A CALORIMETER FOR MEASURING FREE WATER CONTENT OF WET SNOW

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ABSTRACT

A new calorimeter was designed for measuring the free water content of wet snow, aiming at simplicity in mechanism and handling as well as high accuracy and speed in measurements. The mass of hot water to melt the sample and the mass of the mixture (snow sample and hot water) are measurable indoors with sufficient accuracy; therefore, in the field we need only two measurements of temperature (T_1 and T_2); this calorimeter reduces the time of measurement of one snow sample to four or five minutes. Using artificially made wet snow, having a known value of free water content, 121 tests were conducted. Standard deviation of the error was 0.82%

INTRODUCTION

Yosida (1959) designed a calorimeter for measuring the free water content of wet snow. Later Akitaya (1978) made an experimental apparatus of another type of calorimeter. This paper reports on further improvements made in the apparatus and measuring procedures. The free water content of wet snow is obtainable using this calorimeter, based on a melting calorimetric method using the following procedure:

Hot water ($T_1 °C$, M_1 grams) and a sample of wet snow (M_2 grams) are well mixed in a thermal insulating box so that the mixture attains $T_2 °C$, the equilibrium temperature. If heat loss is neglected in this procedure, it follows that

$$cM_1 (T_1 - T_2) = cM_2 T_2 + LI \qquad (1)$$

where c is the specific heat of water (4.18 J/gK) and L is the latent heat of melting of ice (333.6 J/g). W (%), the free water content of the snow, is expressed by

$$W = \left(1 - \frac{I}{M_2}\right) \times 100 = 100 - \frac{1.25(M_1(T_1 - T_2) - M_2 T_2)}{M_2}. \qquad (2)$$

APPARATUS AND OPERATIONAL TECHNIQUE

The new calorimeter has two spaces W and S in which a polythene tube 0.02 mm thick is embedded. The part of the tube in W contains hot water, and the other
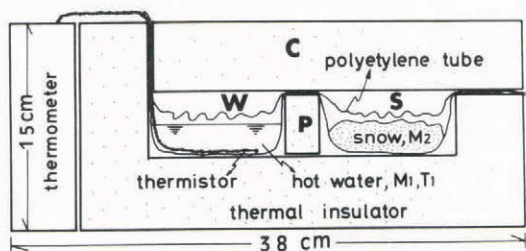

Fig.1. Schema of the calorimeter. Thermal insulator is made from hard plastic foam (density: 0.037g/cm³).

part contains the snow sample. The two parts are divided by a movable parting strip P (Figure 1).

Temperatures T_1 and T_2 are measured by a thermister with small heat capacity and high response, accurate to 0.1 °C. Mass measurements (M_1 and $M_1 + M_2$) are conducted indoors using a balance accurate to 0.1 gram; in the field it is difficult to avoid wind influences on the sample, and especially to prevent it from being heated and cooled from outside. In using the apparatus:

(1) Two plastic bottles A (110 cm³, filled with hot water) and B (250 cm³, empty) are weighed indoors and brought to the observation site in the field.
(2) Hot water is put into one half of the tube, which is inserted into space W with the thermister in it.
(3) A sample of wet snow (30 to 50 g) is put into the other half of the tube and inserted into S. The tube is covered with C and the temperature of hot water T_1 is read on the thermometer while shaking the apparatus.
(4) After reading of T_1, the parting strip P is removed: the snow sample and hot water mix, resulting in a rapid drop in temperature of the water. Equilibrium temperature T_2 of the mixture is read while shaking the apparatus for about one minute.
(5) The mixture ($M_1 + M_2$) is put in bottle B with the tube after the measurement of its temperature T_2. Two bottles A (empty) and B are carried back indoors to weigh them so that masses M_1 and M_2 are measured accurately.

CALIBRATION OF THE APPARATUS

Calibration of free water content was examined by this apparatus in a cold room at 0 °C ± 1 °C, as follows. An adequate amount of the dry snow at 0 °C was put into the tube, and immediately a suitable amount of water at 0 °C was added. The snow sample in the tube thus had acquired a known value of free water content Wa. Measured value of free water content W, calculated by Equation (2), was compared with the known value Wa. The standard deviation of the error (W − Wa) was found to be 0.82% for 121 samples with range of free water content from 0% to 45%.

DISCUSSION OF ERROR

In equations (1) and (2) heat loss from the calorimeter and heat capacity of the tube are neglected. When the two quantities are to be considered, the following equation holds:

$$(cM_1 + c'm)(T_1 - T_2) = T_2(cM_2 + c'm) + LI + Q \qquad (3)$$

where c' is the specific heat of the tube (about 2J/gK), m is the mass of it contacting with the hot water or the snow sample directly (about 0.4 g), and Q is the heat loss in Jules. From Equation (3) the corrected value of free water content W_o% is given by

$$W_o = 100 - \frac{1.25(M_1(T_1 - T_2) - M_2 T_2)}{M_2} + \frac{0.48T_2 - 0.24T_1 + 0.3Q}{M_2} \qquad (4)$$
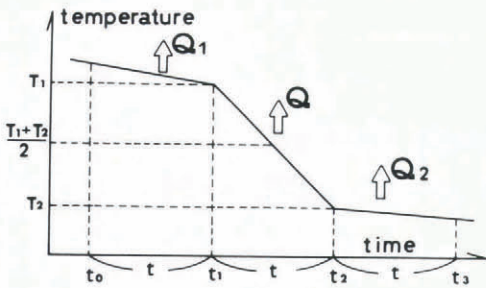
Fig.2. Schematic diagram of the heat loss, Q. Q is a function of $\left[\dfrac{T_1 + T_2}{2}\right]$ since Q_1 (Q_2) is obtained empirically as a function of T_1 (T_2).

Figure 2 shows a schematic diagram representing heat loss through the calorimeter, where t_1 and t_2 are the measuring times of temperatures T_1 and T_2, respectively: Q_1 and Q_2 are resultant heat losses during time t, obtained from the temperature drops. Values of Q_1 and Q_2 were measured against the several ranges of water temperature T at the air temperature 0°C and the following empirical equation was obtained approximately:

$$Q_{1,2} = 4T \ (J/min).\tag{5}$$

The heat loss Q during mixing time $t = t_2 - t_1$ (one minute) in Figure 2 can be given by substituting the mean temperature, $(T_1 + T_2)/2$ into T of Equation (5):

$$Q = 2(T_1 + T_2) \ (J/min)\tag{6}$$

Substituting Equation (6) into (4), we obtain

$$W_o = W + \Delta W\tag{7}$$

where W_o is the corrected value, W is the uncorrected value and

$$\Delta W = \frac{0.4 \ T_1 + 1.1 \ T_2}{M_2} \ (\%) \ .\tag{8}$$

The equation shows that ΔW is inversely proportional to M_2 and increases with T_1. The error ΔW can be calculated against T_1 and M_2, because the almost constant mass of hot water M_1 is prepared (about 110 g) and T_2 is the function of T_1, M_1 and M_2. When the free water content is 0 %, equilibrium temperature T_2 is given by substituting $I = M_2$ in Equation (1) and Equation (8) becomes

$$\Delta W = \frac{165 \ T_1 + 0.4 \ T_1 M_2 - 87.7 \ M_2}{M_2 \ (110 + M_2)} \ (\%)\tag{9}$$

Figure 3 shows the error of free water content ΔW due to Equation (2) in which the heat loss and heat capacity of the tube are neglected, and also the guideline of M_2
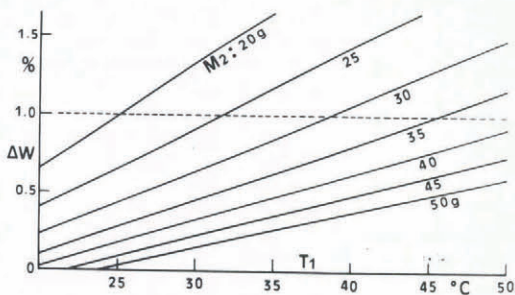

Fig.3. The guideline of M_2 against T_1. M_2; the mass of a snow sample, T_1; the temperature of hot water.

against T_1. Allowing for 1% of the error, the appropriate value of M_2 is given against T_1 from this figure. For instance, if $M_1 = 110$ g, then $M_2 = 40$ gram at $T_1 = 50$°C and $M_2 = 35$ gram at $T_1 = 40$°C.

REFERENCES

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