

# THE MAIN PURPOSE FOR THE APPLICATION OF DOUBLE LAYER TIPPING BUCKET SENSORS IN RAINFALL MEASUREMENTS

## *TUJUAN UTAMA PENERAPAN SENSOR-SENSOR CAWAN BERJUNGKIT DUA TINGKAT DALAM PENGUKURAN CURAH HUJAN*

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### **ABSTRACT**

The aim of this study is to investigate the main purpose for the utilization of double layer tipping bucket sensors, such as installed in Tegal Climatological Station (TCS), Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG). Hydraulic to electric analogy and rainfall interception models from Calder, Rutter, and Gash are used as the investigation method. The result shows that double layer tipping bucket sensors are dedicated to measure high intensity rainfalls.

**Keywords:** double layer tipping bucket sensor, rainfall, rain intensity, hydraulic to electric analogy

### **ABSTRAK**

*Tujuan dari studi ini adalah untuk menyelidiki tujuan utama penggunaan sensor-sensor cawan berjungkit dua tingkat, seperti yang dipasang di Stasiun Klimatologi Tegal, Badan Meteorologi, Klimatologi, dan Geofisika Indonesia (BMKG). Analogi hidraulik ke listrik dan model-model intersepsi curah hujan dari Calder, Rutter, dan Gash digunakan sebagai metode investigasi. Hasilnya menunjukkan bahwa sensor cawan berjungkit dua tingkat didedikasikan untuk mengukur curah hujan dengan intensitas tinggi.*

**Kata kunci:** sensor cawan berjungkit dua tingkat, curah hujan, intensitas hujan, analogi hidraulik ke listrik

## **A. INTRODUCTION**

TCS of the BMKG has a very rare rain gauge which is called double layer tipping bucket sensor. Unfortunately, this sensor was not equipped with its manual or other supporting information. Rain gauges in Indonesia are dominated with observatory, Hellman and tipping bucket types (Maftukhah, Wijonarko, & Rustandi, 2016). Hence, exploring further information about the manual of double layer tipping bucket sensor from concerned departments, agencies or institutes in Indonesia gave no result.

Double layer tipping bucket sensor was not a favorite rain gauge. From some WMO rain gauge intercomparison, no participant countries used double layer tipping buckets in the intercomparison events (Yang et al., 1998; Goodison, Louie, & Yang, 1998; Lanza, Leroy, Alexandropoulos, Stagi, & Wauben, n.d.; Lanza & Stagi, n.d.). Even, there was no information

concerning the use of the double layer tipping bucket sensor from some WMO documents such as WMO-N0. 49 (WMO, 2006), WMO-N0. 488 (WMO, 2007), WMO-N0. 8 (WMO, 2008a), and WMO-N0. 168 (WMO, 2008b; WMO, 2009). This means that the application of double layer tipping bucket sensors in many countries throughout the world is also very limited. It is not known whether the double layer tipping bucket sensor is a new type so that it is not used widely in many countries yet, especially in developed countries. Therefore, it is reasonable that articles concerning this sensor, particularly its philosophical aspect, were difficult to find.

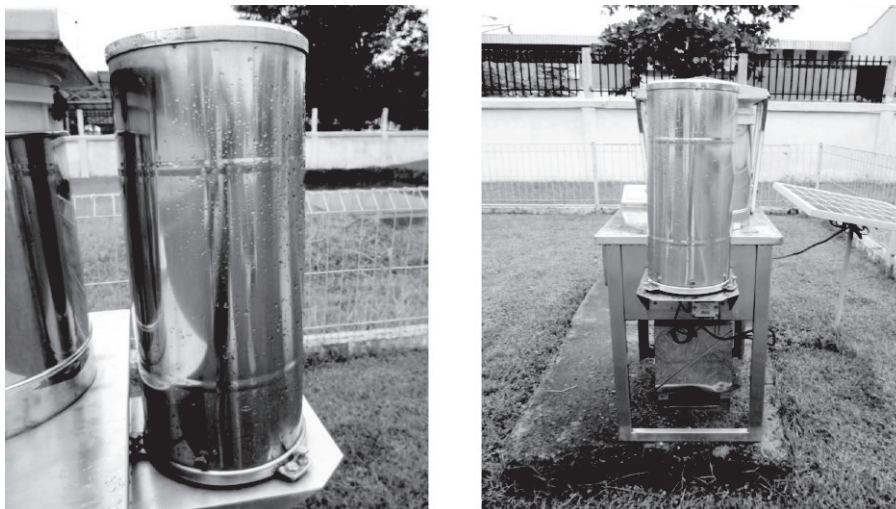
The purpose of this study is to investigate the main aim for the employment of double layer tipping bucket sensors based on sensor in TCS. As soon as the result is obtained, ideas for further innovation to this technological asset might be created. The analysis of this paper is highlighted on the parts which are generally not used in single layer tipping bucket sensors.

## B. BASIC THEORY

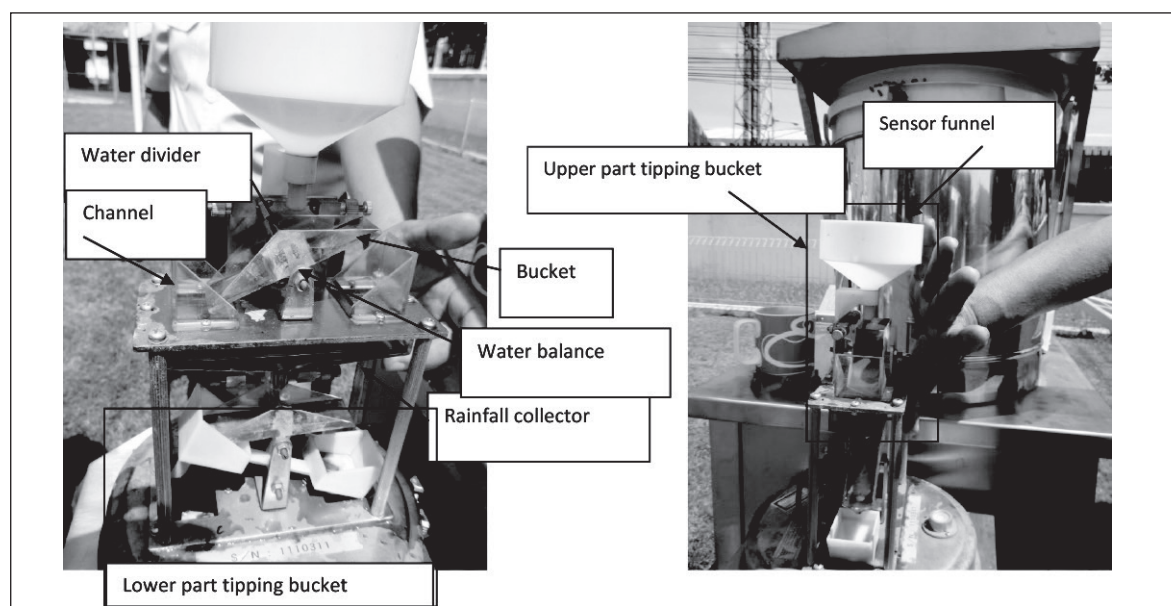
In a complete condition, a double layer tipping bucket sensor (Figure 1) seems like a single layer tipping bucket sensor. The differences may be only on their height and weight. Normally, the double layer tipping bucket sensor should be higher and heavier than the single one.

As soon as the casing is open, the shape of both sensors can be differentiated immediately. The main difference is located on the quantity of tipping bucket, namely two pairs for the double layer tipping bucket sensor (Figure 2) and one

pair for the single layer tipping bucket sensor. The next description will be highlighted on the front parts of the double layer tipping bucket, while the description of rear parts might be obtained for example from some articles on the references (Hampton, 2016a; Hampton, 2016b; Hampton, 2016c; Plummer, Allsopp, & Lopez, 2003; Hodgkinson, Pepper, & Wilson, 2004; Lukito, Sunarjo, & Rimba, n.d.; Environmental Measurements Limited, n.d.; Wijonarko & Maftukhah, 2014; Wijonarko & Maftukhah, 2016; Maftukhah, Wijonarko, & Rustandi, 2016; Wijonarko, Maftukhah, & Rustandi, 2017).



**Figure 1.** A Covered Double Layer Tipping Bucket Sensor in TCS from Front and Side Views



**Figure 2.** An Uncovered Double Layer Tipping Bucket Sensor in TCS from Front and Side Views

The upper part of the tipping bucket is not directly used for rainfall measurements. Hence, there are no additional components for data readings on the upper part. This top layer is utilized as a rainfall distributor to its rainfall collector.

The collector is used to save for a while some rainfall water especially needed during extreme rains. This water is then distributed via an air media to the lower part tipping bucket for measurement processes.

### C. METHODOLOGY

There are two main methods applied in this study. Analogy of hydraulic or mechanical quantities to electrical quantities (Firestone, 1933) is the first method. The transformation model from the hydraulic model to the electric model is chosen because the electric concepts and theories are proven method to analyze electrical networks both in small and large scales. The analogy method has also been used by some researchers, such as Verbeeck et al. (2007) and Wang (2008) to explain a transpiration process.

The second method is adopted from some interception models. A water filling process in the collector of a double layer tipping bucket sensor is almost similar to an interception process on plant leaves and branches. The interception models are proven models. The adoption of the proven methods means the use of strong foundations from the methodology aspect.

The second method consists of some principles where the first principle is taken from Rutter Model (Rutter, Kershaw, Robins, & Morton, 1971) as

$$\sum I = \sum E = \sum R = \sum T \quad (1)$$

where,

- I : interception (mm)
- E : evaporation (mm)
- R : rainfall (mm)
- T : throughfall (mm)

Wani and Manhas (2012) added stemflow variable for the second formula. From this formula, it is clear that Rutter model is based on a running water balance (Gash & Morton,

1978). In this model, the change in the amount of water entering a system is equal to the sum of changes in the amount of water in the process and the output.

The second principle is Calder model. Calder has published some models, e.g. a model of evaporation loss (Calder, 1977), transpiration model (Calder, 1992), and model prediction of lake level (Calder et al., 1995). For this case, the model that will be adopted is Calder's stochastic model (Calder, Wright, & Murdiyarso, 1986), namely a model that uses Poisson probability statistics (Calder, Hall, Rosier, Bastable, & Prasanna, 1996). Calder (1986) wrote that if a surface area consists of elemental areas, then the Poisson probabilities  $P_0, P_1, P_2, \dots, P_r$  of elements being struck by 0, 1, 2, ..., r raindrops is then given by:

$$\sum_{x=0}^r P_x = e^{-m} + \frac{m}{1!} e^{-m} + \frac{m^2}{2!} e^{-m} \dots \frac{m^r}{r!} e^{-m} \quad (2)$$

The variable  $m$  is the mean number of raindrop strikes per element (Hall, 1992; Calder, 1996a; Calder, 1996b). From this formula, it can be seen that every spot on the earth surface might have different possibilities.

The third principle is the analytical model of Gash that classifies the model based on small storms and heavy storms (Valente, David, & Gash, 1997). According to Návar & Bryan (1994), the complete formula is shown in Equation (3).

$$\sum_{j=1}^{n+m} I_j = (1-p-p_t) \sum_{j=1}^m P_{Gj} + \frac{E}{R} \sum_{j=1}^n (P_{Gj} - P'_{Gj}) + qS_t + p_t \sum_{j=1}^{m+n} P_{Gj} \quad (3)$$

where,

$\sum_{j=1}^{n+m} I_j$  : the total interception (mm)

$n$  : the number of storms which would saturate the canopy

$m$  : the number of storms which would not saturate the canopy

$q$  : the number of storms which would saturate the trunks ( $\text{rainfall} > S_t/P_t$ )

$S_t$  : trunk water store (mm)

$\overline{E}$  : the average evaporation rate taking place during the storm after canopy saturation (mm/h)

$\overline{R}$  : the average rainfall rate onto a saturated canopy (mm/h)

$p$  : the free throughfall coefficient

$p_t$  : the stemflow proportion

$P'_G$  : the rainfall necessary to achieve canopy saturation (mm)

$P_{Gf}$  : the gross rainfall (mm)

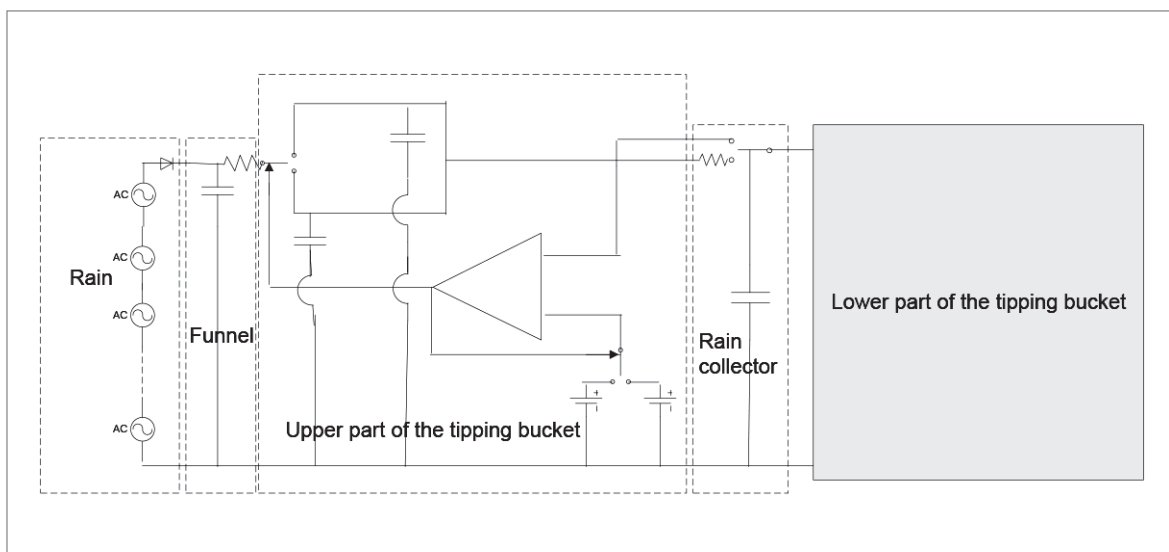
For heavy rain events, interception of rain has several phases called as a wetting-up (rainfall which is less than the threshold value necessary to saturate the canopy) period, a period of saturation and a period of drying out after rainfall ceases (Gash, Lloyd, & Lachaud, 1995). At the time of saturation, drips occur. On the contrary, there are no saturation and no drips for small rains.

## D. RESULT AND DISCUSSION

Applying the first method and the first principle, a double layer tipping bucket sensor with its measurands can be presented in the form of an electrical circuit (Figure 3) that comprises both active and passive components. A double layer tipping bucket sensor is the integration of a funnel, an upper part of the tipping bucket (dummy sensor), a rainfall collector, a lower part of the tipping bucket (real sensor), and a supporting part. Parts from measurands to the rainfall collector are analyzed one by one.

Measurands in this case are rainfall and rain intensity. For a double layer tipping bucket sensor, rainfall and rain intensity are two parameters in one measurement. Although in one object, they are different.

Rainfall represents a distribution of differently sized drops that attain corresponding different terminal velocities in stable air (van-Dijk, Bruijnzeel, & Rosewell, 2012) or is the rain variable that shows the depth of rain, that usually expressed in mm unit. One millimeter of rainfall is the volume of one liter of rainwater that falls on one square meter of the earth's surface. Data obtained from measurements of rainfall are usually expressed in daily, monthly or yearly forms. The amount of rainfall is not constant to times, but there is a tendency that the magnitude is increasing in the future due to global climate change (McClatchey, Devoy, Woolf, Bremner, & James, 2014). This means



**Figure 3.** An Electrical Analogy of A Double Layer Tipping Bucket Sensor



that rainfall amount, duration, and/or intensity will be increasing in the future.

Rain intensity is the amount of precipitation collected per unit time interval (Lanza, Leroy, Alexandropoulos, Stagi, & Wauben, n.d.) or rainfall per unit of time, such as second, minute, hour, and day. In many application, the intensity of rain is usually expressed in mm/hour or mm/day. The rain intensity can vary between 0–2000 mm/hour (WMO, 2008a).

Due to the above difference, it is sometimes necessary to differentiate between rainfall gauges (rain gauges) and rain intensity gauges. There are some instruments that can only be used to measure rainfall or rain intensity, but there are also some instruments that can be utilized to measure both parameters together.

Rain characteristics are discrete (Valente et al., 1997; Šraj, Brilly, & Mikoš, 2008), changing over time (Zeng, Shuttleworth, & Gash, 2000), and place (Rodrigo & Àvila, 2001). The number of rain drops for every spot on the earth surface may have different possibilities (the second principle). These statements mean that rainfalls can be represented by a series of AC generators and a diode. The number of AC generators is depended on the number of the rain drops while the voltage of each generator is a function of rain intensity at every rain drop. Rain enters the system from the air or above the double layer tipping bucket sensor. Hence, although it is not constant, the voltage or current from the AC generators actually is fluctuated, but always positive. That is why a diode is connected on the circuit at the phase line of the AC generator series.

The sensor funnel collects all rainfalls falling in it. So, it works like a water collector and regulator. In the electrical circuit, the funnel body is represented with a capacitor. This capacitor will works as a collector that saves electrical charges and work as a regulator that makes ripples from the AC generators much smoother. Hence, the output from the capacitor looks like a DC generator, but its voltage or current is superseded with smooth ripples.

The outlet diameter of the funnel is smaller than its inlet diameter. So, the outlet might be represented with a resistance. The higher the

ratio between the outlet and inlet diameters, the smaller the resistance. The smaller the resistance, the higher the water discharges from the funnel.

The upper part of the tipping bucket actually is a part that consists of a water divider, two buckets, two channels, and a water balance. These components can be represented with a single pole double throw (SPDT) switch, two capacitors, two conductors, and a comparator with two reference voltages. On Figure 3, the water divider can be represented as a SPDT with two outputs connected to each other. As soon as a certain volume of water on one of the buckets (collectors or capacitors) is exceeded, the SPDT changes over to the other output. The water from the upper bucket, for example, goes to the right channel (conductor A). The process will be repeated for the other bucket and the other channel (conductor B). The process couple shows the mechanism of a water balance. The water balance will go on automatically until no sufficient water to alternate the water divider (SPDT).

The water divider movement is triggered by the equilibrium of the buckets. As soon as the weight of upper part bucket (1A) and its water in it is heavier than the weight of lower part bucket (1B), the water divider moves from right to left. The lower part bucket now becomes the upper part bucket. When the weight of upper part bucket (1B) and its water in it is heavier than the weight of lower part bucket (1A), the water divider moves from left to right. The triggering mechanism can be represented with a comparator. The inputs of the comparator are the weight of upper part bucket and its water (1A or 1B) on one side and lower part bucket on the other side (1B or 1A). The weight of the higher part bucket and its water in it can be replaced with an input voltage, and the weight of the lower part bucket can be changed with a reference voltage. The reference voltage VA is used to compare the voltage from 1B, and the reference voltage VB is used to compare the voltage from 1A. The output of the comparator is a signal that is able to change over the SPDT outputs.

The output of upper part tipping bucket is conducted to a rainfall collector. There are two ways at the input of the rain collector. The first way is used for the discharge that is equal or lower to the maximum capacity of the rain collector. The second way is utilized for the discharge that is bigger than the maximum capacity of the rain collector. For the first case, water goes totally to the rain collector; while for the second possibility, the water excess is spilled out. These phenomena can be represented with a resistance and a conductor that are connected at their output to the body of the rain collector. Their inputs, however, are separated and used alternately based on the case. In the first case, the conductor is selected. For the second case, the resistance is chosen. The selection mechanism is controlled with a comparator that triggers a SPDT.

A rainfall collector consists of a collector with its outlet which is smaller than its inlet. So, the rainfall collector can be represented as a circuit with a capacitor and a resistance on it. In other words, the rainfall collector works as a low pass filter. The lower the input frequency, the better the result on the output is. So, the main task of this collector is to reduce the intensity of rainwater.

Rain for a double layer tipping bucket sensor can be classified into three, i.e. under saturated condition, saturated condition, and over saturated condition. They are water drops where the rainfall is only able to fill a portion of rainfall collector (tank, reservoir), fully cover the whole tank, and surpass the reservoir capacity respectively.

In case of under saturated condition, this system works like a Gash model for small rainfall interception. Ideally, quantity of the incoming rainfall to the sensor equals to the outgoing rainfall from the sensor. The rain intensity is presented by the sensor almost exactly as its original characteristics. So, this kind of measurement can be called as a real time measurement because the time difference between the input and output is only caused by the rainfall collection and measurement process.

At saturated condition, no rainfall is lost. The measurement intensity, however, is lower

than the real intensity. The real intensity occurs during wetting up and saturated time, while the measurement intensity happens from wetting up to drying up time (the third principle). So, the measurement time is slightly lagging from the real intensity due to the drying up process.

At over saturated condition, a part of rainfalls is lost because it is directly wasted to the earth surface. The quantity of this lost, however, is unknown, because there is no sensor to measure water from the spill way. Although, the wetting-up process at over saturated condition is quicker than that at saturated condition, while their drying-up processes are the same.

Briefly, there is a difference if the system operates under saturated, saturated, and over saturated conditions. At the under saturated condition, the value of measurands (rainfall and its intensity) is almost the same with the measurement result. At saturated condition, the value of rainfall almost equals to the measurement result, but the intensity is bigger than the measurement result. At over saturated condition, rainfall and intensity values are bigger than the measurement results because there are losses due the exceeding water.

Measurands, a funnel, an upper part tipping bucket, and a rainfall collector have been described. The remaining parts, namely a lower part of the tipping bucket and supporting parts are not discussed further because they work like a single layer tipping bucket sensor.

From the above description, it is seen that the upper part tipping bucket and rain collector work like a low pass filter which in this case serves to pass low intensity rainfall and withstand high intensity rainfall. Therefore in making and using a double layer tipping bucket, it is necessary to know the maximum intensity that can be measured and the duration of rain with intensity which is higher than sensor ability. The multiplication of intensity, duration, and sensor area should be less than the rain collector capacity. Otherwise, rainfall or rain intensity can not be measured correctly.

Results of the WMO intercomparison for rain gauges in 2004 showed that the error of rain gauges tend to increase with rain intensity (Yang et al., 1998; Lanza, Vuerich, & Gnecco,

2010). The double layer tipping bucket sensor looks to be designed to cope this kind of problem by increasing its capability to measure high intensity rainfall. This statement is strengthened by the study of Stagnaro, Colli, Lanza, and Chan (2016) who show that double layer tipping bucket is able to measure rain intensity 240 mm/hour, while single layer tipping bucket is 200 mm/hour.

## E. CONCLUSION AND RECOMMENDATION

The main purpose for the application of double layer tipping bucket sensors is to measure high intensity rainfall by sacrificing the real rain intensity measurement. Should the capacity of rain collector is surpassed, the sensor does not work accurately. So, attention should be paid for sensor design process that is suitable with rain characteristics at the installation location.

In order to have better data, it is, therefore, recommended that this sensor is assessed deeper. If it is feasible, then it is made and applied especially for high rainfall intensity areas.

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