ACOUSTIC DETECTION OF FRAZIL FORMATION

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Frazil in northern rivers leads to millions of dollars of expense annually, due, for example, to its tendency to adhere to trash racks and seaway gates. This fact has motivated much research on frazil. From a different point of view, frazil has interesting characteristics, such as the small amount of supercooling which precedes its formation and the flat circular disks which are at least one of its characteristic morphologies in the early stage of its formation, before it gathers together into flocs of slush. During studies of these distinctive features Hanley (1978) has observed acoustic signals emitted during the formation of frazil. The present paper is to report further studies of these acoustic emissions and of their possible utility.

Experimental details

Frazil was formed by allowing water to cool in a plastic bucket in a top-loading household-type freezer. Usually a depth of 30 to 40 mm of water was used in a container 160 mm in diameter. To achieve the turbulence needed to produce frazil a magnetic Teflon-coated stirring bar was rotated at a suitable speed.

A piezoelectric transducer suspended with its sensitive end about 5 mm below the surface of the water. The signal from the transducer was preamplified in a band from 10 KHz to 30 or 300 KHz and fed to a pulse counter and an oscilloscope. With this arrangement the output is at the resonant frequency of the transducer and multiple pulses were counted on strong signals; for this reason an electronic switch was included before the counter to switch off the input for one millisecond after each count.

Temperatures were monitored by a thermistor immersed in the water. To find the mass of ice produced in a given time, the water and ice were poured into a medium-mesh nylon bag. Water was allowed to drain from the bag and then the bag and ice were weighed. Subsequently the total mass of ice and of the water used in a given experiment was found. This method is crude, but it gave remarkably consistent results and we have not considered it worth while to devise a more accurate procedure. In each experiment the ratio of the mass of ice produced in a given time (usually 4 minutes) to the total mass of water and ice was expressed as a percentage and called the reduced mass of ice.

Results and discussion

At air temperature from $-8^{\circ}C$ to $-17^{\circ}C$ the reduced mass of ice produced in 4 minutes varied approximately linearly with air temperature. At a given air temperature the reduced mass of ice increased approximately as the square root of the time.

Before frazil begins to form the counter records a small background count which is apparently due to stirrer noise and perhaps to noise arising from water turbulence and to transients in the electrical lines. As frazil begins to form the number of counts rises dramatically. By noting the increment in the number N of counts in successive time intervals Δt it is easy to find a count rate $R(t) = \Delta N / \Delta t$. Fig. 1 shows this count rate averaged over three runs and plotted as a function of time for two cases - moderate stirring rate (mild turbulence) and vigorous stirring rate (strong turbulence). For each of these cases the curve of water temperature has been plotted on the same time scale. It is well known that the frazil crystals begin to grow at the time when the decreasing temperature line ceases to be linear. Fig. 1 shows clearly that the sharp increase in count rate begins about one minute after frazil begins to form.

It has been suggested (Hanley, 1978) that these acoustic emissions may be a result of either (1) stress-relieving imperfections developed during growth of the crystals, (2) collisions between crystals tumbling in the turbulent water, or (3) fracture of crystals during growth. To check the first of these we have grown disk-shaped ice crystals in non-turbulent water, and have not observed acoustic emissions during this growth. The second mechanism seems to be the one most compatible with Fig. 1. Collisions between crystals cannot be expected to register on the counter until the crystals are large enough to release sufficent energy to trigger the counter. Then as the crystals begin to gather together into flocs of slush, fewer crystals will be free to collide and vibrate, and the count rate can be expected to decrease as shown in Fig. 1. Equations for the vibration of the crystals yield frequency eigenvalues in a reasonable range of frequencies, and we are considering experiments to obtain more information about frazil growth from a study of these frequencies.

An electronic device has been planned and assembled at the University of Regina which attempts to discriminate between the acoustic emissions from frazil and the random background signals. At present it is designed to turn on an alarm when frazil begins to form; if successful in its tests, it could easily be adapted to activate heaters at the same time and so save the energy used by heaters when no frazil is present. In laboratory tests the device works well, showing a strong margin between the GO and NO-GO states. Field tests have had to wait until the next frazil season, but plans are being made to perform such tests this year during October-November.

Conclusions

Acoustic pulses observed during frazil formation are found to be related to the well-known temperature pattern which precedes and accompanies the production of frazil. The most likely source of the emissions appears to be collisions between the ice crystals as they tumble in the water. Plans are underway to attempt to verify this explanation and to use the results to learn more about frazil growth. A device to detect fresh frazil by its acoustic emissions has been constructed and has functioned well in laboratory tests. If field tests are successful, the device may prove useful for activating alarms or heaters on industrial trash racks or on seaway gates.

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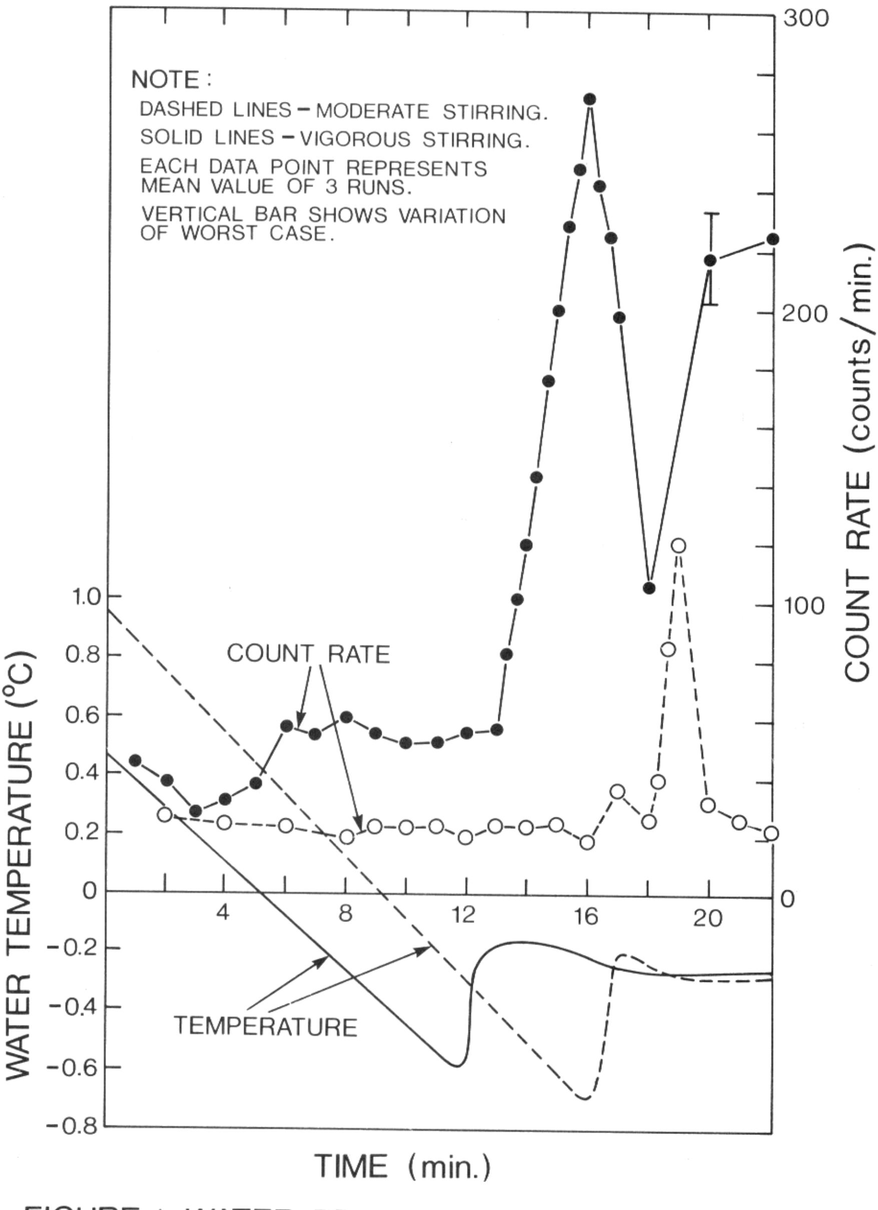

FIGURE 1. WATER TEMPERATURE AND ACOUSTIC COUNT RATE PLOTTED AGAINST TIME DURING FRAZIL PRODUCTION

References

Hanley, Thos. O'D. (1978) Early detection of frazil. Proceedings, I.A.H.R. Symposium on Ice Problems (Luleo, Sweden) Vol. 2, pp. 95-102.

Discussion:

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These experiments are very interesting. However, as a practical device for warning of a frazil run, acoustic sensing may be no better than traditional means whereby a combination of meteorological factors and water temperature are employed, i.e. for long-term meteorological forecast of wind, cloud, and air temperature and for short-term observed water temperature droprate, wind, air temperature, and net radiation. These experiments are worthwhile in another sense as they could yield knowledge of mass frazil growth rate since this may correlate with the pulse count rate.

REPLY BY Thos. O'D. Hanley, S.J.

It is true that by measuring the four quantities mentioned and supplementing them with meteorological forecasts we can predict the formation of frazil well enough to have grill heaters activated in anticipation of a frazil run. The acoustic device is designed to detect the actual formation of frazil and activate alarms or heater switches within a few minutes after the initial appearance of the ice upstream. We hope to ascertain during the 1980-81 freezeup how well the field tests compare with its behaviour in the laboratory.

A later paper will show that the relation between the mass of frazil and the acoustic count is not simple, although it may yet yield useful information.