10^{-5}$
M [kg]	$(2{,}55.10^{-5}+6{,}3.10^{-6}.M^2/\tau^2)^{1/2}$
ρ [kg.m^{-3}]	0,35
τ [s]	$8{,}5.10^{-4}$

8 kg.h-1 ≤ qm ≤ 30 kg.h-1

Water temperature	Reference quantity	Accreditated uncertainty (k=2)
15°C ≤ t ≤ 30°C (cold water)	Volume flow rate	$1{,}7.10^{-3}.q_v$
	Mass flow rate	$1{,}5.10^{-3}.q_m$
	Dynamic volume	$1{,}7.10^{-3}.V'$
	Dynamic Mass	$1{,}5.10^{-3}.M'$
30°C < t ≤ 90°C (hot water)	Volume flow rate	$1{,}7.10^{-3}.q_v$
	Mass flow rate	$1{,}5.10^{-3}.q_m$
	Dynamic volume	$1{,}7.10^{-3}.V'$
	Dynamic Mass	$1{,}5.10^{-3}.M'$

$30\ kg.h^{-1} < q_m \leq 75\ kg.h^{-1}$

Water temperature	Reference quantity	Accreditated uncertainty (k=2)
15°C ≤ t ≤ 30°C (cold water)	Volume flow rate	$1{,}3.10^{-3}.q_v$
	Mass flow rate	$5.10^{-4}.q_m$
	Dynamic volume	$1{,}3.10^{-3}.V'$
	Dynamic Mass	$5.10^{-4}.M'$
30°C < t ≤ 90°C (hot water)	Volume flow rate	$1{,}3.10^{-3}.q_v$
	Mass flow rate	$1.10^{-3}.q_m$
	Dynamic volume	$1{,}3.10^{-3}.V'$
	Dynamic Mass	$1.10^{-3}.M'$

$75\ kg.h^{-1} < q_m \leq 36000\ kg.h^{-1}$

Water temperature	Reference quantity	Accreditated uncertainty (k=2)
15°C ≤ t ≤ 30°C (cold water)	Volume flow rate	$1.10^{-3}.q_v$
	Mass flow rate	$5.10^{-4}.q_m$
	Dynamic volume	$1.10^{-3}.V'$
	Dynamic Mass	$5.10^{-4}.M'$
30°C < t ≤ 90°C (hot water)	Volume flow rate	$1.10^{-3}.q_v$
	Mass flow rate	$8.10^{-4}.q_m$
	Dynamic volume	$1.10^{-3}.V'$
	Dynamic Mass	$8.10^{-4}.M'$