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TWO NOTES RELATING TO FRAZIL ICE FORMATION

BY

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1. AN EMPIRICAL METHOD OF ESTIMATING TOTAL HEAT LOSSES FROM OPEN - WATER SURFACES.

2. SOME OBSERVATIONS ON SUPER - COOLING AND FRAZIL ICE PRODUCTION.

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AN EMPIRICAL METHOD OF ESTIMATING TOTAL HEAT LOSSES FROM OPEN-WATER SURFACES

by

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This report presents some information on the heat losses from the surface of a tank of water, 10 feet in diameter, exposed to various atmospheric conditions at Ottawa during the period January to April 1959.

There are two approaches to estimating the total heat loss from open water surfaces under field conditions. One can attempt to measure or calculate the various components of the heat balance; or attempt to relate the total heat loss by an empirical formula to readily observable factors such as the difference between mean air temperature and mean water surface temperature. Because of the difficulties of obtaining reliable estimates of the radiation, convective and evaporative components of the heat balance, engineers have usually been satisfied with the empirical approach. These empirical formulae are limited because air temperature does not properly account for radiation effects.

In an attempt to improve on these empirical formulae the concept of sol-air temperature has been introduced in the studies reported herewith. Sol-air has been described as a fictitious temperature which will combine the effects of heat transfer by radiation and convection (1). As there is a relationship between evaporation and convection losses from water surfaces given by what meteorologists call the Bowen ratio (2), the fictitious sol-air temperature is possibly a measure of the heat transfer by evaporation and condensation also.

Sol-air temperature was measured by means of a thermocouple embedded in the centre of a disc-like, light-mass body approximately 12 inches in

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diameter, painted black and mounted 3 feet above the ground.

Water temperatures were measured by means of thermocouples located at 2-inch intervals throughout the 12-inch depth of the water. The water was kept mixed by mechanical stirrers, to maintain uniform water temperatures throughout the mass. The surface water temperature was assumed equal to that given by a thermocouple located approximately $\frac{1}{2}$ inch below the water surface.

During the period from January to April 1959, the total heat loss from the water surface was calculated from the measured change in water temperature over observation periods from 5 to 10 hours in length. During these same time intervals the mean sol-air temperature was obtained by averaging the recorded sol-air temperatures. The difference between the mean sol-air temperature and mean surface water temperature was compared to the total heat loss or gain as shown on Fig. 1.

Figure 1 indicates that there is a good correlation between this temperature difference and the total heat loss or gain at the water surface. During the night periods mean sol-air temperatures were slightly lower than mean air temperatures, as measured in a Stevenson screen. However, during the daylight hours, the mean sol-air temperature was usually several degrees (°C) higher than the mean air temperature. These experiments indicated that during daylight periods, when radiation effects are a maximum, sol-air temperature would have to be used instead of mean air temperature to obtain a reasonable correlation with heat loss from an open water surface.

The observations during cooling trials shown in Fig. 1, have been compared with various empirical formula (3, 4, 5) as shown by Fig. 2. It should be noted that the temperature difference of these empirical formula is the difference between mean air temperature and mean water temperature, whereas the temperature difference of the experimental observations is between sol-air temperature and mean air temperature. Figure 2 indicates that the heat losses obtained from the experimental tank compare reasonably well with other reported heat losses. These results suggest that the difference between water surface temperature and mean sol-air temperature can be used to predict the rate of heat losses from a body of water and hence be a means of predicting frazil ice formation.

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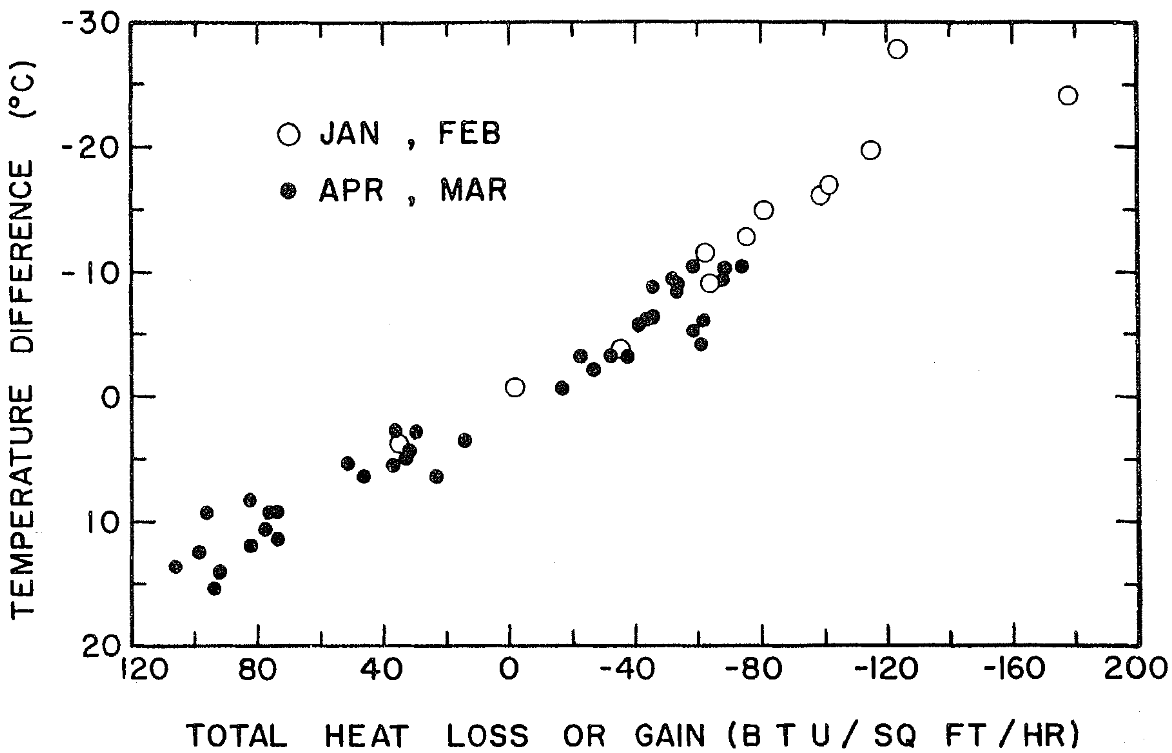
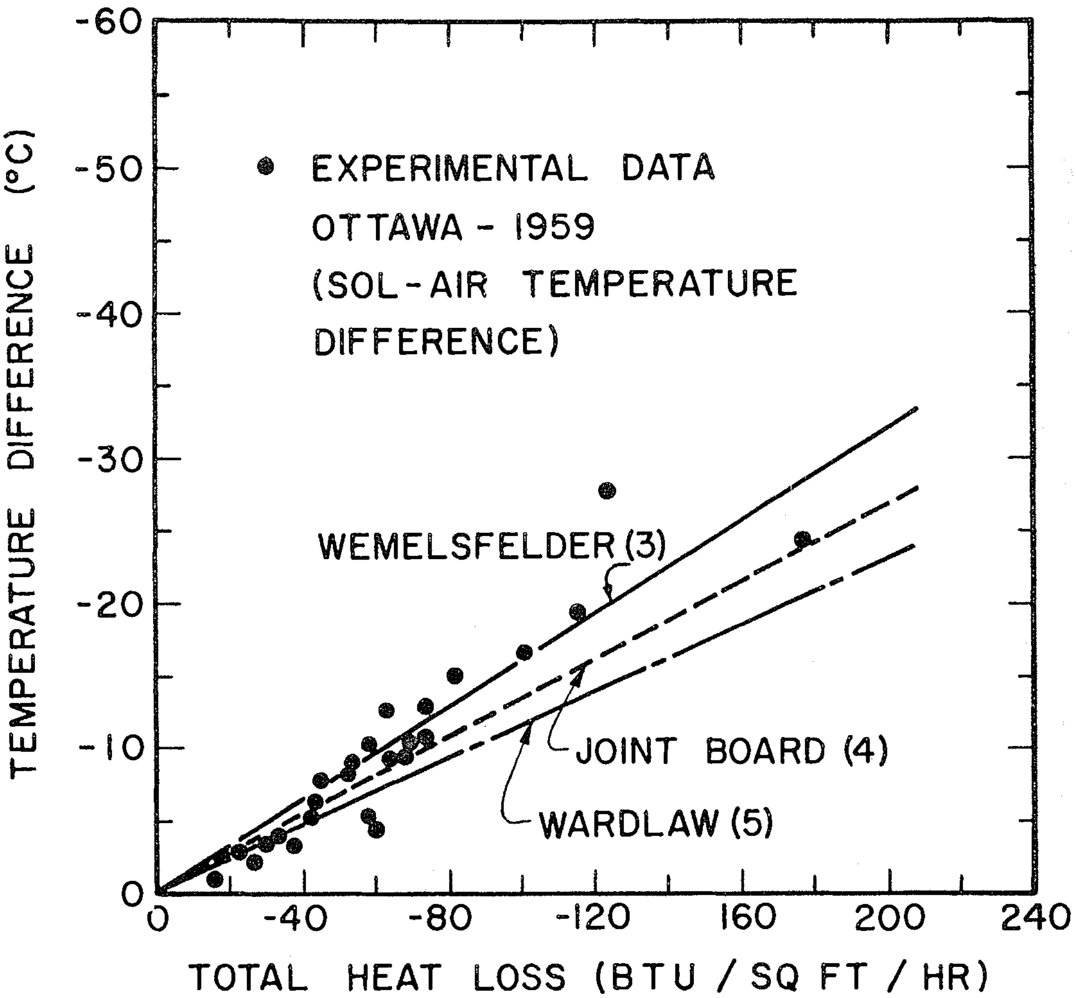


RELATIONSHIP BETWEEN HEAT LOSS OR GAIN FROM 10 FOOT DIAMETER WATER SURFACE AND DIFFERENCE BETWEEN SOL - AIR TEMPERATURE AND WATER TEMPERATURE

FIGURE 1



<u>A COMPARISON OF EXPERIMENTAL OBSERVATIONS WITH VARIOUS EMPIRICAL FORMULA</u>

<u>FIGURE 2</u>

SOME OBSERVATIONS ON SUPER-COOLING AND FRAZIL ICE PRODUCTION

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This report presents some laboratory investigations of the factors that determine the super-cooling of water during frazil ice formation.

Frazil ice was produced in a plastic vessel (23 inches by 23 inches by 13 inches deep) filled with water. The water surface was exposed to temperatures below 0°C and was kept mixed with a mechanical stirrer.

Two methods of measuring water temperature were used. The first method employed a Mueller bridge and a platinum resistance thermometer calibrated to 1/1000°C. The second used a sensitive Rubicon bridge with a thermocouple submerged in the centre of the bath, enabling water temperatures to be read to 1/100°C.

The water bath was kept inside a cold room, and the measuring bridges were kept in a room at a constant temperature of +70°F. It was necessary to calibrate the bridges for the long leads that connected the bridge with the bath. It was also found necessary to cover the thermocouple with a plastic covering to prevent frazil ice adhering to it.

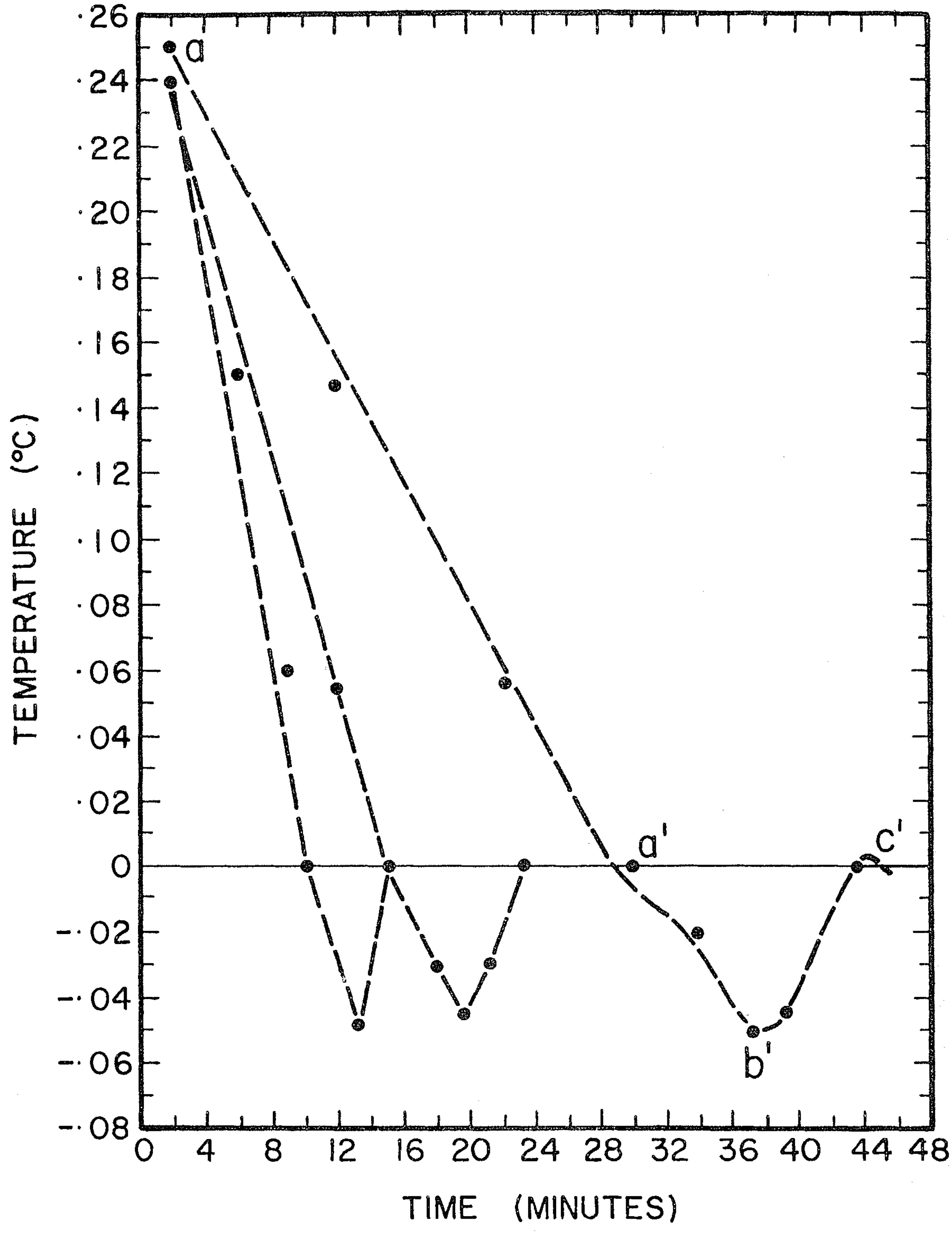
When water temperature is measured to 1/100°C factors such as temperature lag of the thermocouple, minute quantities of ice on the thermocouple, distance of the thermocouple from the water surface, amount of conduction down the thermocouple wire need to be considered. Even under laboratory conditions it is difficult to control these factors, and thus obtain exact values for the amount of super-cooling.

Figure 1 shows some typical changes of water temperature with time for different rates of cooling obtained during these experiments. Some conclusions can be drawn from these curves which are of interest in explaining the heat exchange aspects of frazil ice formation.

During the first stage of cooling, a-a' in Figure 1, the heat removed from the water surface by convection, evaporation, and radiation causes a gradual cooling of the water. During the second stage of cooling, a'-b', frazil ice has started to form, the released heat results in a reduced rate of water cooling. As the rate of ice formation increases, the heat released also increases until the point b' is reached where it must just balance the rate of heat loss from the air-water surface. For the period b'-c', the heat released through ice formation will exceed the loss from the surface until the point c' is reached, where the temperature is 0°C, after which they must balance.

The amount of super-cooling should depend upon the rate at which heat is being removed from the water mass, the amount of mixing, and the surface area available upon which ice may form (i.e. the number and size of frazil ice particles per unit volume). Attempts to make a precise analysis of these factors were not successful. Under the laboratory conditions of this experiment it was impossible to obtain realistic values for the number and size of the ice particles or to estimate the rate of growth of these particles.

These observations indicate that super-cooling of a stream during frazil ice formation is a transient phenomenon depending on the rate of cooling and the amount of ice surface available for ice formation. The small super-cooling effects observed (0.05°F) and the difficulties of measuring temperatures to the accuracy required, suggest that it will be difficult to obtain meaningful values for the amount of super-cooling in river water under field conditions.



COMPARISON OF DIFFERENT RATES OF COOLING

FIGURE I