Development of standard calibration equipment for the rain gauges

Gang-Wook Shin*, Sung-Taek Hong , Dong-Keun Lee

* Korea Institute of Water and Environment, KOWACO, Daejeon, Korea
(Tel : +82-42-860-0413; E-mail: gwshin@kowaco.or.kr)
(Tel : +82-42-860-0418; E-mail:sthong@kowaco.or.kr)
(Tel : +82-42-860-0410; E-mail: dongkeun@kowaco.or.kr)

Abstract: Because the rain gauges of tipping bucket type can easily use the digital signal, the rain gauges are widely used for the meteorological observation. In general, the resolution of rain gauges of tipping bucket type can be categorized by the 0.1mm, 0.5mm, and 1.0mm classes. But, the error of the tipping bucket rain gauges is made by the intensity of rainfalls and is expected to make the standard calibration method for error measurement. Thus, we developed the hardware of standard calibration facility for rain gauges by weighting measurement method and proposed the standard procedure by rainfall intensity in this study
Also, we calculated the error for the rainfall intensity and obtained useful result through the proposed calibration method.

Keywords: Rain gauge, Calibration, Rainfall, Tipping bucket

1. INTRODUCTION

WMO(World Meteorological Organization) recommends the standard for the measurement methods and equipments of the rain gauges used to measure rainfall among equipments for meteorological observation.[1]

To measure the amount of rainfall, various rain gauges, which are tank type, weighting type and load-cell type etc, are now developed. But tipping bucket type gauges are widely used for the meteorological observation because of simplicity of the system.[2]

The tipping-bucket rain gauges are classified according to resolution-0.1mm, 0.2mm, 0.5mm and 1.0mm types. The 0.1mm and the 0.2mm type gauges are used for observation of weather. But the gauge for basin operation are mainly used 1.0mm type rain gauge.[3]

These tipping-bucket gauges should be applied by selection of gauge type in order to minimize error according to rainfall intensity. But it is not easy for obtaining the exact error factor in accordance with rainfall intensity. Because the inertia of tipping bucket varies according to rainfall intensity, the rainfall loss breaks out.

Thus, this study developed the standard calibration facility to measure error characteristic of rain gauges by rainfall intensity and standardized the procedure to upgrade the accuracy of calibration. Using the developed facility, this paper presents a fitting rain gauge by test result and provides the compensation value to improve the data quality of rainfall.

2. THEORY

2.1 Tipping Bucket Rain Gauges

The amount of rainfall mean the height of rainwater at fixed space, and the rain gauge is to simply measure the height using equipment. The structure of tipping-bucket rain gauges consists of rain receiptor, tipping bucket and pulse sensor such as fig.1. The diameter types of receiptor are 200mm, 227.5mm, and 447.2mm but, 200mm type among various types is mostly used at field. The tipping-bucket mean a tool to measure the amount of rain when the height of rainwater is 1 mm at rain receiptor area. The two buckets discharge the rainwater one after another when the buckets are filled with rainwater. The rain gauges records the number of discharge.

Fig. 1. Tipping Bucket Rain Gauge

2.2 Principal of Calibration

The calibration method of rain gauges is that generally compare a volume of rainwater by cylinder with tipping number by automatic pipette. This method should calibrate a cylinder or an automatic pipette because of using calibrated tools. But calibration method using mass measurement does not need the calibration of volume tools and has merit of directly measuring by weighting machine and is a method that is improved the accuracy.

The calibration using mass measurement method, first, installs the precision balance on balance table to free from vibration influence, puts a water vessel on the precision balance, discharges the water in vessel using peristaltic pump to rain gauges, converts mass change by weight machine into the amount of rainfall, and compare the amount with tipping number of rain gauges.

Mass of water will be obtained amount of rainfall by the volume that is measured using calibrated standard weight such as Eq. (1).

The parameters used at Eq. (1) are expressed as follow.

m_1 : Balance value before discharged (g)

m_2 : Balance value after discharged (g)

S : Balance sensitivity (g/div.)

ρ_a : Air density at measuring the balance sensitivity (g/m^3)

ρ_b : The density of standard weight used to measure the balance sensitivity (g/m^3)

ρ_w : The water density (g/m^3)

t : Water temperature (^oC)

D : A diameter of receiptor of rain gauges(cm)

$$y = \frac{40(m_1 - m_2)\cdot s \cdot (1 - \frac{\rho_a}{\rho_b})\cdot(\frac{1}{\rho_w - \rho_a})}{\pi D^2} \quad \text{(mm)} \quad (1)$$

$$\rho_a = \frac{0.00348444P - H(0.00252t - 0.020582)}{(t+273.15)\cdot 1000}(g/cm^3)$$

(2)

$$\rho(t)/\rho(\max) = 1 - \frac{(t-3.98152)^2(t+396.18534)(t+32.28853)}{609628.6(t+83.12333)(t+30.24455)}$$

(3)

$$\rho(\max) = 999.9734 kg/m^3$$

ρ_a could be obtained using Eq. (2) and balance sensitivity could be calculated through Eq. (4)

$$s = \frac{m_s}{L} \quad (4)$$

where,

m_s : Mass of standard weight

L : Variation between put standard weight on balance and not

3. Standard Calibration Facility

3.1 Configuration

The developed facility for calibration of rain gauges is composed of a water container, a precision weighting machine, a balance weight, two peristaltic pumps, a controller, environment sensors, and a data acquisition equipment

The main functions of the facility could be presented as follows. First, the facility can be automatically set for calibration test by initial data. And to measure the uncertainty variation by the amount and intensity of rainfall, it can control the amount of water according to test time. The facility can compare the applied water with the measured data of rain gauge. Using the standard calibration facility, the uncertainty calculation for rain gauge can include the environment factors, which are weight, temperature, operation time, measurement iteration number, humidity, and pressure.

Fig. 2 shows the configuration of standard calibration facility.

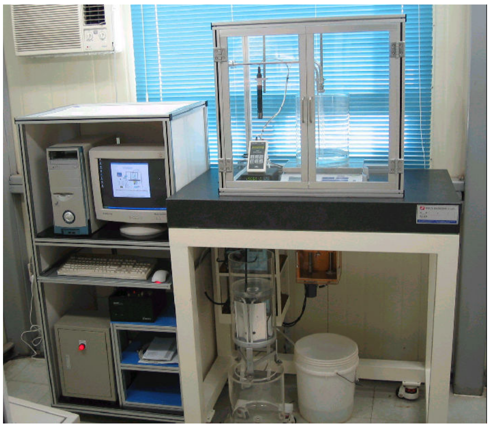

Fig. 2. Standard Calibration Facility for rain gauges

3.2 Detailed Structure

(1) Water vessel and precision balance

The object of water vessel is to keep the water for calibration of rain gauges and the structure consists of 235mm for diameter, 300mm for height, respectively. And maximum amount for calibration is up to 13㎘.

The precision balance as main equipment at standard calibration facility is made by Mettler Toledo Co. and it has the characteristics of 16100g for maximum capacity, 0.1g for resolution.

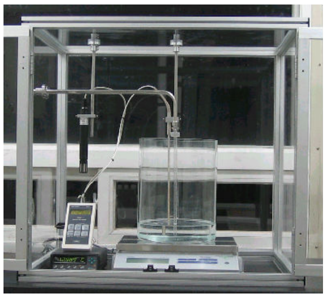

Fig. 3. Water vessel and precision balance

(2) Standard Weight

Because an error is generated according to the use of the balance, the balance must be compared with standard weight to improve the accuracy of mass measurement. Thus, this study made the 3 ㎏ weight to obtain the balance sensitivity. Fig. 4 shows the loading equipment on balance.

Fig. 4. Standard weight

(3) Peristaltic pump and Controller

Two peristaltic pumps were equipped at standard calibration facility to provide water to rain gauges from water vessel and to fill up water in water vessel.

One pump can apply maximum 150 ㎖/min to rain gauges and change the rainfall intensity. The other pump operates to keep the water in vessel and applies maximum 300 ㎖/min to the water vessel.

Table 1. Characteristics of peristaltic pump

Item	Characteristic
Flow Capacity	0.9～600 ㎖/min
rpm Range	15～125 rpm
Max Torque	0.7～2.7(Max 6.5) ㎏/㎠
Voltage	220 V
Fuse Rating	2.0/250
Motor Type	Magnet DC
Motor Size	25 W
Temp. Operating	0～40
Interface	RS 232 interface, Adjustable flow rate

Fig. 5. Peristaltic pump

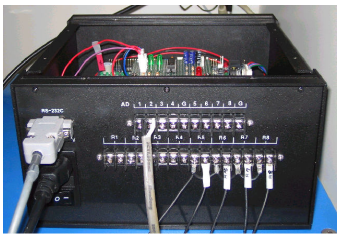

Fig. 6. Facility Controller

All measurement for calibration is realized by the data acquisition PC and controller, and the controller controls input/output signal transmitted from each sensor such as Fig. 6

(4) Environment instrument and data acquisition equipment

The balance table was made in order that vessel and balance could be avoided from the environment influence. The accuracy of thermometer as instrument to measure the water density is 0.05℃. And that has functions of RS-232C communication and easy maintenance.

Table 2. Characteristics of thermometer

Item	Characteristic
Range	-183.000 ～ 850.00℃
Resolution	0.001℃ : -183.000～100.009℃ 0.01℃ : 100.01℃～850.00℃
Accuracy	0.05℃
Display	8-digit alphanumeric LED, 7/16"H
Source	110 VAC, 50/60 Hz or 220 VAC, 50/60 Hz
Output	RS-232 interface, DB9 male connector,
Speed	300 ～ 2400 baud
Probe	four-wire 100 Pt RTD probe
Probe Reg.	General 100 (at 32℃)
Probe Reg. Stability	0.01℃/year
Probe Stability	-50℃ : 0.01℃, 0℃ : 0.007℃ 200℃ : 0.024℃, 400℃ : 0.033℃
Size	65㎜(W) 69㎜(H) 224㎜(D)
Weight	3.2kg

Environment instrument is to calibrate the air density by measuring temperature, humidity and pressure. And Fig. 3 shows the characteristics of environment instrument.

Table 3. Environment Instrument

Item	Range	Resolution
Temp.	Sensor 1: -40～60	0.1
	Sensor 2: -50～200	0.1
Humidity	0～100% rH	0.1% rH
Pressure	225～1125hPa	0.1hPa

4. Standard Calibration Procedure

4.1 Program

A program was developed to operate standard calibration equipment of rain gauge using microsoft visual c++.

There are the functions of the program; First, the data is automatically obtained according to standard calibration procedure. Secondly, the program calculates uncertainty in measurement by precisely collecting data such as mass, water temperature, operation time of peristaltic pump, number of measurement frequency, temperature of interior, humidity, pressure, and more, which are necessary to calculate uncertainty from standard calibration equipment. Thirdly, the program provides the results according to the form for output when the calculation for uncertainty in measurement is completed. Fourthly, the equipment saves the achieved data and automatically functions to produce files after calculating the uncertainty, or during or after measurement.

Fig. 7 shows the initial screen of this program to operate standard calibration equipment, which allows to confirm tipping time of tipping-bucket rain gauge and measurement data on real-time.

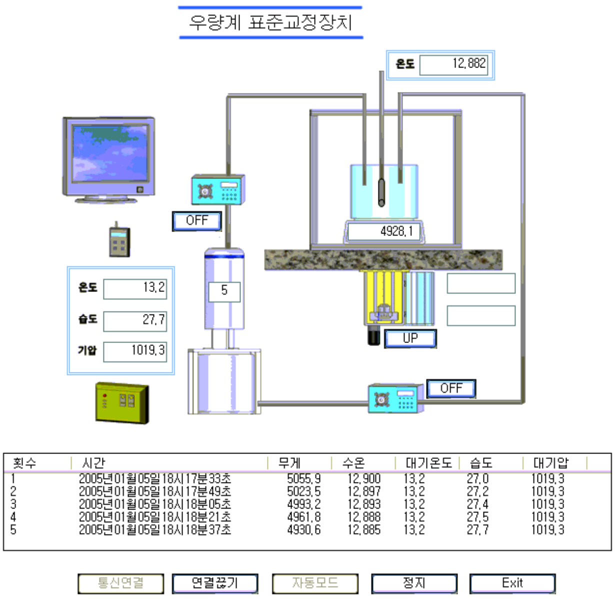

Fig. 7. The initial screen of standard calibration equipment

4.2 Procedure

Fig. 8 shows the developed standard calibration procedure of rain gauge in this study. Therefore, execute calibration according to the flow map in fig. 8 for rain gauge calibration.

First, we set initial parameters for measurement such as the quantity of needed water, tipping counter number, measure number, rainfall intensity, and file name for data saving , and more.

We start the measure procedure after filling up the experiment vessel with the water quantity set before for measurement by operating the peristaltic pump, then measure the overall mass of water filled up in the vessel and the vessel itself, and provide water to rain gauge for calibration using the peristaltic pump.

This system measures the mass of discharged vessel after tipping, and saves the environment data such as temperature of water and air, humidity, pressure, and more.

And it measures the water temperature, the environment, and mass of vessel whenever the bucket is tipped in this way, so the quantity of discharge on tipping bucket and tipping count can be compared. Also, it waits for about 10 seconds to stabilize scale-indicating-value once the change of tipping bucket is completed just as the frequency set before is completed. Then read the scale value, load standard weight, and measure the scale sensitivity.

After unloading the weight, it calculates the scale sensitivity by compensating the scale drift by calibrating the scale-indicating-value.

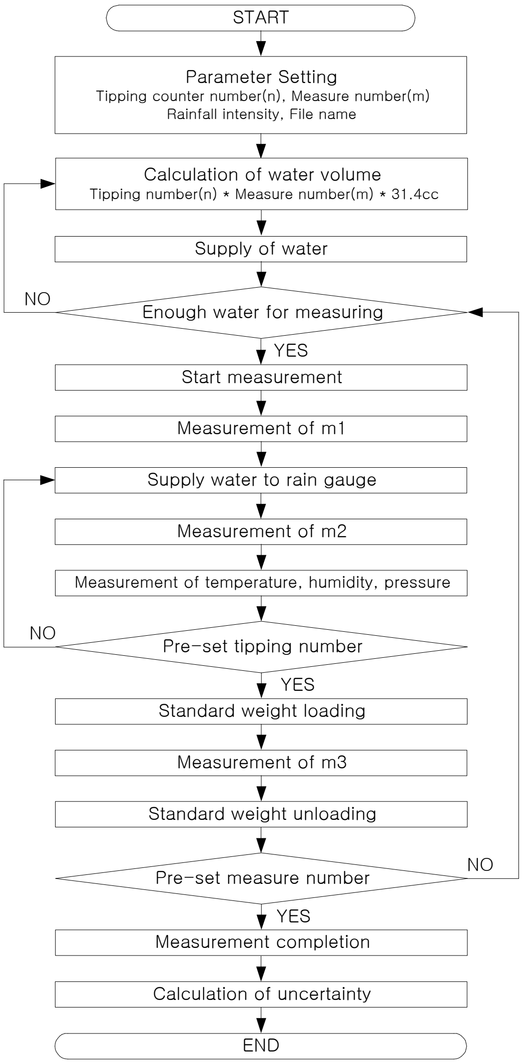

Fig. 8. The standard calibration procedure of rain gauge

5. Measurement Test

This study made experiment about the error property of 1.0mm tipping bucket rain gauge for developed standard calibration facility. After setting the providing amount of rain quantity to 120㎖/min for pump A, the tipping bucket is set to change 20 times. Table 4 shows environmental measurement data such as vessel mass, temperature, humidity, pressure, and more other than data of measurement over 20 times of repetition and measurement date. It took 6.5833 minutes to measure, and the amount of water used in measurement was in total 638.1g.

Table 4 1.0㎜ rain gauge test data(I)

ime (s/m/h/date	Balance (g)	Barometer (hPa	umidity (% R.H	TEMP1
34411628	5188.2	1018.7	17.7	28.7
55411628	5158.8	1018.7	17.9	28.7
12421628	5126.6	1018.8	18	28.7
28421628	5094.5	1018.7	18	28.7
45421628	5062.4	1018.8	17.8	28.8
1431628	5031.4	1018.7	17.8	28.8
17431628	4999.3	1018.8	17.7	28.8
34431628	4966.2	1018.8	17.7	28.8
51431628	4934.2	1018.8	17.8	28.8
7441628	4903	1018.8	17.9	28.8
23441628	4870.8	1018.8	18	28.8
40441628	4838.7	1018.8	18.1	28.8
57441628	4805.7	1018.9	17.9	28.8
13451628	4774.5	1018.9	18.1	28.8
29451628	4742.6	1018.9	18.1	28.8
46451628	4710.4	1018.9	18	28.8
2461628	4678.3	1018.9	18	28.8
18461628	4647.2	1018.9	18	28.8
35461628	4615.1	1018.9	18.1	28.8
51461628	4582.9	1018.9	18.1	28.9
9471628	4550.1	1018.9	17.9	28.9
	4550.2			
Sen. WT	7659.6			
	4550.4			

Table 5 shows scale sensitivity calculated from measurement data, precipitation and air density for each change and the amount of water.

Table 5 1.0㎜ rain gauge test data (II)

측정순서	Bucket mass (g)	Air density	Water density	Water volume	Falling rain (mm)
1	29.4	0.0011729	0.99603	29.573	0.941
2	32.2	0.0011729	0.99603	32.389	1.031
3	32.1	0.001173	0.99603	32.289	1.028
4	32.1	0.0011729	0.99603	32.289	1.028
5	31	0.0011726	0.99600	31.183	0.993
6	32.1	0.0011725	0.99600	32.290	1.028
7	33.1	0.0011726	0.99600	33.296	1.060
8	32	0.0011726	0.99600	32.189	1.025
9	31.2	0.0011726	0.99600	31.384	0.999
10	32.2	0.0011726	0.99600	32.390	1.031
11	32.1	0.0011726	0.99600	32.290	1.028
12	33	0.0011726	0.99600	33.195	1.057
13	31.2	0.0011727	0.99600	31.384	0.999
14	31.9	0.0011727	0.99600	32.088	1.021
15	32.2	0.0011727	0.99600	32.390	1.031
16	32.1	0.0011727	0.99600	32.290	1.028
17	31.1	0.0011727	0.99600	31.284	0.996
18	32.1	0.0011727	0.99600	32.290	1.028
19	32.2	0.0011727	0.99600	32.390	1.031
20	32.8	0.0011723	0.99597	32.995	1.050
Total water mass (g)	Total rain (mm)	One bucket (mm)	Falling rain strength (mm/hr)	Rec. sen	
638.1	20.43126	1.0215631	186.208977	1.0008555	
Raining time					
Beginning	Finish				
34411628	9471628				
Total raining time (min)	6.5833				

The sensitivity is calculated first using the weight to get a precise error for the measurement value of rain gauge concerning total precipitation. First of all, to get the value for sensitivity; First, in order to obtain a reverse sensitivity

- Stabilized value of balance(after 20 change) : 4550.2 g
- Balance (after loading the weight) : 7659.6 g
- Balance (after unloading the weight) : 4550.4 g
- Balance : 7659.6 -(4550.2 + 4550.4)/2 = 3109.3 g
- Mass of weight : 3111.96 g

The sensitivity using the measurement value above is 3111.96/3109.3 = 1.000855 g/div.. Air density uses formula (2) and water density uses formula (3). By applying the value below using formula (1) to get the buck precipitation for each time concerning measurement value, the first change precipitation is 0.941 ㎜.

- m1 : 5188.2 g
- m2 : 5158.8 g
- S : 1.000855 g/div.
- ρ_A: 0.0011729 g/cm^3
- ρ_b : 8.0 g/cm^3
- ρ_w : 0.99603 g/cm^3
- ρ_a : 0.0011729 g/cm^3
- t : 28.7 ℃
- D : 20 cm

The calculation of per rainfall is values on the right procession of table 5. Also, the rainfall intensity concerning measurement calculates rainfall for an hour using the overall rainfall 20.431 ㎜ and continuing time of rainfall 6.68 minutes; 20.4313 ㎜ × 60 min. / 6.5833 min.= 186.209 ㎜ /hr.

The average rainfall per bucket through the formula above is 1.022 ㎜, and the correction amount of tipping bucket is 0.022/1 × 100 % = 2.2 % with the error of 0.022 ㎜.

The rainfall intensity needs to be measured with modification since the rain gauge has certain errors according to the rainfall intensity. This experiment measured in rainfall intensity of 125 ㎜/h to compare with the value for 186 ㎜/h. Table 6 is the comparison of errors with 125 ㎜/h and 186 ㎜/h, and fig. 9 is the change of error according to the rainfall intensity.

Table 6. The error rate of rainfall intensity

	Rec.Sen. (g/div.)	Rain strength (mm/h)	One bucket (mm)	Error (%)
125	1.000839	125	1.0105	1.05
186	1.000855	186	1.0216	2.16

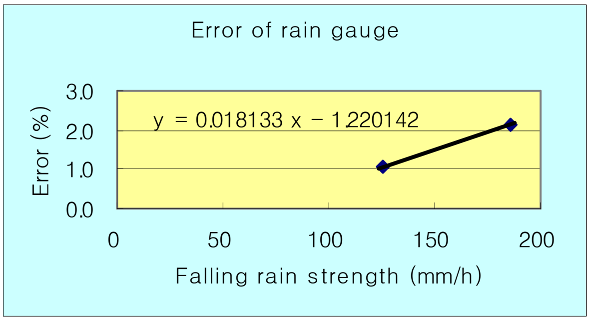

Fig. 9. The change of error rate of rainfall intensity

As can be seen in fig. 9, the error can be achieved as mentioned below with rainfall intensity of 100 ㎜/h if error property is set in linear according to the increase of rainfall intensity

$$\text{Error} = 0.018133 \times 100 - 1.220142 = 0.59\% \quad (5)$$

Therefore, the rain gauge in this study has 0.59% error possibility in rainfall intensity of 100 ㎜/h.

6. CONCLUSIONS

This study developed standard calibration facility that can analyze the error property of rain gauge and equipment calibration. Also, the calibration procedure of rain gauge is standardized by developing the standard calibration procedure using the standard calibration facility. An error property test is executed concerning 1.0mm tipping-bucket rain gauge using such calibration facility and procedure. As a result, it shows 1.05% error possibility in rainfall intensity of 125㎜/h, and 2.16% error possibility in rainfall intensity of 186 ㎜/h. It also shows real rainfall by correcting 0.0105㎜ correction value with rainfall intensity of 125㎜/h, and 0.0216㎜ with rainfall intensity of 186 ㎜/h. Through the results of experiment, the error property is 0.59% in case of representative rainfall intensity of 100 ㎜/h.

Using this way, the standard calibration facility and the procedure are allowed to know the precise calibration factor of tipping-bucket rain gauge according to the rainfall intensity.

REFERENCES

[1] M. Leroy, "Calibration and Control Methods for Tipping-Bucket raingauges.", Instruments and Observing Methods Report, No. 74, pp. 92-95, 2000

[2] D.W. Kim and B.Y. Lee, "Development of Rain Gauge and Observation Error," J. of the Environmental Sciences, Vol. 11, pp. 1055-1060, 2002.

[3] D.M. Woo, "The characteristics of the rainfall intensity by the tipping-bucket rain gauge." J. of meteorological , No. 38, Vol. 5, pp. 479-491, 2002.