

FREEZING WATER AND SUPERCOOLING

Anchor Ice and Frazil Ice

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ABSTRACT. The supercooling of water in nature occurs more frequently than is generally known. It always takes place when still water is in process of being covered with the first ice needles. It is of even greater importance when ice formation takes place in running and turbulent water, in which case it represents the necessary conditions for the formation of frazil and anchor ice. The supercooling may be observed by a sensitive thermometer when the bulb is heated before being immersed in the water. The degree of supercooling of still water may be more than 1°C . in a thin surface layer as the author has demonstrated by measuring the temperature by a recording thermopile exposed to radiation from the surface. It is emphasized that the state of supercooling in water is a stable one, the formation of ice being dependent upon the existence of nuclei or solid boundary surfaces from which crystallization will start and from which liberated heat of solidification will flow. This process of thermal conduction needs time.

ZUSAMMENFASSUNG. Die Unterkühlung des Wassers in der Natur kommt öfter vor als allgemein angenommen wird. Der Vorgang findet immer statt, wenn ruhendes Wasser mit den ersten Eisnadeln bedeckt wird. Er ist von noch grösserer Bedeutung, wenn Eis in strömendem und wirbelndem Wasser gebildet wird, und bildet in diesem Falle die notwendige Bedingung für die Bildung von Grundeis. Die Unterkühlung kann mit einem empfindlichen Thermometer gemessen werden, wenn die Kugel vor dem Eintauchen ins Wasser vorgewärmt wird. Die Unterkühlung von ruhendem Wasser kann in der dünnen Oberflächenschicht mehr als 1°C . erreichen, wie es der Verfasser durch Messen der Temperatur mittels einer Thermosäule, welche der Strahlung der Oberfläche ausgesetzt war, gezeigt hat. Es wird betont, dass der Zustand der Unterkühlung im Wasser ein stabiler ist, weil die Eisbildung von dem Vorkommen von Kernen oder von festen Grenzflächen abhängig ist, an welchen die Kristallisationswärme strömen wird. Dieser Vorgang der Wärmeleitung braucht Zeit.

ICE formation in lakes and ponds is a familiar process and it is generally considered to be of a rather simple nature. Nevertheless careful observation of ice formation in running water has disclosed the puzzling development of anchor ice, which appears to be a more complicated process.

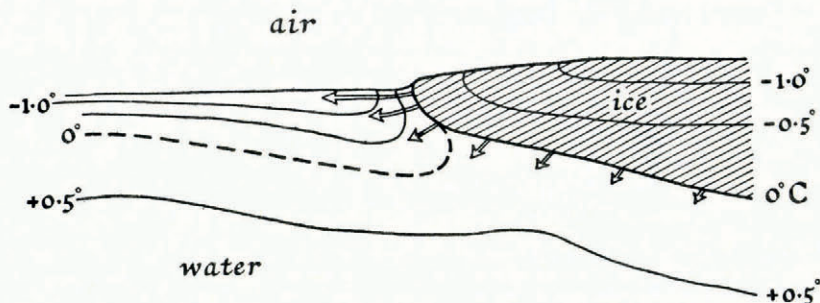


Fig. 1. Growth of ice in supercooled water (See Geog. Journ. Vol. 103, 1944, p. 193)

In this short survey no account will be given of the quantitative evaluation of the heat processes which take place at the water surface in winter when ice formation is about to begin.* The fundamental fact is emphasized that the crystallization process does not start by itself when the water has been cooled down to 0°C . The process requires starting points, *i.e.* particles or structures of solid matter which already have a crystalline structure.

When an ice crystal has begun to grow upon a solid particle, the heat of solidification must be carried away. This means that the temperature on one or both sides of the crystal surface must be lower than the temperature of the crystal surface itself, which is 0°C .

Fig. 1 shows how the growth of ice takes place when an ice crystal floats on still water. The dimensions are exaggerated and the conditions simplified. The arrows indicate the growth which will be greatest in the surface layer. That is the reason why ice needles can shoot over the surface of a pond in an amazingly short time.

The amount of supercooling will differ widely according to the movement of the water, because

* Reference may be made to a paper by the author in *Geofysiske Publikasjoner*, Vol. 9, No. 1, 1932, in which formulae and tables are given making it possible to evaluate the net loss of heat from a surface of water, ice or snow respectively, under given meteorological conditions.

the heat exchange to the air is confined to the uppermost thin surface layer. This may be at rest in still water but will constantly be moved away to deeper strata in turbulent water. Measurement of the degree of supercooling is therefore a different problem in the two cases.

Any thermometer of ordinary type will give the average temperature in a water layer of the same thickness as the size of the bulb. This is sufficient in turbulent water since here the temperature will be fairly evenly distributed. It is necessary, however, to take the precaution of heating the bulb to above 0°C . before immersing it in the water. Otherwise the thermometer, when brought from the cold air into the water, will immediately be covered by a thin sheet of ice and will show the freezing point only. By pre-heating the bulb before immersing it in the water, it is not difficult to measure some hundredths of a degree Centigrade below zero in turbulent brooklets or rivers in very cold conditions. The freezing point of the thermometer is best observed simply by covering the submerged thermometer with granulated ice from the river itself.

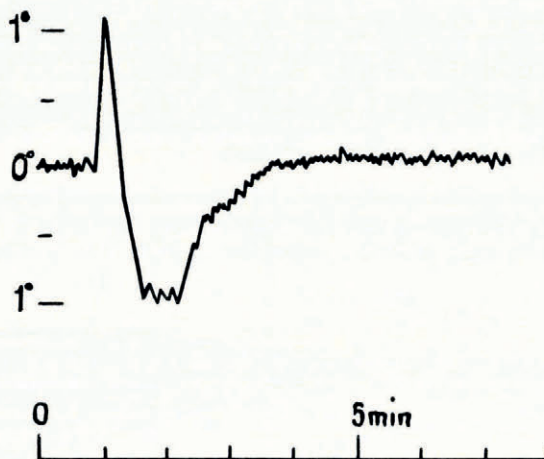


Fig. 2. Water surface temperature at Toemte, 15 Jan. 1942, 2100h

In still water, on the other hand, one might expect considerable supercooling in the thin surface layer where the heat exchange with the air actually takes place. In this case, however, other methods of observation must be used.

During the winter of 1941-42 the author carried out a series of measurements with a Moll thermopile radiation receiver which was placed above the water surface in order to measure the temperature of the surface itself by means of the outgoing heat radiation.* The potential delivered by the thermopile was compensated by a compensating bridge so that only the changes were measured. For this purpose a sensitive galvanometer was used, the light spot of which was photographically recorded.

Fig. 2 shows a recording which is typical for a series of experiments performed in December 1941-January 1942, at Toemte, Nannestad. Two wooden cylindrical vessels were placed side by side in the open air. The experiment was generally begun by placing the thermopile radiation receiver over the first vessel containing water with a thin ice cover, the surface temperature of which would be zero or slightly below. After recording had started, water at a temperature of 1° to 2°C . was poured into the second vessel and the receiver quickly placed over it. The recording curve (Fig. 2) shows, first a rapid rise, and then from the sharp apex an exponentially falling curve corresponding to the cooling of the water surface. The curve passes below the 0° line to a broad minimum and then slowly rises again. During this part of the curve ice formation is started on

* Details of apparatus and measurements are given in *Geofysiske Publikasjoner*, Vol. 13, No. 8, 1942

different nuclei on the water surface and continues until a continuous thin ice cover has been formed, after which the curve approaches the zero line again. It will be seen from Fig. 2 that the supercooling of the surface in this case amounted to -1°C . If the water remains calm the supercooling may reach even greater values, and if nuclei are scarce it may take a long time to produce a continuous ice cover. On the other hand, the elements of ice structure first formed will have grown thicker and will later be seen as ripples on the ice cover.

In the transition stage needles of ice may form as a network with open spaces of supercooled water between. It is of fundamental importance to the understanding of ice formation processes to bear in mind that this growth of ice into surrounding supercooled water is a process which takes time, because the heat of solidification must be carried away. One can thus expect the surprising phenomenon that ice particles may be suspended or may float in supercooled water masses.

The first measurements of supercooling in rivers were made by W. Altberg in the Neva during the years 1916-17 and 1920-21. He measured conditions of supercooling which generally amounted to some hundredths of a degree centigrade, but in particular cases even to -0.1°C . This was measured through the whole section of the river and even at the bottom. He observed the formation of small ice crystals within the water and on the surface of objects under water.

Similar formation of ice at the bottom of a turbulent brook or river may often be observed when persistent winter cold has cooled the water masses down to about 0°C . From then on the loss of heat from the surface will produce supercooling slightly under 0°C . throughout the whole turbulent water mass.

Wherever such supercooled water currents contain solid particles or pass solid objects, ice will be formed. It is evident that the formation of ice on fixed objects will take place at the highest rate where the motion of the flowing supercooled water is greatest, because there the actual gradient of temperature will have extreme values. Consequently every peak of fixed ice structure will have a tendency to grow, so that the irregularities will not be smoothed out, but, on the contrary, exaggerated.

The ice which is thus deposited under water is generally very spongy in texture. The supercooled water will, however, filter through and gradually fill up parts of the space between the walls and needles of ice. If a pole is placed in the water for some hours, it will become covered with a spongy ice structure.

If the supercooling is sufficient and the turbulent action strong there will be formation of similar ice structures at the bottom of the river, the so-called anchor ice. This name is due to the fact that when the air temperature is raised and supercooled water is replaced by water slightly above 0°C ., the ice at the bottom will loosen and come to the surface; if the masses are big enough, they may lift heavy objects, even such things as anchors, from the bottom.

The development of frazil ice and anchor ice will take place chiefly in rapids and may be even more pronounced in places below the rapids. The frazil ice may be carried down stream and may severely hamper traffic on the rivers. In northern latitudes it can often be seen how nature itself counteracts the formation of ice of these types by building up ice dams, thus producing a sort of staircase in the river. To keep traffic moving one will evidently need to follow the example of nature itself and reshape the river by reducing the rapids, or rather by concentrating them by means of dams erected at the appropriate places, building locks where necessary.

In many of the Scandinavian hydraulic power plants difficulties are caused in early winter by the formation of anchor ice at the grids which are placed in front of the inlets to the turbines. The remedy is to heat the grid so as to keep its surface slightly warmer than the supercooled water passing through. If this precaution should be insufficient it may be necessary to reduce the supercooling of the water by facilitating the formation of a shielding ice cover on the reservoir, reshape the channel and stream-line the inlet passages in order to reduce the turbulence of the water.

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