THE BIAS OF WEB BASED RAIN GAUGE CALIBRATOR DUE TO BUBBLES

KESALAHAN KALIBRATOR PENGUKUR CURAH HUJAN BERBASIS WEB AKIBAT GELEMBUNG

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ABSTRACT

This study was devoted to investigate the bias due to entrapped air - in the cylindrical tube water - to a web based rain gauge calibrator (WBRGC). This study was carried out in laboratory temperature around 25 °C using experiment method, especially by comparing the mass of the water with and without bubbles. The entrapped air used the space for 1.57 g of 1009.82 g of water if there were no bubbles, so this condition made bias around - 0.16 %. This bias was very significant in contributing the uncertainty of WBRGC, where in this case was 3 ml for 966 ml of water (0.31 %). Hence, this bias should be promptly overcome.

Keywords: web based rain gauge calibrator, bias, mass, bubbles, water

INTISARI

Studi ini ditujukan untuk meneliti kesalahan yang disebabkan oleh udara yang terjebak di dalam air tabung silinder terhadap suatu kalibrator pengukur hujan berbasis web (WBRGC). Studi ini dilaksanakan pada temperatur laboratorium sekitar 25 °C dengan memakai metode eksperimen, khususnya dengan membandingkan massa air tanpa gelembung dan dengan gelembung. Udara yang terjebak menggunakan ruang untuk 1,57 gram dari 1009,82 gram air jika tidak ada gelembung, sehingga kondisi ini membuat kesalahan sekitar - 0,16 %. Kesalahan ini sangat bermakna dalam menyumbang ketidakpastian WBRGC, di mana dalam kasus ini 3 ml dari 966 ml air (0,31 %). Oleh karena itu, kesalahan ini seyogyanya segera diatasi.

Kata Kunci: Kalibrator pengukur curah hujan berbasis web, kesalahan, massa, gelembung, air
1. INTRODUCTION
There are many types of rain gauges (liquid precipitation gauges). Rain gauges in this study are limited to a contacting rain gauge type, particularly tipping bucket. Radar (Chandrasekar, 2016) as a non-contacting rain gauge type, for example, has its own calibration method. Hence, it is beyond this scope.

Tipping bucket type can also be applied to sense not only rain fall, but also other variables such as interception (Wijonarko & Maftukhah, 2014) and infiltration (Wijonarko & Maftukhah, 2016). Although often be employed as a set and forget sensor, tipping buckets employed at fields are numerous in number. They need recalibration at least twice a year (Wijonarko et al., 2019). Hence, a better calibration method for this rain gauge is needed.

At least, there are four methods to calibrate contacting rain gauges. The first and the second are Static Calibration and Dynamic Calibration methods respectively (Calder & Kidd, 1978). The third is Automated Dynamic Calibration method (Humphrey et al., 1997), while the fourth is Web Based Calibration method (Wijonarko et al., 2017). The static and dynamic methods have been used by Marsalek (1981) and Costello & Williams Jr. (1991) respectively. The dynamic calibration method has been used for example by Vasva’ri (2005) and Shedekear et al. (2016). The fourth has been used, one of which by Wijonarko et al. (2019). The first two methods are still manual, but relatively small; so that they can be used to calibrate a rain gauge directly at rain gauge stations. The third is automatic, but it is usually so big and heavy to bring (Wijonarko et al., 2016). Therefore, it is dedicated to use in laboratories. The fourth is not only portable and automatic, but it is also web based. Hence, it can be applied at fields or laboratories, might give a direct result, and is able to reduce human activities.

The aforementioned Web Based Calibration method has been applied using WBRGC (Wijonarko et al., 2019; Maftukhah & Wijonarko, 2019). In the indoor or outdoor environments, WBRGC has many bubbles attached in it, when it is filled directly with water. According to Leja (1982), bubbles can be generated in liquids by several different methods, for example by an increase in temperature to cause boiling (Technique 1); a decrease in pressure to cause precipitation of bubbles (only dissolved gases are released, Technique 2), a mechanical agitation to cause gas entrapment (Technique 3), and an injection of pressurized gas through an orifice or a porous membrane (Technique...
Bubbles in liquids are nearly always observed in a trapped state, i.e., on the sides or bottom of a container; or in freely rising bubbles that are less commonly observed because they rapidly ascend and disappear unless extremely small, and not easily visible (Liebermann, 1957). The container or physical structures might be physical elements, permeable materials, hydrophobicity of the substrate (Pereiro, 2019) or pore formation (Wei et al., 2019). According to a graph made by Detsch & Harris (2002), bubbles with the majority diameter between 1 mm and 2 mm should have rise velocities > 12 cm/s.

Generally bubbles in water are intended and even generated in periodic generation (Quan, Chen, Cheng, 2010), but it is different in this study. The attached bubbles where the last one can reach 28 hours often trigger a question mark to user candidates. Is this calibrator accurate enough to be utilized as a calibrator?

The aim of this study was to measure the bias of the WBRGC due to air entrapped in its water. The study result can be used as one of data to evaluate the WBRGC performance.

2. METHODOLOGY
A bubble can be formed in the body of a liquid (water in this study) by the vaporization of molecules of the liquid into a cavity, which may be considered as any space within the liquid phase unoccupied by liquid molecules, either empty or occupied by vapor (Bernath, 1952). When this process occurs due to the boiling temperature of the liquid is exceeded, the process is called superheating (Technique 1), and cavitation is resulted when it occurs at negative pressures (Technique 2).

When, water surface tension is disrupted by the physical force (Technique 3), then a diffusion process occurs. Atmosphere air enters to the water. Bubbles (Technique 4) occur when air is blown steadily through an orifice submerged in a liquid (Davidson & Schüler, 1960; Zhang & Tan, 2000; Sun et al., 2019), where one of which is using a syringe (Jamaludin et al., 2016).

Bubbles in water can change the water density, and then can be one of bias contributor. Bias (offset (Khanam, 2009) or systematic error (Yang et al. 1998)) is the difference between the average value of all the measurements (μ) and the true value (μ₀) or a reference value (Khanam, 2009). Averaging value of all measurements can be assumed to eliminate random error. Error is the difference between the result and the true value (Khanam & Morse, 2003); or the result of a measurement.
minus a true value of the measurand, where the true value in practice is a conventional true value (assigned value, best estimate of the value, conventional value or reference value) (JCGM, 2008). Hence, bias is a systematic error, where in this case can be written as

\[
A_d = W_{wua} - W_{dw} \quad \text{[1]}
\]

where:

\[
A_d = \text{bias (accuracy difference, y)}
\]
\[
W_{wua} = \text{total mass of beaker, water, and bubbles (g)}
\]
\[
W_{dw} = \text{total mass of beaker and water (g)}
\]

Bias can also be attained from the average mass difference between water of WBRGC when bubbles were absent and present in the water respectively.

\[
A_d = W_{w0} - W_{w} \quad \text{[2]}
\]

where:

\[
W_{dw} = \text{total mass of water and bubbles (g)}
\]
\[
W_{uw} = \text{mass of water (g)}
\]

The bias in percentage (\(A_{a%}\)) can also be presented as

\[
A_{a%} = \frac{A_d}{W_{w0}} \times 100 \quad \text{[3]}
\]

The mass of water without bubbles seen by naked eyes was used as the reference. Hence compare to water with bubbles, the water without bubbles must have higher density and is closer to the initial water density in the beaker.

Besides air density measurement, there were three other density measurements in this study. First, the density of initial water used for this study was measured. The last two were densities of water after the water entered to the cylindrical tube directly (water with bubbles) and indirectly using a custom made funnel (water without bubbles) respectively.

The mass measurements were started with beaker measurements (\(W_{w0}\)) several times. The beaker must be in a dry condition for every measurement. So, it is assumed that there was no remaining water in the beaker.

Fill the beaker with water. Pour water in the beaker to the input (highest position) of cylindrical tube in the calibration unit until the abstraction level. Hence, there was no overflow from the cylindrical tube. If the overflow still occurs on the top of the cylindrical tube, it should be absorbed using dry tissues. This step is only used as a prevention to avoid water flows to the desk where the calibration unit is located. Pour the remaining water in the beaker to the tipping bucket under calibration. Wipe the beaker until it is dry.
The beaker in a dry condition was located under the output or outlet (lowest position) of cylindrical tube in the calibration unit. The calibration unit was connected to the data processing unit via a USB communication cable. The calibration unit was instructed to open its output, so water from the calibration unit flowed down until the lowest limit to the beaker. Measure the total mass of the beaker, and water and bubbles in it \( W_{\text{dry}} \) as soon as the calibration unit stopped automatically.

Repeat the above measurement, but the cylindrical tube was filled very carefully with water from the beaker through a custom made funnel. The rest process was similar to the above measurement process. The difference is located on the measurement result. This mass is the total mass of the beaker and water \( W_{\text{w}} \), but with no appeared bubbles anymore.

The data gathering for \( W_{b} \), \( W_{\text{dryw}} \), and \( W_{\text{wbw}} \) were repeated several (6) times respectively. Then, count the water mass difference due to the absence and presence of bubbles inside the cylindrical tube in laboratory temperature around 25 °C.

The air density was calculated using the ordinary formula.

\[
\rho_{\text{dry}} = \frac{P}{RT} \quad \text{.......................... [4]}
\]

where:
\[
\rho_{\text{dry}} = \text{dry unit density (kg/m}^3\text{ or g/l)}
\]
\[
P = \text{atm pressure (Pa)}
\]
\[
R = \text{specific gas constant for dry atm, 287.05 (J/(kg.K)}
\]
\[
T = \text{temperature (K)}
\]

3. EXPERIMENTAL SETUP

The equipment and material for this experiment were setup (Figure 1). The experiment needed WBRGC, balance, beaker, tailor made funnel, dipper, water, and air conditioned room.

A WBRGC comprises three integrated units, namely calibration unit, data processing unit, and calibration authentication unit (Wijonarko et al., 2017). The calibration unit consists of a standard part and a data logger. The main of standard part is a cylindrical tube. The cylindrical part is filled with water that will be used as a rainfall simulator for the rain gauge under calibration. The cylindrical part can be refilled as many the operator like.
A certain balance was needed for this experiment. The balance should be able to show 0.01 g in digital form. It has a span around 3 kg.

During a water filling process, many bubbles may emerge in the cylindrical unit water. Bubbles will be disappeared as soon as the water is flushed, so it is assumed that there is no bubbles accumulation in successive measurements. The water can be reused for the next measurements.

4. RESULT AND DISCUSSION

Entrapped air is caused from the existence of a central cavity that is followed by the closure of the top region of the drop (Hung et al., 2013). The drop in this study that came from water fillings to the cylindrical tube emerged bubbles where some of them were attached on the cylindrical tube (Figure 2). Every filling triggered bubbles with different distributions. This was caused by manual water fillings, so that every filling could not be imitated precisely.
Although water and air are categorized as fluid, the fluid reference for the WBRGC is always water, not air. From equation 4, the density \( \rho \) for air at 25°C is 1.184 g/l. Based on the measurement, the average density of water used in this experiment - calculated from the measurement ratio between its mass and its volume - was around 0.988 g/ml. Hence, the density ratio between air and water was around 0.0012.

Bubbles reduced 1.57 g for every 1011.39 g of cylindrical tube water in a WBRGC (Table 1). Therefore, the bias due to the entrapped air was - 0.16 %. This is a significant number to contribute to the uncertainty of WBRGC (3 ml/966 ml or 0.31 %). The uncertainty of Class A IUT (instrument under test, UUT, unit under test, UUC, unit under calibration) for liquid precipitation is usually \( \geq 5 \% \) (WMO, 2008; 2012). The past requirements of TUR (test uncertainty ratio, the comparison between the accuracy of the UUT and the estimated calibration uncertainty (Bennett & Zion, 2005) and TAR (Test Accuracy Ratio) were 10:1 or 5:1, but now are typically stated as a 4:1 requirement, or 25% of tolerance (Mitutoyo, 2018). For some users, a TUR of 3:1, 2:1 or even 1:1 is acceptable (Bennett & Zion, 2005). A TUR value > 10 is usually unnecessarily expensive (Macii & Petrii, 2003). The TUR for this WBRGC, however, is still \( \geq 10 \) or the uncertainty of WBRGC should be \( \leq 0.5 \% \). Consumer’s risk (CR, user in this case) and producer’s risk (PR, calibration office in this case) can be reduced by high TUR. This can also be used to anticipate technological development that can realize a rain gauge uncertainty < 5 %.

Figure 2. Entrapped air in the water of WBRGC
Table 1. The average value from the data collection process

| ρ_w | ρ_wa | W_b | W_bw | W_bwa | W_w | W_wa |
|-----|------|-----|------|-------|-----|------|
| 0.992 | 0.990 | 532.01 | 1543.40 | 1541.83 | 1011.39 | 1009.82 |

ρ is g/ml, while W is in g

The bias in this study is a representation of void fraction. Void fraction (holdup or fraction in two-phase flows) (Shafquet & Ismail, 2012) in this case is the ratio of the volume of bubbles to the total volume of the cylindrical tube. Two-phase flow consists of two phases in one flow system or it is the interactive motion of two different kinds of media (Shafquet, Ismail, & Karsiti, 2010), where in this case are water and air. The void fraction is significantly affected by the gas (air) velocity (Ismail, Shafquet, & Karsiti 2011) and bubble shape (Liu et al., 2016). All bubbles attached on the tube would be disappearing in around 28 hours. From at least six kinds of bubble forms, namely spherical, wobbling, ellipsoidal, spherical cap, skirted, and dimpled spherical cap (Legendre & Zevenhoven, 2017), the form of bubbles in this study is spherical. It means that the bubbles were in low Reynold Number and Bond Number.

The utilization of tailor made funnel was useful in reducing the appearance of bubbles. This, however, was not sufficient to diminish bubbles especially seen by naked eyes. Some bubbles were still present particularly at the bottom and at the top of cylindrical tube when the water filling was not carried out carefully. Hence, a new work out should be initiated, such as using high voltage pulses (van Heesch, 1994).

5. CONCLUSION AND SUGGESTION

The bias due to bubbles to the web based rain gauge calibrator was around -0.16 %, or the absolute value of bias was 0.16 %. This bias was too big compared to the uncertainty of WBRGC when there were no bubbles (0.31 %). If the bias due to bubbles can be coped, the uncertainty should be better.

ACKNOWLEDGEMENT

The funding for this study was obtained from LIPI 2017.

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