HONG KONG OBSERVATORY

Technical Note (Local) No. 79

A Study of Drop-counting Rain Gauges

by

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Published February 2004

Prepared by

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摘要

本報告描述香港天文台在香港國際機場使用的兩部滴水式雨量計(簡稱為雨量計 A 及 B)的刻度結果及水滴大小值的變化。刻度結果顯示，A 雨量計在降雨率大於約 20 毫米/小時後開始偏離世界氣象組織對降雨量度準確度的要求，B 雨量計相對應的降雨率則約為 100 毫米/小時。進一步研究顯示，兩部雨量計的水滴大小值隨降雨率有不同的變化，這與它們使用不同的水滴產生機制有關。此外，對於每一部雨量計，不存在一個固定的名義水滴大小值，足以保障與實際水滴大小值的偏差，保持在世界氣象組織對降雨量度準確度的要求之內。一般來說，採用固定的名義水滴大小值在一定程度上限制了滴水式雨量計的應用。

Abstract

This report describes the calibration and the determination of drop size variations for two different models of drop-counting rain gauges used by the Hong Kong Observatory at the Hong Kong International Airport (named as rain gauges A and B). Calibration results show that deviation from the accuracy requirement for rainfall measurement of the World Meteorological Organization (WMO) starts as the rainfall rate exceeds about 20 mm/h for rain gauge A, and about 100 mm/h for rain gauge B. On further analysis, the drop size was found to vary with the rainfall rate in different manners for the two gauges. This was found to be related to the different drop-formation mechanisms adopted in the gauges. Moreover, for either rain gauge, it was not possible in practice to assume a nominal constant drop size that differed from the actual drop size within the WMO accuracy requirement for rainfall measurement. In general, the use of a nominal constant drop size limits to some extent the application of the drop-counting rain gauge.

CONTENTS

FIGURES

1. INTRODUCTION

A 0.1-mm drop-counting rain gauge (named as rain gauge A hereafter) has been used operationally by the Hong Kong Observatory at the Hong Kong International Airport (HKIA) since 1997. A 0.5-mm tipping-bucket rain gauge has also been used since about the same time for checking purpose.

The rain gauge A has been maintained in accordance with the procedures provided by the manufacturer. However, the rainfall data it provided occasionally did not agree with those of the tipping-bucket gauge, with a tendency towards under-estimation. For example, in August 2000, there were 5 days with daily rainfall exceeding 30 mm, and the daily rainfall figures from the rain gauge A were generally smaller than those from the tipping-bucket gauge, sometimes by about 15%. For this reason, another 0.1-mm drop-counting rain gauge (named as "rain gauge B" hereafter) was installed at the HKIA in 2001. The rain gauge B was found to provide rainfall measurements that were comparable with those of the tipping-bucket gauge.

The measurement of rainfall by the two drop-counting rain gauges assumes a constant drop size. It was hypothesized that the observed discrepancies of the rainfall data provided by the two gauges might be the result of drop size variation which in turn was related to the drop-formation mechanism in the gauge designs. This study verifies the hypothesis and evaluates the possible impact on rainfall measurement due to such drop size variation.

This report describes the setup and the results of the experiment, which includes the calibration of the two drop-counting rain gauges and the determination of the variation of the drop size with the rainfall rate. Section 2 provides background information of the two drop-counting rain gauges. Section 3 gives an account of the experimental design and results. Section 4 presents further analysis of the experimental results, by studying the variation of the drop size with the rainfall rate and the implication of this variation on operational rainfall measurement. Section 5 gives a discussion and conclusion of the study.

2. DESCRIPTION OF THE TWO DROP-COUNTING RAIN GAUGES

The two drop-counting rain gauges in this study measure rainfall at 0.1-mm resolution by means of different drop-formation mechanisms:-

(a) Rain gauge A (Fig. 1a) – Rain is collected by a funnel and formed into drops at the nozzle of the funnel stem below. According to the manufacturer’s specification, a drop corresponds to a rainfall of 0.005 mm. The total rainfall over a time period is determined by counting the number of drops passing through an optical counter (a light chopper) underneath the nozzle within that time. The rain gauge is also equipped with a 0.1-mm tipping bucket directly under the nozzle. The drop-counting and tipping bucket mechanisms thus provide two sets of rainfall data to enable internal consistency checking of the measurements. The manufacturer states that this rain gauge is capable of measuring rainfall at rates up to 120 mm/h.

(b) Rain gauge B (Fig. 1b) – This is the latest model of a similar rain gauge that has been in use at the Hong Kong Observatory Headquarters since 1990s. The construction is slightly different from that of the rain gauge A in that it has a reservoir between the water collecting funnel and the drop formation device. The reservoir is always maintained full to ensure a practically constant static water pressure for water drop formation. Rain collected at the funnel first flows into the bottom of the reservoir, displacing the water inside the reservoir which then flows out at the top through a tube. At the other end of the tube, water drops are formed at a nozzle. According to the manufacturer’s specification, a drop corresponds to a rainfall of 0.01 mm. The total rainfall is determined by counting the number of drops passing through an optical counter. The manufacturer states that the gauge is capable of making measurements at rainfall rates reaching 200 mm/h.

3. EXPERIMENT AND RESULTS

3.1 The experiment

The experiment aims at calibrating the two drop-counting rain gauges by comparing the measured rainfall rate as reported by the rain gauges with the simulated rainfall rate. According to the regulation of the World Meteorological Organization (WMO, 1996), the achievable operational accuracy of rainfall measurement shall be +/- 5%.

The equipment depicted in Fig. 2 was used to calibrate the two rain gauges. It consists of a water tank acting as a reservoir and a tap for adjusting the rate of water outflow. To ensure that the equipment was able to deliver a steady water flow (hence a steady simulated rainfall rate), a separate experiment was conducted which confirmed that the equipment was capable of delivering a steady water flow up to an equivalent rainfall rate of about 190 mm/h (Fig. 3). The calibration steps are summarized in the Appendix.

The calibration was performed based on the factory-supplied parameters for the two rain gauges (such as the assumed constant size of the rain drop).

3.2 The results

For the rain gauge A (Fig. 4a), the calibration results show that the measured rainfall rate was generally smaller than the simulated rainfall rate. They were close to each other (within 5%) below about 20 mm/h. The difference increased as the rainfall rate became higher, trespassing the 5% WMO accuracy requirement. Beyond 115 mm/h, calibration was not possible because, instead of forming into drops, the water flowing out from the funnel formed a continuous stream.

For the rain gauge B (Fig. 4b), the measured rainfall rate was close to the simulated rainfall rate (within 5%) up to about 100 mm/h. Beyond that, the measured rainfall rate became higher than the simulated rainfall rate, trespassing the 5% WMO accuracy requirement. Calibration was performed up to a simulated rainfall rate of 147 mm/h when individual water drops still formed at the nozzle of the drop-formation device.

4. ANALYSIS OF EXPERIMENTAL RESULTS

4.1 Theoretical considerations

The relationship between the drop size *v* and the rainfall rate *r* is:-

$$v\,(\mathrm{mm}^3\,/\,\mathrm{drop}) = \frac{r\,(\mathrm{mm/h}) * A\,(\mathrm{mm}^2)}{f\ (\mathrm{drops/h})} \qquad (1)$$

where *f* is the frequency (i.e. number of water drops per hour) measured by a drop counter during the calibration, and *A* the area of the gauge orifice. *v* is usually taken to be a constant by virtue of the rain-gauge design. From physical consideration, however, it is related to the rain gauge's drop-formation mechanism, and the formation of drops is a result of interaction between the static pressure of the rain water accumulated inside the funnel and the surface tension of the water drop formed at the nozzle. It follows that if the static pressure is not constant, the drop size may vary instead of remaining constant.

From Eq. (1), as the errors in *f* and *A* are relatively small, the error in the drop size is directly proportional to the error in rainfall rate.

4.2 Drop size variation with the rainfall rate

From the experimental results presented in Section 3, the drop size *v* was calculated in accordance with Eq. (1), using the simulated rainfall rate *r* and the frequency *f* measured by a drop counter during the calibration. The drop size was then plotted against the simulated rainfall rate.

For the rain gauge A (Fig. 5a), the drop size generally increased with the rainfall rate throughout the calibration range from 5 to 115 mm/h. It varied between 0.093 and 0.109 cm^3, i.e. a change of 0.016 cm^3 over a rainfall rate range of 110 mm/h.

During the calibration, it was observed that as the rainfall rate increased, there was a tendency for the water to stay longer in the collecting funnel. It took time for the water to drain away, and the situation worsened with higher rainfall rates as more water accumulated. This resulted in the build-up of a larger static water pressure inside the funnel, which favoured the formation of larger water drops. This observation was consistent with the general trend of drop size increasing with the rainfall rate (Fig. 5a).

For the rain gauge B (Fig. 5b), the drop size increased with the rainfall rate from 5 mm/h to about 70 mm/h, after which it started to decrease. It varied between 0.052 and 0.070 cm^3 in the calibration range of 5 to 147 mm/h, i.e. a change of 0.018 cm^3 over a rainfall rate range of 142 mm/h. This change is comparatively much smaller than that for the rain gauge A (0.018/142 < 0.016/110). It thus appears that the internal reservoir in the rain gauge B might have played a useful role in regulating the drop size.

4.3 Implication to the selection of a constant drop size

In the operation of a drop-counting rain gauge, it is a common practice to assume a constant drop size that is independent of the rainfall rate. However, as the above results show, the actual drop size does vary with the rainfall rate. The difference between the measured drop size and the constant drop size assumed, as plotted in Fig. 5(a) and 5(b), represents the 'error' in the drop size. As discussed in Section 4.1 above, the error in the rainfall rate is directly proportional to the error in the drop size. This means that the actual drop size shall not differ from the constant drop size assumed by more than 5%, the WMO accuracy requirement for rainfall measurement.

However, for either rain gauge in this study, it is not possible to select a nominal constant drop size that would meet the 5% accuracy requirement within the entire range of rainfall rates in the calibration. One possible approach is to identify a nominal constant drop size that is different from the actual drop size by no more than 5% within the largest possible range of rainfall rates. For practical reason, this largest range of rainfall rates should start from the lowest rainfall rate in the calibration (i.e. 5 mm/h for both rain gauges) because rainfall measurement has to be accurate at least at low rainfall rates.

Based on the results in Fig. 5, the constant drop size is determined to be 0.0979 and 0.0667 cm^3 for rain gauge A and B respectively. The error in the drop size following the use of this constant value is presented in Fig. 6. For the rain gauge A, the error is within 5% up to a rainfall rate of 28 mm/h, while for the rain gauge B the maximum rainfall rate reached is 100 mm/h for the same 5% error.

5. DISCUSSION AND CONCLUSION

Two drop-counting rain gauges (named as A and B) are used for rainfall measurement at the Hong Kong International Airport. To study the discrepancy of the rainfall data recorded by the two gauges, a laboratory calibration was carried out. The two gauges were found to behave differently. For the rain gauge A, the measured rainfall rate was close to the simulated rainfall rate (within 5%) up to about 20 mm/h, and it was generally smaller than the latter in the whole calibration range. For the rain gauge B, the measured rainfall rate was close to the simulated rainfall rate up to about 100 mm/h, becoming larger than the latter at higher rainfall rates.

The difference in the calibration results for the two gauges is related to the variation of drop size with the rainfall rate. The drop size of the rain gauge A was found to generally increase with the rainfall rate. On the other hand, the drop size of the rain gauge B was found to rise with the rainfall rate up to about 70 mm/h, and then generally decrease at higher rainfall rates. Such differences in the variation of drop size arise from the use of different drop-formation mechanisms inside two gauges. In particular, it appears that the internal reservoir in the rain gauge B might have played a useful role in regulating the drop size over a larger range of rainfall rates.

For a drop-counting rain gauge, it is a common practice to assume a nominal constant drop size for operational rainfall measurement. The difference between the actual drop size and the constant drop size assumed is equal to the error in rainfall measurement. For either of the two drop-counting rain gauges in this study, however, it is not possible to select a constant drop size that fulfills the WMO accuracy requirement of 5% for the entire range of rainfall rates in the calibration. One possible approach is to identify a constant drop size that differs from the actual drop size by no more than 5% within the largest possible range of rainfall rates. This range is found to be 5 to 28 mm/h for the rain gauge A, and 5 to 100 mm/h for the rain gauge B.

Nevertheless, in subtropical places like Hong Kong it is common for the rainfall rate to exceed the maximum ‘applicable’ rainfall rate of 100 mm/h for the rain gauge B, not to mention the 28 mm/h rate for the rain gauge A. The use of a constant drop size therefore limits to some extent the application of the drop-counting rain gauge. An alternative approach is to use a variable drop size that changes with the rainfall rate in accordance with the laboratory calibration results. The feasibility of this approach calls for a separate study.

REFERENCE

World Meteorological Organization, 1996: Guide to meteorological instruments and methods of observation (6th edition). World Meteorological Organization, Geneva, Switzerland.

APPENDIX

STEPS IN THE CALIBRATION OF A DROP-COUNTING RAIN GAUGE

(a) Clean the rain gauge thoroughly to ensure that it is dirt-free. The electronic device for displaying the measured rainfall rate of the gauge is also checked.

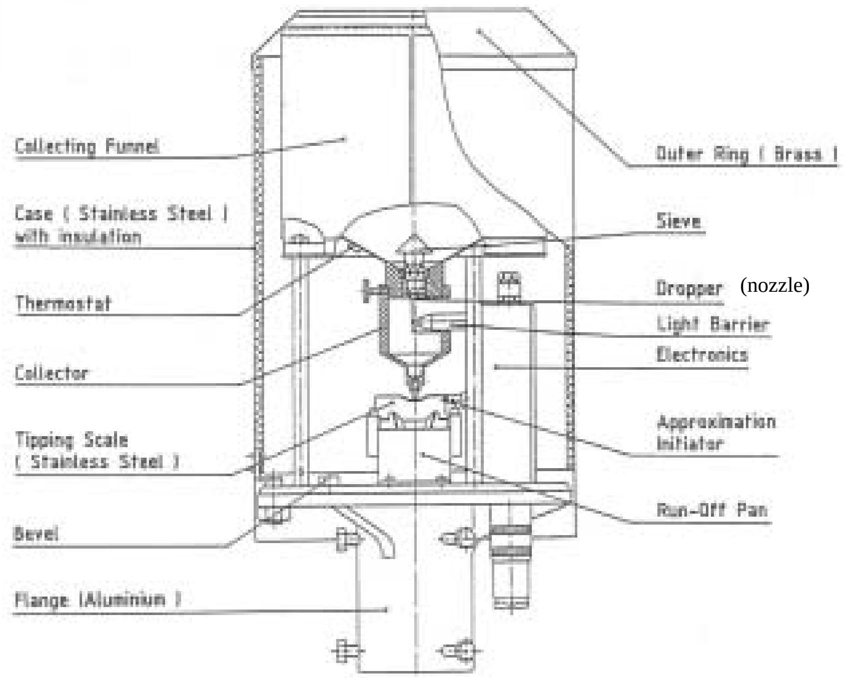
(b) Fill the water bucket (Fig. 2a) with water to a level that water starts to flow out from the plastic tube on one side (Fig. 2b).

(c) Turn on the water tap. Wait for a minute to ensure that the water flow from the tap becomes steady. Place a measuring cylinder under the tap, collect the water for a given period of time, and determine the flow rate. Adjust the flow rate to a specified value by turning the water tap and repeating this step.

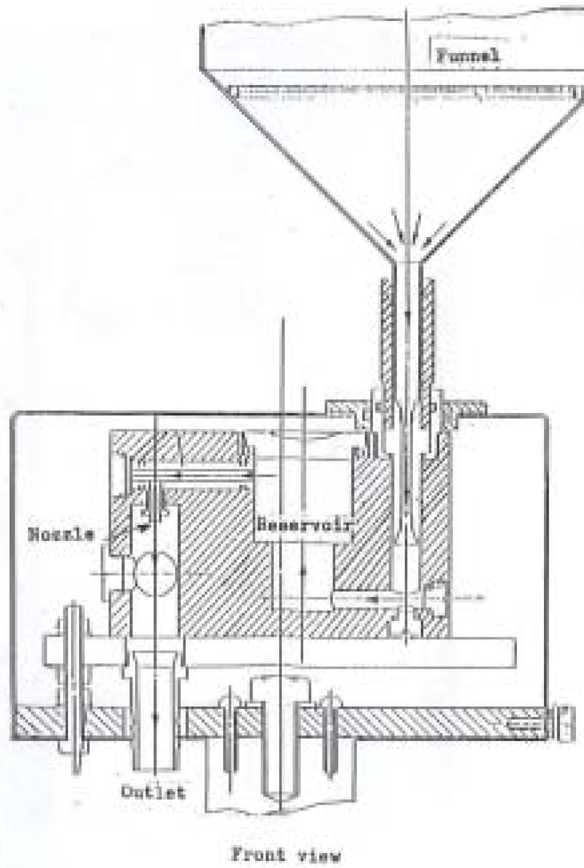
(d) Once a specified flow rate is achieved, place the rain gauge under the tap and another measuring cylinder beneath the gauge. Let the water flow for up to 30 minutes.

(e) The simulated "rainfall" rate is equal to the amount of water collected with the measuring cylinder divided by the collection time. The measured "rainfall" rate is displayed on the electronic device.

(f) Repeat the above steps for other flow rates.



(a) rain gauge A



(b) rain gauge B

Fig. 1 Construction of the two rain gauges in the present study.

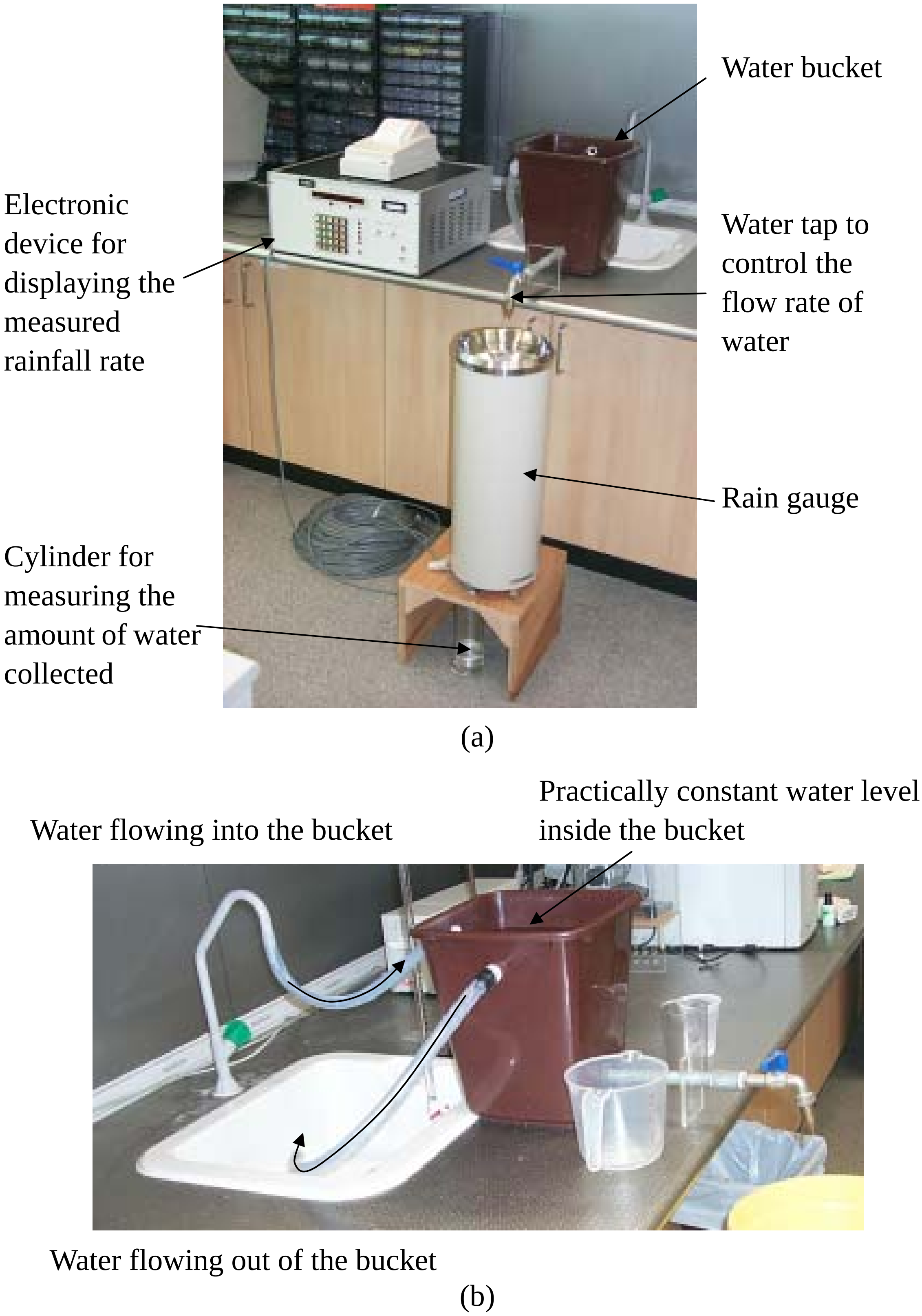


Fig. 2 Equipment set-up in the laboratory calibration of a rain gauge: (a) overall view, (b) close-up view of the water bucket and the water flow.

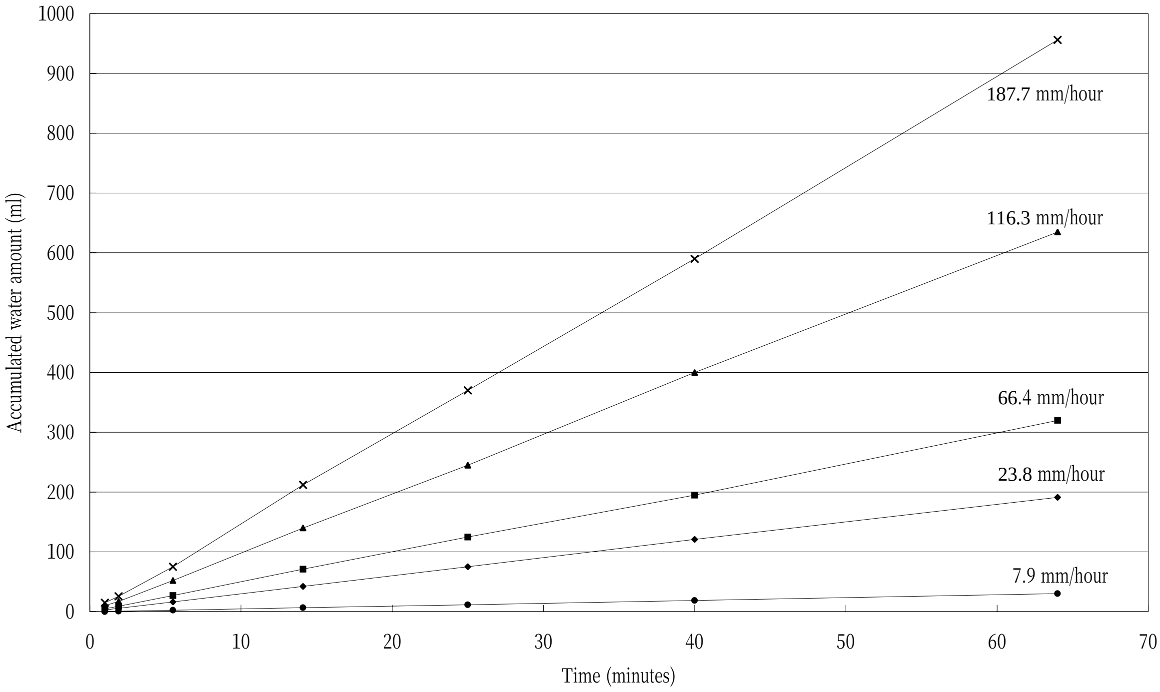
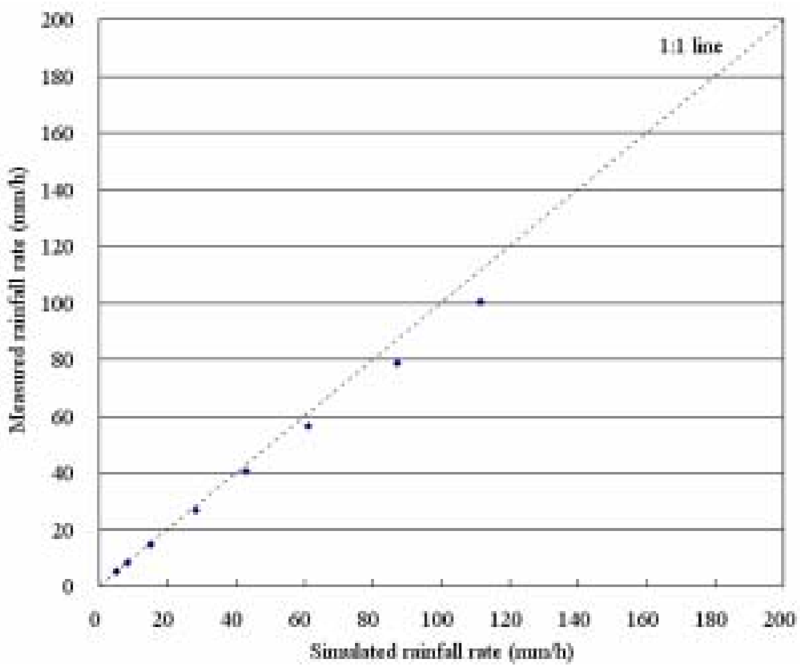
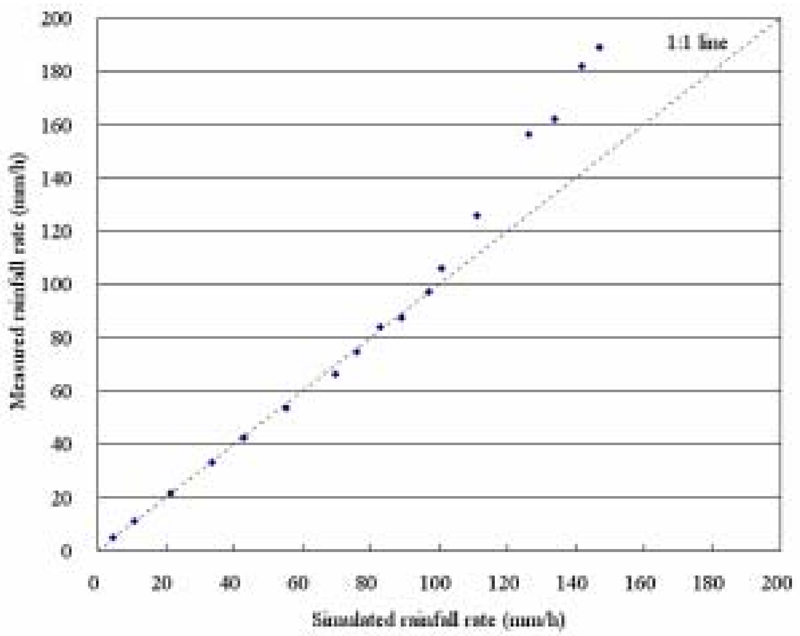


Fig. 3 The accumulated amount of water flowing out from the calibration equipment at different flow rates, as a function of time. [Note: For ease of comparison with the calibration results of individual rain gauges, the water flow rate in this experiment was converted from ml/h to mm/h on the basis of a common orifice diameter of 12.7 cm (5 inches).]

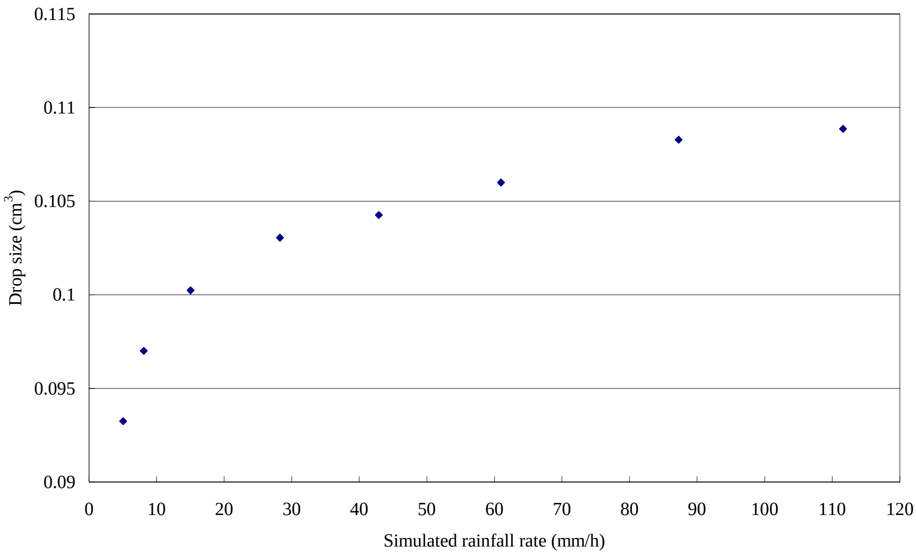


(a) rain gauge A

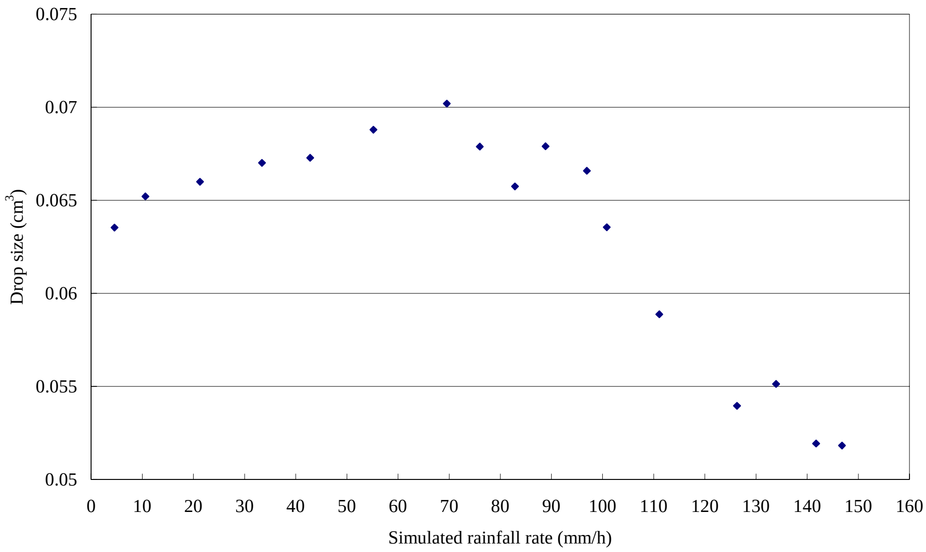


(b) rain gauge B

Fig. 4 Rainfall rate measured by the two rain gauges against the simulated rainfall rate.

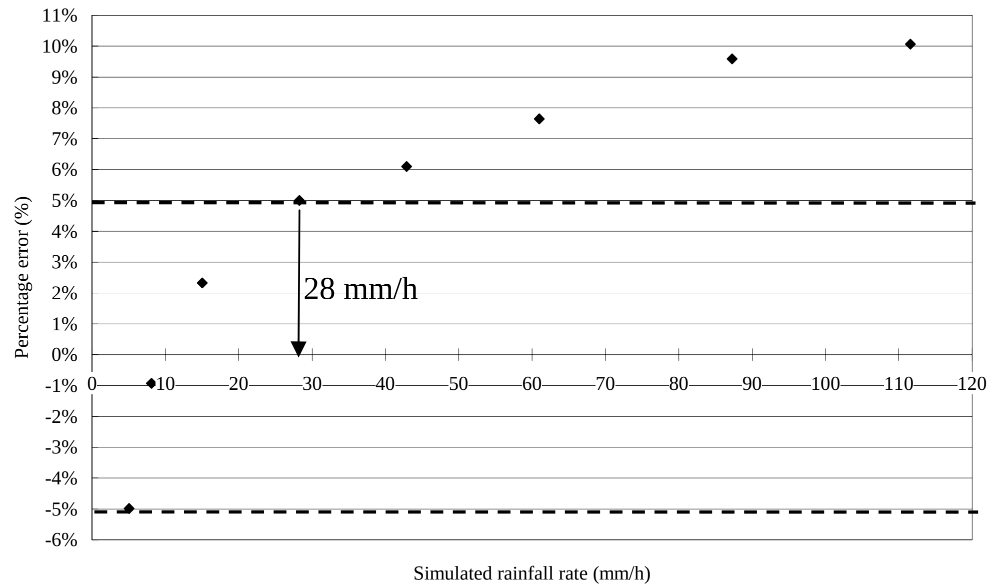


(a) rain gauge A

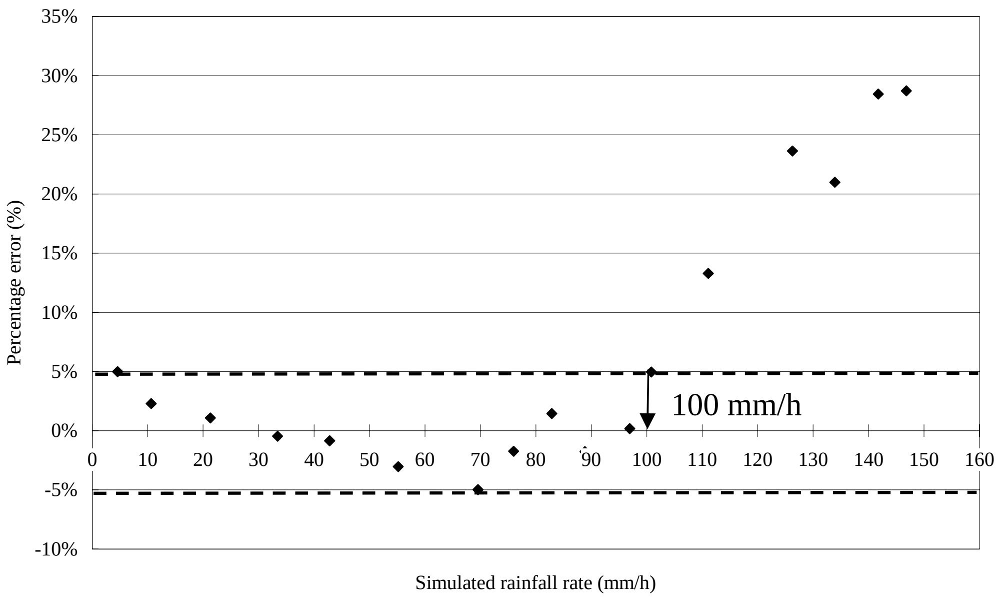


(b) rain gauge B

Fig. 5 Drop size variation of the two rain gauges with the rainfall rate.



(a) rain gauge A



(b) rain gauge B

Fig. 6 Percentage error in the rainfall measurement as a function of rainfall rate after assuming a constant drop size for each of the two rain gauges (0.0979 cm^3 for the rain gauge A and 0.0667 cm^3 for the rain gauge B). The WMO accuracy requirement of +/- 5% is highlighted by horizontal dotted lines. The vertical arrow shows the maximum rainfall rate at which the WMO accuracy requirement is met by assuming the constant drop size.