Design of an improvised tipping bucket rain gauge for measurement of rain and snow precipitation

Rajiv Kumar Das*

Snow and Avalanche Study Establishment (SASE),
Ministry of Defence, Government of India,
Him Parisar, Plot-1, Sector-37A,
Chandigarh – 160036, India
Fax: 0172-2699970
E-mail: rkd.421@gmail.com
*Corresponding author

Neelam Rup Prakash

Department of Electronics and
Electrical Communication Engineering,
PEC University of Technology,
Sector-12, Chandigarh – 160036, India
E-mail: neelamprakash@pec.ac.in

Abstract: Snow water equivalent is the amount of water contained within a snowpack. It is important to have accurate and timely winter precipitation information for agriculture and especially for flood and stream flow forecasting. Moreover, if the density of the snow is known, then the snow water equivalent data can be used to determine snow depth which is an important parameter for avalanche forecasting (McClung and Schaerer, 1993). In this paper, the design of a new tipping bucket rain gauge (TBRG) and an antifreeze-based attachment have been discussed which would measure rain as well as snow precipitation. The TBRG and the antifreeze-based attachment have been designed to reduce the shortcomings of commercial TBRGs and antifreeze-based attachments. Our TBRG provides faster rain and snow water equivalent data. The highest measurement rate for rain and snow water equivalent is found to be 375 mm/hr and 16.4 mm/hr respectively. The design considerations, field and laboratory trials and results of the TBRG and the antifreeze-based attachment have been discussed in detail in this paper.

Keywords: tipping bucket rain gauge; TBRG; proximity sensor; antifreeze attachment; snow precipitation measurement.


Biographical notes: Rajiv Kumar Das received his BTech in Electronics and Communication Engineering from the National Institute of Technology Hamirpur, India in 2000 and ME in Electronics Engineering from the PEC, Chandigarh in 2009. Presently, he is working as Scientist ‘D’ at the Snow and Avalanche Study Establishment (SASE), Chandigarh under Defence
Design of an improvised tipping bucket rain gauge

Research and Development Organisation, Government of India. Instruments developed by him include: contact-less tipping bucket rain gauge, improvised anti-freeze-based attachment for tipping bucket rain gauges, stand-alone snow temperature profiler, hand-held portable snow temperature profiler, instrument for measurement of extinction coefficient of snow, datalogging system for radiometers, solar charging system for WSN motes and 3-axis sonic wind sensor.

Neelam Rup Prakash received her BE, ME and PhD from the PEC University of Technology, Chandigarh, India. Presently, she is working as Professor in the Department of Electronics and Electrical Communication Engineering at the PEC. She is an expert in the field of digital system design, computer aided diagnostic systems and digital communication. She has guided more than ten PhD and MTech theses.

1 Introduction

The tipping bucket rain gauge (TBRG) consists of a large cylinder fixed to the ground. At the top of the cylinder is a funnel that collects and channels the precipitation. The precipitation falls onto one of two small buckets or levers which are balanced in the same manner as a scale or a child’s seesaw. After an amount of precipitation has fallen, the lever tips which varies from manufacturer to manufacturer depending on the size, weight and design of the lever and an electrical signal is sent to the recorder. Modern TBRGs consist of a plastic or metallic collector balanced over a pivot. When it tips, it actuates a switch which is then electronically recorded. TBRGs have been often used in hydro-meteorological instrumentation such as rain-gauges or stem flow metres (White and Rhodes, 1970), for run-off measurements (Pillbury et al., 1962; Edwards et al., 1974; Khan and Ong, 1997). They are also used in wick samplers and lysimeters for the measurement and sampling of seepage water and for multi-compartment sampling (Meissner et al., 2010). The major disadvantages of these tipping buckets are:

1. The amount of precipitation at which the lever of the rain gauge tips, varies for different manufacturers and models, affecting the resolution of the tipping bucket.

2. The actuating electronics used in most TBRGs are magnetically actuated proximity switches. These switches are very sensitive to interference from other nearby magnetic fields or electromagnets with field strength greater than 0.16 mT (application note, magnetically actuated proximity sensors, Festo Corporation, USA 2005). The disadvantages of using such switch sensors include contact bounce and limited device life due to presence of mechanical element like in the Reed switch.

3. The use of inductive-magnetic proximity sensor has the disadvantage that its performance may be affected by the presence of nearby ferromagnetic materials. Moreover, when inductive loads are switched, a high voltage peak occurs due to opening of the contacts and for this reason, extra protective circuitry is required for using such switches (application note, magnetically actuated proximity sensors, Festo Corporation, USA 2005).
4 In magnetically actuated proximity sensors like the Reed switch, the use of a long cable is not advisable as a significant capacitance can exist between the conductors which can discharge across the switch as it closes (user guide, Model R102/R102H-C TBRG, Campbell Scientific Inc., UK 1998). This not only shortens the life of the switch but also a voltage transient may be induced in any other wire which run close to the rain gauge cable each time the bucket tips.

5 TBRGs suffer from under-catch as compared to the actual amount of rainfall as the rain rate (or rain intensity) increases. The reason for under-catch is that rain is not measured during the finite time required for the bucket to tip from one side to the other (Duchon and Essenberg, 2001; Duchon and Biddle, 2010; Savina et al., 2010).

6 The TBRG is not as accurate as the standard rain gauge because the rainfall may stop before the lever has tipped. When the next period of rain begins it may take no more than one or two drops to tip the lever. This would then indicate that more rain has fallen when in fact only a minute amount has. The error will be more when the volume of tip is large (http://en.wikipedia.org/wiki/Rain_gauge; Yu et al., 1997; Nehls et al., 2010).

An effort has been made to design and develop a new contact-less TBRG using capacitive proximity sensor to solve the disadvantages mentioned above. Effort has also been made to utilise the tipping bucket to measure snow precipitation. The commercially available antifreeze-based attachment for TBRG to measure snow precipitation has inherent delays and is not suitable for real-time precipitation measurements. For rainfall at 25°C, a delay of several minutes is expected after the rain gauge receives a minimum accumulation of ~0.03 inch. For snowfall, a delay of few hours to tens of hours is expected. The longest delays should be expected for low density snow at very cold air temperatures (McCaughey and Farnes, 1996). However, all precipitation falling into the catch tube of the rain gauge eventually flows through the overflow tube and is measured by the tipping bucket below. Apart from the delay, it is seen that the orifice of the antifreeze-based gauge is susceptible to capping or snow bridging. An antifreeze-based attachment for the TBRG has been designed to measure snow precipitation which would overcome the inherent delays. The paper discusses the design and development, field trials and the results of the tipping bucket and the antifreeze attachment.

2 Tipping bucket rain gauge

The design of the new tipping bucket was made so that the disadvantages in the common tipping buckets could be removed or reduced. The principle of operation of the TBRG was to count the number of tips of the tipping lever and convert it to the volume of liquid at which the lever is adjusted to make a tip. The following changes were incorporated in the design of a common TBRG to overcome the disadvantages discussed in the preceding paragraphs:

1 Two adjustable stoppers were incorporated on either side of the lever, so that the volume at which the lever tips could be adjusted (Wilford, 1984). This would provide the user the facility to change the resolution of the rain gauge. The resolution of the tipping bucket could be varied from 10 ml to 50 ml.
2 The actuating electronics to count the tips was changed to non-contact type capacitive proximity sensor. A capacitive proximity sensor, CJ8-18GM-E of Pepperl and Fuch, was used. Capacitive proximity sensors are not influenced by magnetic fields and do not require any extra circuitry for proper operation.

3 An interrupter was fitted on the tipping lever so that a single proximity sensor could count tips of the lever in both directions.

2.1 Design and development

A 43 cm (17 inch) long aluminium tube of 2 mm gage and having a diameter of 32 cm was used to make the catch tube of the tipping bucket. A window of five square inch was cut into the tube and then covered with a transparent acrylic glass sheet. The window was made to observe water spill from the levers if any, during testing. The base plate for the tipping bucket was also made from aluminium metal. A bubble leveller was fitted onto the base plate for levelling of the tipping bucket during installation. The base plate had hooks to clamp the catch tube tightly to it. It could be bolted onto a concrete platform with metallic bolts. A funnel was made from aluminium sheet of 1 mm gage and fitted inside the catch tube. The dimensions are shown in Figure 1.

Figure 1 The tipping bucket design

The tipping lever was made from acrylic sheet. It was made 20 cm long and 4 cm wide and a partition of 4 cm high was put at the centre so that the lever was divided into two equal water collecting portions. A ‘⊃-shaped’ very thin sheet of aluminium was attached to one side of the tipping lever which acted as an interrupter for the proximity sensor. This interrupter helped in counting the tips of the lever on both the sides using only one proximity sensor because either the upper part or the lower part of the interrupter would come in front of the sensor after a tip has occurred and thus would enable the sensor to
count the tips in either direction. The width of the interrupter was kept such that misreading due to contact bounce of the lever could be overcome. This is shown in Figure 2.

**Figure 2** The aluminium interrupter

A 5 cm long metallic rod of 0.4 cm diameter was fitted at the centre and bottom of the tipping lever which acted as the axle. Two sealed roller bearings were then fitted on each side of the rod to facilitate free movement of the lever. The bearings were themselves fitted in two press fit type bearing retainers. Two adjustable stoppers were put below either side of the tipping lever for adjusting the tip volume and correcting any mismatch in balance of the lever. The stoppers could be screwed into the base for increasing the volume of the tip (up to 50 ml) and unscrewed from the base to reduce the volume of the tip (up to 10 ml). The lever arrangement was fitted onto the base plate of the tipping bucket. The proximity sensor was placed in front of the interrupter. The fitment of the proximity sensor was made such that the sensor could be adjusted for height and proximity. A Campbell Scientific Inc., make data logger, model CR23X, was programmed to log data from the rain gauge. The lever arrangement after it was fitted onto the base plate along with the proximity sensor and the datalogger is shown in Figure 3.

**Figure 3** The tipping lever arrangement with proximity sensor and datalogger
2.2 Trials

2.2.1 Laboratory tests

The TBRG was tested in the Electronics and Instrumentation Laboratory of Snow and Avalanche Study Establishment (SASE) for finding possible flaws in welding, leakage, loose parts, etc. Splashing of water during movement of the tipping levers was also checked. Splashing from the partition of the lever occur most when the resolution of the tip is kept maximum or in other words when the lever tips at minimum volume of water. This is because when the lever is adjusted to tip at lesser volume then it will tip at much faster rate. This means that the partition will come in front of water flow from the funnel more frequently resulting in more spillage. As the tipping bucket is designed for operation between 10 ml to 50 ml resolution, tests for finding out highest rain rate measurement capability was carried out by adjusting the tip of the lever to 10 ml volume or 0.1240 mm height of rainfall.

The rain rate measurement capability was tested by simulating steady water flow from a tap fitted with a shower on to the funnel of the tipping bucket from a height of 1 m. Water at different rates was allowed to fall on the funnel for a duration of five minutes each. The water that had fallen on the funnel and measured by the tipping bucket was then collected and the difference with the tipping bucket reading was compared for calculation of error in measurement.

The TBRG was tested for prolonged duration with a shielded Teflon cable of 30 m length to connect the capacitive proximity sensor to the datalogger. This was done to observe the affect of long cable length on the performance of the proximity sensor.

2.2.2 Field trials

The TBRG was installed in the observatory area of SASE, Chandigarh (longitude: 76° 47' East, latitude: 30° 43' North) which is at an altitude of 350 m from sea level. The rainfall measurements were made during July–August of 2008. The tipping bucket was installed on a slightly raised concrete platform 4 metres away from the data logger. The data logger continuously logged data during the trial period. Data was also received wirelessly at a central receiving station, a few metres away, via a radio modem.

2.3 Results

During laboratory tests, it was observed that splashing of water is insignificant at lower rain rate; however it became quite significant (accuracy fell below 4%) at higher rain rates above 375 mm/hr which for this particular design meant a rate above 500 ml of water per minute. This can be taken as the upper limit for rain rate measurement of the tipping bucket. Splashing from the funnel of the tipping bucket was not found significant below 500 ml/min. It was also observed that longer cable lengths do not hamper the performance of capacitive proximity sensors.

The tipping bucket was tested from 31st July to 23rd August 2008. It was able to measure and log data satisfactorily. There were 14 days when rain was recorded in the area in this period. The resolution of the tip was adjusted to 10 ml using the adjustable stoppers which gave the least count (resolution) of each tip as 0.1240 mm. The data was compared with the data of a standard rain gauge of 0.1 mm resolution. The data showed
excellent correlation of 0.99 and rms error of 0.57. The graph showing the tipping bucket and the rain gauge readings is shown in Figure 4.

**Figure 4** The tipping bucket and the rain gauge readings for July–August 2008

During this period a total of 612.4 mm of rain fall was recorded by the rain gauge while the TBRG recorded a total of 605.3 mm, a difference of 7.1 mm (−1.15%).

3 Antifreeze-based attachment for snow precipitation measurement

There are two ways to use the TBRG to measure snow precipitation. First is to make arrangement of heaters inside the rain gauge to melt solid precipitation. Such TBRGs are called heated tipping buckets. Heated tipping buckets have many deficiencies like requirement of AC power which is generally not available in the remote field locations (AgriMet precipitation measurements – Bureau of Reclamation web link http://www.usbr.gov/pn/agrimet/precip.html). Moreover, during melting by the heaters, significant amounts of the precipitation evaporate due to power and position of the heaters (Yigit and Cakil, 2006). Another loss occurs when snowflakes are deflected away from the collector by the warm air rising from the gauge when the heaters are operating. Also, snow may sublimate if the gage is kept much above freezing.

Another way of using the TBRG for snow precipitation measurement is to use an antifreeze-based attachment with it. The first antifreeze-based attachment was suggested by McCaughey and Farnes in 1996. The whole system consists of a catch tube, an antifreeze reservoir and an overflow tube. Snow captured in the catch tube slowly melts into the antifreeze solution contained in the antifreeze reservoir which prevents the water from freezing. As the snow melts, the level in the antifreeze reservoir rises. This change
in level results in a mixture of antifreeze and water flowing through the overflow tube to
the funnel of the tipping bucket where it is measured.

The commercially available antifreeze-based attachment for TBRG to measure snow
precipitation has inherent delays and is a drawback for real-time precipitation
measurements. Recent studies have showed a substantial delay (on the order of
20–30 min) in identifying the beginning of snowfall events (Savina et al., 2010). Three
factors contribute to the delays (McCaughey and Farnes, 1996):
1 surface tension in the overflow tube
2 the form of the precipitation
3 temperatures of air and liquid in the reservoir.

For rainfall, delays of several minutes could be expected, while for snowfall, delays of
several hours could be expected. The longest delays occur for low density snow at very
low air temperatures. Apart from the above disadvantages, the orifice of the catch tube is
also susceptible to capping or snow bridging.

3.1 Design and development

An attachment to hold antifreeze liquid was constructed that could be fitted on top of the
new tipping bucket. The design considerations for an antifreeze attachment are discussed
in the following paragraphs which can be used with the new TBRG for the measurement
of snow precipitation. The design suggested mainly concentrates on removal or reduction
of the inherent delays in commercial antifreeze-based systems.

3.1.1 Reduction of delay due to surface tension in the overflow tube

It could be observed that two main elements influence the antifreeze flow rate in the
commercial antifreeze system (Carcoana and Enz, 2000).
1 wrinkles on the arched area of the overflow tube
2 surface tension of the antifreeze solution which accumulates in overflow tube
creating a ‘dam like’ restriction until ‘bursting’ down creating unreal (time wise)
and/or delayed values.

During manufacturing process, the overflow tube gets bent and wrinkled that could be
observed in the commercial antifreeze system. The wrinkles delay the free overflow of
the antifreeze solution creating a ‘dam’ effect followed by a spontaneous spill called the
‘burst’ effect. To overcome this, an inverted V-shaped overflow tube was constructed and
fitted inside the antifreeze reservoir that would considerably reduce the delay in readings
of the tipping bucket as compared to the round overflow tube (Carcoana and Enz, 2000).
A slit was made at the top of the overflow tube to prevent the tube from developing a
siphon.

The surface tension in the antifreeze solution could be diminished by adding 300-400
grams of surfactant to the existing mixture of antifreeze (McGurk, 1992). The surfactant
would reduce the surface tension of nearly any aqueous solution. In this specific case the
added surfactant would decrease the overflow spill time and eliminate the delay from the
first drop in until the first drop out. It would also improve the flow uniformity by
eliminating the ‘burst’ created by the accumulation due to the surface tension. It is also necessary that an antifreeze liquid of appropriate density be used. The right density of an effective rain gauge antifreeze liquid is about 0.995 kg/l, so that the undiluted antifreeze floats between the evaporation inhibiting oil layer and the water-antifreeze mixture (McSaveney, 1979). Such an antifreeze liquid can be made by mixing almost equal quantities of commercial antifreeze (like ethylene glycol) and methylated spirits (like methanol).

3.1.2 Reduction of delay due to form of the precipitation

The longest delays of the commercial antifreeze-based TBRGs are expected for low density snow at very low air temperatures. During snow events, snow accumulates on the top of the overflow tube for a period of time before melting. An internal snow cap forms by build up of snow on the overflow tube and by sticking onto the sidewalls of the catchment tube (McCaughey and Farnes, 1996). To reduce this delay, two U-shaped heaters of nichrome element were fitted inside the antifreeze reservoir. The heaters consumed approximately 2 amps of current at 24 V DC delivering a total output power of approximately 48 watts. The level of current was not controlled. The heaters would get activated as soon as snow fall starts, according to the algorithm discussed in the next section, and provide heat to the antifreeze liquid and the tube. This would prevent the formation of snow cap or snow bridge at the orifice of the gauge and will increase the rate of melting of the snow and thereby reducing the delay in recording the actual precipitation. The design of the improvised antifreeze attachment is shown in Figure 5.

All the parts of the attachment were made from aluminium. The catch tube and the antifreeze reservoir were made as a single unit which could be fitted onto the top of the TBRG. The V-shaped overflow tube was fitted at the centre of the reservoir. The heaters were fixed on the bottom plate of the catch tube and drew current from the battery via a relay. A thermistor was also fitted inside the antifreeze reservoir. This sensor provided temperature information of the antifreeze liquid to the datalogger which was used in the algorithm to control the switching of the heaters.

**Figure 5** The antifreeze attachment design
3.1.3 Heater control algorithm

The deployment of the tipping bucket along with the antifreeze attachment would raise an important point of concern. The use of the heaters in the antifreeze attachment would consume about 2 A of current which is of concern for long term standalone operation of the instrument as the sole power source of the instrument would be two 12 V, 50 Ah batteries connected in series. Though the batteries could be solar charged, yet taking into account no sunshine days during winters, it becomes necessary to regulate the operation of the heaters.

SASE has been using automatic weather stations (AWS) equipped with various sensors for acquisition of snow and meteorological data. These AWSs are installed at remote snow bound locations which remain inaccessible to human even for three to four months. In such a scenario, large consumption of power may disrupt the functioning of the whole AWS let alone a single sensor. Therefore, for continuous operation of the tipping bucket at such remote locations, an algorithm has been suggested for controlling the switching ON and OFF of the heaters which would minimise the power consumption from the battery of the system. The flow chart of the algorithm is shown in Figure 6.

One of the many snow-met sensors integrated to the AWS that SASE is using is the pyranometer which is used for measurement of solar radiation. This sensor along with a precipitation detector, like the Vaisala DRD11A, and the thermistor in the antifreeze reservoir could be used to regulate the switching of the heaters. The information from these three sensors could be utilised in the algorithm running in the data logger to regulate the switching ON and OFF of the heaters. Three essential conditions which would be needed to be satisfied for switching ON the heaters are:

1. the temperature of the antifreeze liquid is below 0ºC
2. the solar radiation falling on the pyranometer is less than 60 W/m². According to WMO guidelines, the threshold of direct solar irradiance on the pyranometer to distinguish bright sunshine is 120 W/m² (measurement of sunshine duration, WMO guide to meteorological instruments and methods of observation, WMO – No. 8, 2006). Taking some margin, 60 W/m² could be taken as cloudy sky
3. the Vaisala DRD11A precipitation detector outputs high (+1) logic when precipitation starts.

The third condition would be checked only when the first two conditions have been satisfied. This would be necessary because the DRD11A also uses a small heater which consumes about 50 mA of current (instruction manual, Model DDR11A precipitation detector, Vaisala instruments, USA 2000). The essential condition to switch OFF the heaters would be that the temperature of the antifreeze liquid is either equal to or greater than +1ºC.

Since the heater of the DRD11A consumes only 50 mA of current whereas the heaters consumes 2 A, therefore by implementing this algorithm, as shown in Table 1, we would be able to save approx 50% of power which would have been otherwise consumed if only the heaters were used.
Figure 6  The flow chart to regulate the operation of the heaters

Start

Is heater switched OFF?

Yes

Switch ON DRD11A & wait for 2 minutes

No

Is Temp ≥+1°C?

Yes

Switch Off Heater

No

Is Temp <0°C?

Yes

Is Radln <60 W/m²?

Yes

Switch ON DRD11A & wait for 2 minutes

No

Is O/P of DRD11A=1?

Yes

Switch ON Heater & Switch OFF DRD11A

No

Switch OFF DRD11A
Table 1  ON and OFF conditions of DRD11A precipitation detector and the heaters

<table>
<thead>
<tr>
<th>Weather condition</th>
<th>DRD11A</th>
<th>Heaters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold, cloudy day, no snowfall</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>Cold, night, no snowfall</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>Cold, cloudy day, snowfall</td>
<td>ON</td>
<td>ON</td>
</tr>
<tr>
<td>Cold, night, snowfall</td>
<td>ON</td>
<td>ON</td>
</tr>
</tbody>
</table>

3.2 Laboratory tests

Laboratory tests of the antifreeze-based attachment were conducted at the cold chambers of SASE at Manali in Himachal Pradesh in the month of November 2008. To simulate the most likely field conditions during snowfall, the following assumptions were made (Gorman, 2003):

1. most snow will fall with an ambient air temperature in the range of 5°C to 0°C with the temperature rapidly falling to 0°C
2. when snow strikes the ground its temperature is approximately 0°C.

Tests were carried out with snow samples of density 0.35 g/cm³ for both the conditions of keeping the heaters ON and OFF at different antifreeze temperatures. The antifreeze liquid in the reservoir was first allowed to settle to the set temperature of the chamber and then the chamber temperature was rapidly ramped to 0°C before conducting each test. A sample of snow weighing 450 g was then sieved with a sieve of 1mm grating and allowed to fall on the antifreeze at a steady rate of 100 gm/minute or 7.5 cm/hr. There was no
snow capping observed, however lots of snow stuck to the sidewalls. The idea was to record the time taken to measure 440 ml of water equivalent of the snow sample in the datalogger. The datalogger sampling time was kept at 1 second and recording time was kept at five minutes interval. The data logger and the batteries were kept outside the test chamber. For comparison, a Campbell TE525 TBRG with a CS705 antifreeze attachment was also tested. The new TBRG with the antifreeze-based attachment during tests is shown in Figure 7.

3.3 Results and discussions

The TBRG with the antifreeze-based attachment showed excellent results with ON condition of the heaters. Tests were conducted at five temperatures, from 0°C to –4°C at one degree celsius interval for both the conditions of the heaters. The heaters provided approximately 48 watts of power to heat the antifreeze. This implies that at 0°C the antifreeze has sufficient heat to melt 519 g of ice per hour assuming Heat of fusion of ice to be 333 J/g (Whitten et al., 1988). This equates to approximately 6.5 mm of equivalent rainfall per hour. It was observed that water equivalent reading for the snow sample was obtained in around 15 to 20 minutes in most of the experiments when the heaters were kept in the ON condition. It can be seen in Figure 8 that while keeping the heaters ON, full readings were obtained in 900 to 1,200 seconds with the antifreeze temperatures of 0°C to –3°C.

Figure 8 The test results with heaters ON condition

This is because the heaters led to the heating of the antifreeze which in turn led to the heating of the antifreeze reservoir. As a result, the snow that had stuck to the sidewalls of the reservoir fell onto the antifreeze and raised its volume leading to quicker overflow of antifreeze-water mixture from the modified overflow tube. The higher initial readings can be attributed mostly to overflow due to submersion of snow.
When the heaters were kept off, the time for recording water equivalent for the snow sample increased. It can be seen in Figure 9 that full readings were obtained only when antifreeze temperature was 0°C and –1°C. Even though the heaters were kept off yet the readings showing full measurement of water equivalent for the sample could be attributed to the overflow due to full submersion of the snow sample in the antifreeze though with delay. However, for lower antifreeze temperature and hence lower reservoir temperature, the snow stuck to the sidewalls of the reservoir remained stuck and hence full reading could not be obtained.

Figure 9 The test results with heaters OFF condition

The comparison between times required for water equivalent measurement for the snow sample with the heaters in ON and OFF conditions for different antifreeze temperatures at 0°C ambient air temperature is shown in Figure 10. The trend lines show that with decreasing antifreeze temperature the effect of the heaters became more prominent on melting of the sample.

The Campbell TE525 tipping bucket with CS705 antifreeze attachment was tested for only two extreme temperatures of the antifreeze with same amount of snow sample as was used for the new tipping bucket and antifreeze-based attachment. The TE525 with the CS705 attachment has a diameter of only eight inches. As a result, multiple layers of the sieved sample settled over the antifreeze liquid making a thicker layer and more snow got stuck to the sidewalls of the catchment tube. The instrument failed to measure water equivalent for whole of the snow sample in the negative temperatures of the antifreeze at times comparable to the new tipping bucket. By considering the total water equivalent measured by the TE525 with the CS705 attachment and the new TBRG with the antifreeze-based attachment, at 0°C of antifreeze temperature, a comparison may be made on the measurement rate of the two instruments as shown in Table 2.
Figure 10  Comparison of melting time of sample with heaters ON and OFF condition

![Time Comparison of Heater ON & OFF Conditions](image)

Table 2  Comparison of measurement rates

<table>
<thead>
<tr>
<th></th>
<th>TE525 with CS705 attachment</th>
<th>New TBRG with heaters ON</th>
<th>New TBRG with heaters OFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to Melt Sample</td>
<td>9.4 mm/hr</td>
<td>16.4 mm/hr</td>
<td>10.9 mm/hr</td>
</tr>
</tbody>
</table>

4 Conclusions

A new contact-less TBRG was designed to reduce the common shortcomings of commercial tipping buckets. A capacitive proximity sensor was used instead of a magnetically actuated proximity sensor to eliminate the effect of magnetic fields on the sensor. The tipping bucket was designed in such way that the user was given more flexibility in adjusting the resolution of the tips, carrying out calibration, maintenance and ease of installation. The field trials of the tipping bucket showed excellent result when compared with a standard rain gauge.

The new antifreeze-based attachment for measurement of snow precipitation has bettered the measurement rate of the commercial antifreeze-based attachment by approx 7 mm/hr. The reduction in the delays found in the commercial antifreeze attachment would greatly improve the timing of the precipitation recordings.

Acknowledgements

The authors would like to express their appreciation and gratitude to Sh.R.K. Garg for his guidance and Dr. J.C. Kapil and Sh. Ashwani Acharya for their help and support in conducting the trials of the TBRG with antifreeze-based attachment in the cold chamber at HQ SASE, Manali, India.
References


