The Case Study of Water Flow Measurement Comparison in the Range of 12-120 L/min

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Abstract. Nowadays, the water flow measurement involves in our daily life such as water meters for tap water, hydrocarbon flow meters at petrol stations, etc. Those flow meters have to be calibrated by higher accuracy equipments with the accredited calibration laboratory. Therefore the accreditation laboratory has to complete the measurement comparison with reliable laboratory or the National Institute of Metrology (Thailand), NIMT which confirms the traceability chain and the measurement capability. However, the liquid primary standard at NIMT applies volumetric principle to measure flow rate which differs from other laboratories using gravimetric method. Thus, the case study of water flow measurement comparison has been done to verify the possibility of compatibility of those two methods. With high accuracy and good repeatability, the Coriolis mass flow meter was used as the transfer standard in the range of 12 – 120 litre per minute and 12 – 120 kilogram per minute. The comparison result of both measurement principles are considered by using the degree of equivalence, E_n ratio. The result shows that E_n ratio is less than 1 which means that both principles are agreed.

1. Introduction

The liquid primary flow standard can be defined by two principles; gravimetric and volumetric measurements. The gravimetric measurements have been widely used in many calibration laboratories in Thailand as the primary standard of liquid flow measurement. In fact, the volumetric measurements can be also used as the primary standard. One of the primary standards using volumetric principle is the Piston prover equipment. The National Institute of Metrology (Thailand), NIMT, has been used the piston prover system as primary standard since 1998 which has been accredited since 2011.

As mention above, the primary liquid flow system of NIMT uses different method from other calibration laboratories. To demonstrate the compatibility and possibility of two standard systems, the case study of water flow measurement comparison in the range of 12-120 litre/minute was organized in Thailand. Five laboratories including NIMT, Endress+Hauser (Thailand) Ltd, Miracle international Technology Co., Ltd, Science Magic Grow Co., Ltd. and Flowlab & Service co.,Ltd. were participated in this study by using the Coriolis meter as the transfer standard.

A protocol [1] was prepared by NIMT and approved by participants. The calibration results obtained from each participating institutes have been submitted and analyzed by NIMT.

2. Theory

Primary flow measurement standards are established without relation to another measurement standard for a quantity of the same kind or basically in the same unit. In fact, the primary flow standards are traceable to mass, length and time in International System of Units, SI unit. Thus, the primary flow standard can be defined by two methods as the measured mass in the collection tank (gravimetric method) or volume in the cylinder (volumetric method). However, the required mass or volume quantity can be calculated from the fluid density.

The choice of measuring method depends on the basis of the flow meter output and fluid media. Some flow meters have a low response time that cannot perform with the volumetric system by using the piston prover because of the limited volume. In general, the gravimetric systems are not suitable to change the fluid media from one to another.

2.1 Volumetric liquid flow system

The primary liquid flow standards with the volumetric methods normally have three systems such as the volumetric tank, pipe prover and piston prover [2]. One of the famous primary flow standards using in the NMIs as well as NIMT is piston prover shown in Figure 1 (a).

The liquid media is collected in the cylinder with a known pulse per volume. The piston is pushed by the compressed air with a known distance as pulse by observing the linear scale. The temperature of fluid media and cylinder should be collected in order to compensate the temperature effect on the piston-cylinder material.

$$q_v = \frac{N_e \times \left(1 + 2\alpha_{PT}\left(T_p - T_r\right)\right)}{t \cdot K_p} \tag{1}$$

where N_e is the number of pulse of linear scale, α_{PT} is the thermal expansion coefficient of the piston-cylinder material, T_p and T_r are the temperature of cylinder and the reference temperature respectively, K_p is the *K*-factor of Piston prover from the calibration certificate and *t* is the time of calibration while collecting the volume.

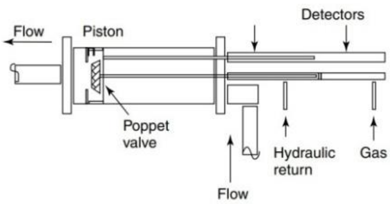
2.2 Gravimetric liquid flow system

The most famous primary flow standard is gravimetric system shown in Figure 1 (b). The liquid flowrate pass through the flow splitter plate and go to the collection tank by using the pump or overhead tank. The time is collected while the diverter changes the direction of flow splitter plate to the collection tank and time is stoped when the direction of the flow splitter plate is in bypass mode. The collection tank is on the weight balance while collecting the fluid media. The tank is weighed and the weight of the collected fluid is known.

$$q_m = \frac{W}{t} \cdot \left\{1 + \rho_a \cdot \left(\frac{1}{\rho_f} - \frac{1}{\rho_w}\right)\right\} \tag{4}$$

where W is the measured weight, ρ_a is the density of air, ρ_f is the density of the fluid, and ρ_w is the density of the calibration weights.

(a) (b)



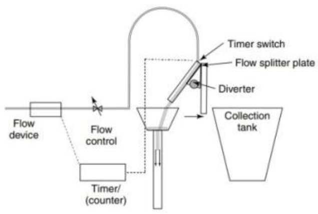


Figure 1. Diagram of Piston prover (a) and gravimetric system (b)

3. Transfer standard and measurement procedures

3.1 Transfer standard

The transfer standard (TS) in this study was the Coriolis mass flow meter model 83F25 8CA9/0 with maximum flow rate 12500 kg/h and accuracy ±0.10% of mass flow rate. The TS was manufactured by Micro Motion meter made by Micro Motion [3]. The Coriolis mass flow meter was widely used in many industries as well as in the laboratories because of no effect of flow profile, very high accuracy, good repeatability and not require the inlet and outlet distances. The advantages of Coriolis mass flow meter are self-evident because this measuring principle is not affected by physical factors such as conductivity, pressure, temperature, density and viscosity. Therefore, in this study can eliminate the effects on those TS.

3.2 Measurement procedures

The comparison between two methods, volumetric and gravimetric flow rate measurement, was consisted of six measurement points which are one nominal Reynolds number and five nominal flow rates. The volumetric flow rate was measured at (12, 30, 60, 90 and 120) litre/minute and Reynolds number at 58300. The mass flow rate was measured at (12, 30, 60, 90 and 120) kg/minute and Reynolds number at 58300. The measurement in each flow rate should be repeated five times. The set flow rate for each measurement should not deviate from nominal value more than ± 3% in order to eliminate the linearity of TS. The temperature of liquid while performing the measurement should be (20-30)±2°C.

4. Calculations of degree of equivalence

The results of the comparison are determined by the degree of equivalence, E_n, as the following [4]

$$E_n = \frac{|E_{Lab} - E_{nimt}|}{\sqrt{U_{Lab}^2 + U_{nimt}^2}} \quad (3)$$

where E are the error term from participating laboratories and NIMT respectively. U are the expanded uncertainty of TS from participating laboratories and NIMT respectively. The measurement is satisfactory if $|E_n \leq|$ 1. The uncertainty state above is evaluated according to JCGM guideline [5].

4. Results of comparisons

Five calibration laboratories participated in this comparison including NIMT. The details of flow system for each participant are shown in Table 1. The comparison was performed in the STAR type (NIMT1 > lab1 > NIMT2 > Lab2 > NIMT3 > Lab3 > NIMT4 > Lab4 > NIMT5), therefore the transfer standard was calibrated at NIMT five times. The results showed that the long-term instability of the transfer standard was significant for all flowrates except low flowrate, 12 litre/minute. This effect possibly caused by the performance of the transfer standard at the low flowrate. Therefore, the flowrate at 12 litre/minute was not considered in this comparison.

4.1 Volumetric flowrate calibration results

Due to the effect of temperature on the fluid density, the correction of the temperature on the fluid shall be made before comparing the results among participants. However, after correcting the temperature, the results show that the effect of temperature can be negligible when the transfer standard was measured in the volumetric measurement. The temperature reference for this comparison was 30°C.

4.2 Mass flowrate calibration results

The liquid primary flow standard of the National Institute of Metrology (Thailand), NIMT is the volumetric system. Therefore, the mass flowrate can be calculated by volumetric flowrate multiply by liquid density.

The comparison results between participants and NIMT for the volume and mass flowrates are shown in Figures 2 (a) and (b) respectively.

Table 1. Details of flow system for each participant

Lab.	Method	Flow range	Capability
E&H	Comparative	(100-70000) kg/h	-
MIT	Gravimetric	(200 – 70000) kg/h	0.040%
SMG	Gravimetric	(1.39 – 31670) g/s	0.080%
Flowlab	Gravimetric	(54 – 300000) kg/h	(0.014-0.04)%
NIMT	Volumetric	(0.2-150) litre/min	0.075%

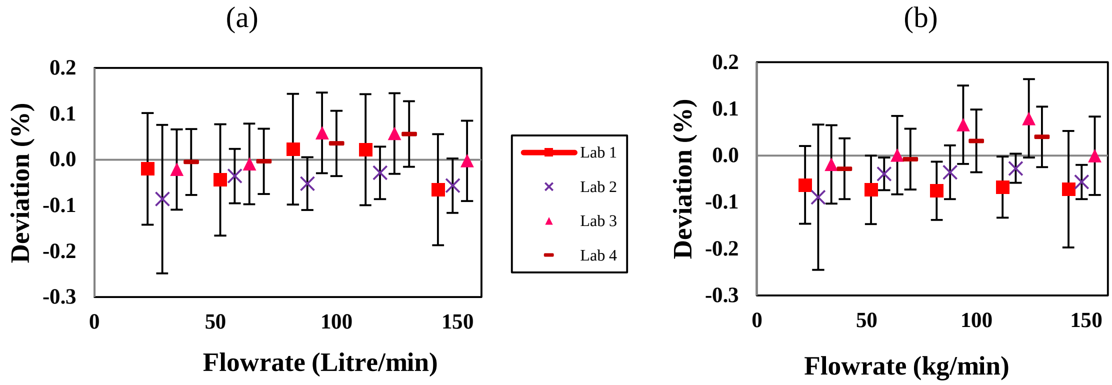


Figure 2. Deviation of the volume and mass flowrate results for participants compared with NIMT results.

4.3 Degree of equivalence (E_n ratio)

The degree of equivalent of the participants is expressed as the normalize error ratios (E_n). E_n ratio can be calculated by equation (3). E_n ratio of the participants compared with NIMT results are shown in Table 2 for volume and mass flowrates.

Table 2. E_n ratio between participants and NIMT for volume and mass flowrate

Flowrate	**Lab 1**		**Lab 2**		**Lab 3**		**Lab 4**	
litre/min	Volume	Mass	Volume	Mass	Volume	Mass	Volume	Mass
30	0.01	0.56	0.49	0.51	0.26	0.17	0.05	0.28
60	0.15	0.70	0.38	0.47	0.08	0.01	0.03	0.08
90	0.29	0.78	0.56	0.43	0.43	0.59	0.35	0.31
120	0.28	0.68	0.31	0.34	0.52	0.71	0.54	0.41
Re58300	0.28	0.49	0.61	0.69	0.07	0.01	-	-

5. Conclusions

The case study of water flow measurement comparison in the range of (12-120) litre/minute and (12- 120) kg/minute was organized by flow laboratory at NIMT in order to verify the possibility of compatibility of the flow measurement between volumetric and gravimetric methods. The Coriolis flow meter was used as the transfer standard. The participants were five laboratories including the National Institute of Metrology (Thailand), NIMT. The comparison results show that the flowrate, measured by volumetric system and gravimetric system, is consistent under the uncertainty claimed by each participant. Therefore, NIMT will organize the official inter-lab comparison in the future in order to compare the performance of primary liquid flow standard in Thailand in the range of 12 to 120 liter/ minute by using the water as the transmitting fluid.

References

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