LABORATORY SIMULATION OF SNOWMELT[1]

By

Michael C. Quick[2]

Introduction

Snowmelt has long been recognized as a complex combination and interaction of a number of physical processes. Some of these processes are extraneous to the snow pack, but the snow itself modifies continuously throughout the process. Many field studies of snowmelt have been made, the more extensive being by the Corps of Engineers and a number of field laboratories.

In the present study an attempt has been made to simulate a number of parameters which produce snowmelt in a controlled laboratory environment. There are a number of serious difficulties facing a simulation of this type, but there are also some compensating advantages. The question to be resolved is whether the difficulties are sufficient to invalidate the simulation, or whether the advantages which a controlled simulation offer are great enough to outweigh the difficulties. In that sense, the present work explores these competing advantages and disadvantages.

The main processes involved in snowmelt are the supply of thermal energy from net radiation and from conduction and convective heat transfer from a warm overlying air mass. These processes are modified by snow albedo and snow crystal structure. In attempting to simulate these processes in the laboratory the main difficulties arise because of the restricted size of the snowpack and because of the limited air-mass which can be circulated over this sample of snow. In nature, the air above the snowpack is a complex boundary layer region in which turbulent mixing, heat conduction and convection, vapour exchange and the associated velocity field are all interacting in a complex manner. The size of a laboratory experiment preclude the possibility of simulating this boundary layer situation correctly. Also, a small laboratory snow sample will be subject to edge effects around the sides and base, where it will be difficult to achieve the natural boundary conditions which this same block of snow would be subject to when surrounded by snow.

The advantages of a laboratory simulation are also considerable.

1. Steady conditions can be maintained for any desired period, whereas in nature air temperature, humidity and radiation are usually varying continuously throughout the day.
2. If the snowpack has been maintained at freezing or below, a certain supply of thermal energy can suddenly be started and maintained at a constant rate. This "square wave" of energy input allows us to study the response of the snowpack system much more easily.
3. We can separate the energy inputs due to radiation and air temperature and study the snowpack response just to radiation or just to air-temperature.
4. We can then apply both radiation and air-temperature simultaneously and check whether the processes can be linearly superimposed.
5. Humidity can be controlled within certain limits and such matters as condensation melt can be studied.
6. It may be possible to simulate rainfall and evaluate rain on snow events.

The Snowmelt Simulator

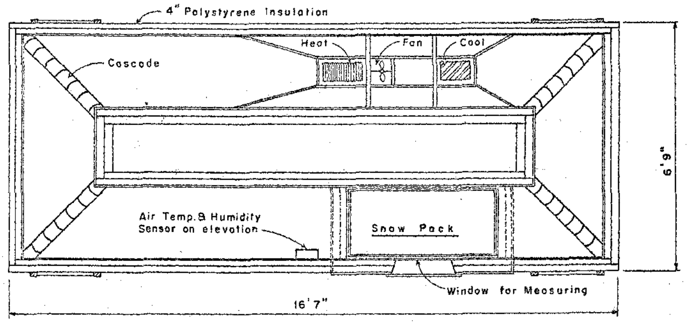
The main part of the equipment is a very low speed return circuit wind tunnel which is used to pass air at controlled temperature and humidity over the sample of snow (Figs. 1 and 2). The snow sample is contained in an insulated compartment which has refrigeration equipment to maintain the sample at the required temperature, namely at freezing or sometimes below freezing. The inner snow container is provided with drainage for collecting melt.

---

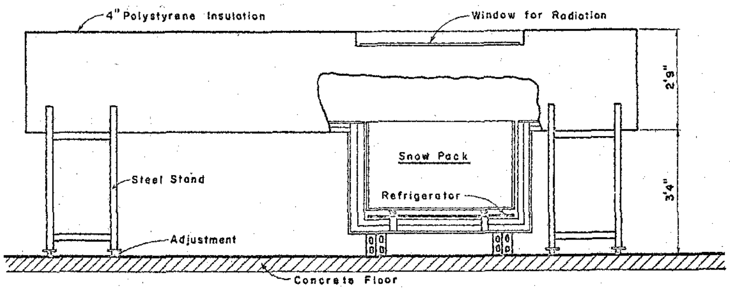
[1] Presented at the Western Snow Conference, April 21-23, 1970, Victoria, B. C.

[2] Assoc. Prof. of Civil Engineering, University of British Columbia, Vancouver 8.

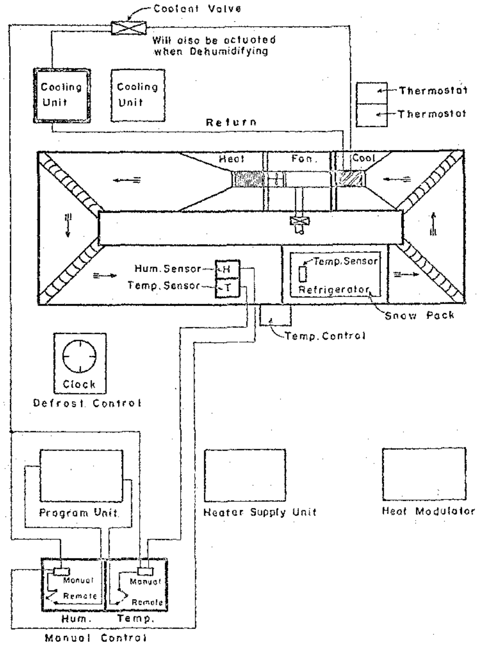
PLAN: SNOWMELT EQUIPMENT - Scale: $\frac{1}{2}$"=1'0".



ELEVATION: SNOWMELT EQUIPMENT - Scale: $\frac{1}{2}$"= 1'0".



COOLING AND DEHUMIDIFY CYCLE.



The wind tunnel working section is 2' x 2' and this section is maintained around most of the circuit. At each corner the tunnel is provided with a cascade of turning vanes to maintain a good velocity distribution. The air conditioning equipment is housed in the return leg of the tunnel and at this point the flow area is contracted in order to achieve good mixing of the air as it is cooled or heated or dried or moistened. This contraction of the flow was designed to suit commercially available heaters, dehumidifiers and fans. The flow is then expanded through a diffuser section before being returned to the working section. The flow velocities around the circuit are very low, the average velocity in the working section being 0.83 ft./sec. This is quite deliberate, the purpose of the tunnel is simply to stir the air and keep it, at a certain air temperature and humidity

The operation of the air-conditioning equipment is controlled by a Honeywell W 816 Controller and W806 A Programmer which can be preset to run at fixed values of air temperature humidity cycle. Air temperature can be controlled to ± 1/2^{o} C. average values, although short term fluctuations of ± 1^{o} C. occur as the heat-cool or humidity-dry cycle occur. Humidity is more difficult to control, especially at low temperatures where the vapour pressure is low and a very small change in moisture content represents a large change in relative humidity. It is noticeable that at any given air temperature setting, there is a preferred relative humidity setting for which the air conditions are most stable. This is easily understandable because reduction in humidity requires the air cooler to operate, while at the same time the required air-temperature setting may demand the air-heater to operate. Alternatively, increased humidity is introduced as steam and this may coincide with operation of the air-cooler. Because of the extreme importance of the relative humidity, as is discussed later, thought is being given to a redesign of the humidity control system to give better flexibility in operation.

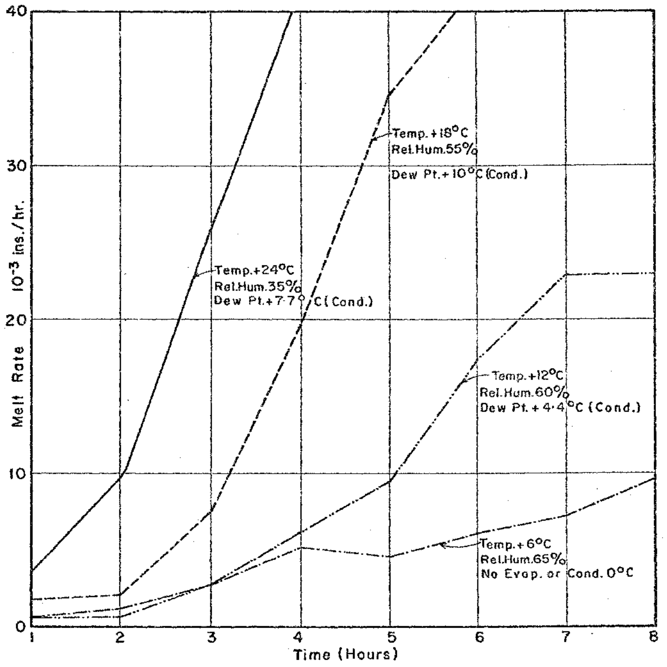
The snow sample is approximately 4 ft. x 2 ft. in surface area and about 2 ft. deep. This was reckoned to be the largest sample which could be collected as an undisturbed sample and manhandled by four people of normal academic strength. The inner snow box has a removable side which permits it to be driven sideways into a prepared vertical snowface. The box is then dug out and the side replaced. A sledge is used to transport the snow sample to the truck in which an outer insulated transportation box is housed. The inner box and snow sample are lifted into the outer box and dry ice (about 5 lbs. is adequate for 3 hours transportation time) is used to keep the snow cool during transport. About half an inch of snow settlement usually occurs during transport. When the snow is collected, small samples of snow are taken at three depths to establish estimates of snow density. Thus, sampling is repeated at intervals during the laboratory testing.

The Snowmelt Experiments

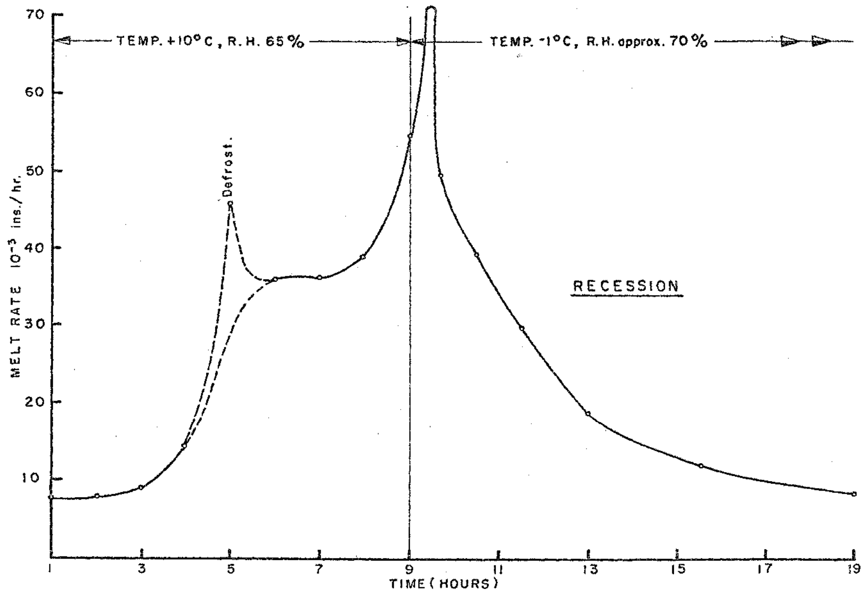
In the first series of tests, air-temperature alone was used to produce melt and the relative humidity was kept as low as possible to minimise condensation melt. The snow sample was maintained at -1^{o} C. overnight and then a certain value of air temperature was set and maintained for about 6 hours. The melt rates were recorded by weighing the melt at 20 min. or 30 min. intervals. This process was repeated for successive days, with overnight freezing and for both the same and different air temperatures.

Some results from these tests are shown in Figs. 3, 4, 5, 6. Fig. 3 indicates the response of a snowpack which has to some extent ripened and the response to increasing temperatures is much as would be expected. However, it is apparent that the storage in the snowpack delays the outflow considerably, and this effect is best illustrated by Fig. 4 which shows the increasing response to air temperature during the first 6 hours and then when the air temperature is reduced to about -1^{o} C. overnight, we can see the long recession flow as water drains from the pack.

Fig. 5 shows two plots of +6^{o} C. air temperature. One plot is for unripened snow which had not undergone any diurnal freeze-thaw cycles. The other curve is for the same snow pack after 7 diurnal freeze-thaw cycles. Although the unripened pack did not produce melt at all for 4 hours, the high melt rate which then took place is in marked contrast to that of the ripened pack. Two points emerge from this test. Firstly, the apparent melt hazard of an unripened pack in the event that a warm air mass should suddenly establish itself over a river basin. Secondly, it is apparent that ripening of a snowpack is by no means a prerequisite for melting: in fact, the contrary is true, in that an unripened pack will melt very fast. Normally, of course, ripening is a natural accompaniment of snowmelt because the usual pattern is for a diurnal freeze-thaw cycle which produces the recrystal-

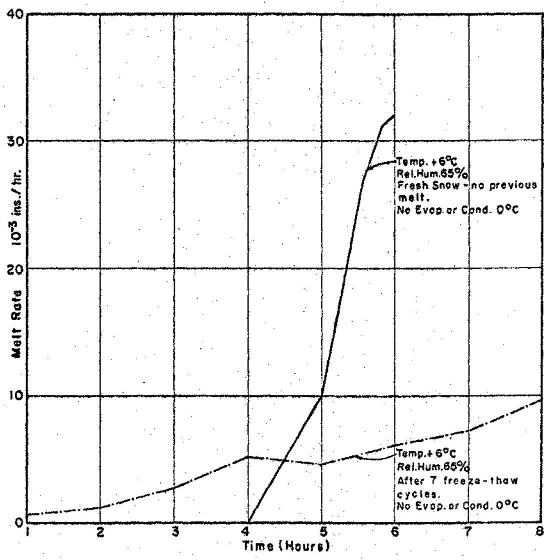


MELT RATES FOR VARIOUS AIR TEMPERATURES.



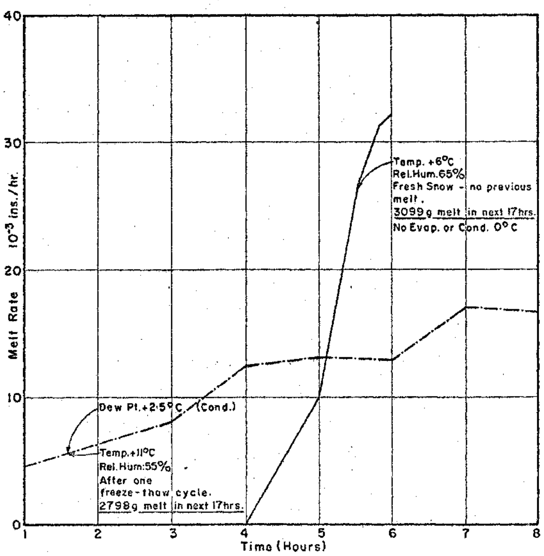
SNOWPACK "HYDROGRAPH."

FIG. 5



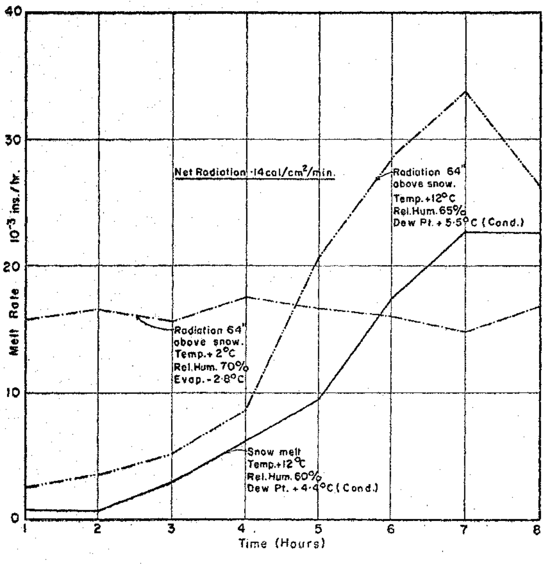
COMPARISON OF MELT FOR UNRIPE AND RIPE SNOW.

FIG. 6



INFLUENCE OF FREEZING OVERNIGHT ON MELT RATE.

FIG. 7



SNOWMELT - COMBINED AND SEPARATE MODES.

lization and coarsening of the snowpack. This coarsening of the crystal structure decreases the effective surface area of the snow and hence, diminishes the rate of heat transfer to the snowpack. Fig. 6 shows the same + 6° C. curve for unripe snow together with a curve for + 11° C. for the following day after only one freeze-thaw cycle. The decrease in response is very marked and, allowing for the higher temperature, represents about a fourfold decrease in melt rate.

Attempts were made to measure the crystal size of the fresh snow and the ripened snow. Estimates under a magnifying lens indicated about 1 m.m. across for the unripened snow and 2 to 4 m.m. for the ripened snow. The surface area being proportional to the length squared, this ripening represents approximately, a 1/4 to 1/16 change in surface area. To compensate for this decrease in surface area, the ripe snow surface seems more open in texture and may permit a freer air circulation.

A further series of tests were made in which air temperature was maintained at about zero (+ 1° C. or + 2° C. was actually the temperature achieved) and radiation was introduced through the double polyethylene window in the top of the tunnel. The resulting melt was very slow in establishing itself and was quite a low value. We left the radiation lamps on overnight and measured the melt rate next day; one such curve is shown in Fig. 7. A curious modification of the snow surface occurred after 2 days, which can only be adequately shown with photographs. As an attempted description, the surface became deeply pitted, leaving small pillers of snow about 1 to 2 cm. in diameter spaced evenly across the surface at about 5 cm. centres. We should be interested to know if such a structure has been seen in nature.

In the next series of tests, both air temperature and radiation were applied together and the results are shown in Fig. 7. It is apparent that the combined melt is different from the sum of the two separate melts from air temperature and radiation. To take a rough example, air temperature at + 6° C. for ripe snow gave 17 x 10^{-3} inches/hour and radiation at 0.14 cal/cm^2/min. also gave 17 x 10^{-3} inches/hour. But the combined air temperature and radiation gave 57 x 10^{-3} inches/hour which is greater by 20 x 10^{-3} inches/hour than the separate effects. These results are somewhat preliminary but give rise to some interesting speculation. Can we explain this considerable discrepancy in terms of the vapour exchange which must occur at the snow surface. When radiation alone was applied at about + 1° C. air temperature and relative humidity of about 65%, the conditions are right for evaporation from the snow surface and consequent cooling or rather removal of the thermal energy by latent heat of vapourization. On the other hand at + 6° C. and 65% humidity the dew point is approximately 0° C. so that neither evaporation nor condensation will occur. The same is true for the combined mode, namely vapour exchange will not occur or at least will be minimal.

These remarks and speculations serve to underline the extreme importance of the vapour pressure and vapour exchange in the process of snowmelt. For this reason we are working towards better control of humidity and more accurate experiments to confirm or modify our present ideas.

Conclusions

1. Simulation of snowmelt is subject to a number of scaling problems associated with representation of the real boundary layer and with size of snow surface.
2. On the other hand, simulation allows simplification of melt patterns and separation of melt producing processes such as radiation and air temperature.
3. The crystal structure of the snowpack appears as a vital factor in rate of snowmelt.
4. Ripening is not an essential factor for melt to occur but happens to be an inseparable associated phenomenon due to the freeze-thaw cycle.
5. It is suggested that an unripe pack could produce much higher melt rates than a ripe pack.
6. Also results indicate that radiation with low air temperatures will produce low melt rates because of evaporation from the snow surface. Thus the combined effect of radiation and air temperature is very different from their separate effects.
7. Future work is needed to confirm these results and special attention must be given to

(a) water vapour measurements
(b) snow crystal structure.

Acknowledgements

This work has been carried out in the Department of Civil Engineering at the University of British Columbia and has been supported by grants from the British Columbia Disaster Relief Fund.

References

1. Snow Hydrology. Report No. PB 151660, U. S. Corps of Engineers, Dept. of Commerce, Washington, D. C.

2. Wilson, W. T. "An Outline of the Thermodynamics of Snowmelt". Trans. Am. Geophs. Union, Pt. 1, pp. 182-195, July, 1941.

3. Chow, Ven Te, "Handbook of Hydrology", Section 10, Snow and Snow Survey.