NWRI CONTRIBUTON 86-107

ES 569

Ford (14)

Madsen (01)

This report has been submitted to the Proceedings of the Fourth Workshop on Hydraulics of River Ice, June 1986, and the contents are subject to change.

This copy is to provide information prior to publication.

FRAZIL ICE RECORDER TESTS

by

J.S. Ford and N.M. Madsen

Engineering Services Section
Hydraulics Division
National Water Reseach Institute
Canada Centre for Inland Waters
Burlington, Ontario, Canada

May, 1986

MANAGEMENT PERSPECTIVE

Long term monitoring of frazil ice in flowing water has two uses. First, it may be useful for operational situations such as the operation of water intakes. Secondly, data on frazil ice formation in the field is needed to evaluate the impact of ice formation on water conveyance projects or for diversions.

This instrument is a successful first attempt to provide reliable monitoring of river frazil ice, and meets a request made by the New Brunswick Ministry of the Environment. It complements the other instrument developed to measure frazil ice concentrations by means of conductivity. Frazil ice could be a significant factor in assessing fresh water resources for northern development. No other similar device is known to exist.

T. Milne Dick

Chief

Hydraulics Division

PERSPECTIVE-GESTION

La surveillance à long terme du frasil dans les cours d'eau sert deux fins. En premier lieu, on peut appliquer les résultats à des situations d'opérations réelles, notamment dans l'exploitation des prises d'eau. En second lieu, il est utile de posséder des données sur la formation du frasil dans des conditions réelles afin d'évaluer les effets de la formation des glaces dans la réalisation de projets de transport ou de dérivation des eaux.

Premier dispositif de ce genre, l'appareil permet de surveiller avec exactitude le frasil dans les cours d'eau et répond à une demande du ministère de l'Environnement du Nouveau-Brunswick. La surveillance du frasil peut s'avérer un élément important de l'évaluation des ressources d'eau douce dans le développement des régions du nord. À notre connaissance, cet appareil est unique en son genre.

Le chef,

T. Milne Dick

Division de l'hydraulique

RÉSUMÉ

On a mis au point une méthode basée sur la calorimétrie pour détecter et mesurer le frasil pendant une longue période : le prototype soumis à des essais en laboratoire a fourni des résultats satisfaisants. Au cours d'une des épreuves en conditions réelles, le dispositif d'enregistrement a été placé devant la grille de protection d'une turbine hydro-électrique. À l'heure actuelle, on prépare les commentaires sur les premières données recueillies sur le terrain. Il sera nécessaire d'apporter des améliorations au prototype. Il a été proposé d'utiliser un mécanisme pour dresser des profils.

TERMES CLÉS : Frasil, Mesure, Quantité, Calorimétrie, Essais

ABSTRACT

A means of recording the presence and quantity of frazil ice, over an extended period, has been devised using a calorimetric method. A prototype system was tested in the laboratory and gave reasonable data. In one of the field tests, the sensing body was placed ahead of the trash rack of a hydroelectric generator. Comments are made on the first field data. Improvements in the prototype are required. The use of a profiling mechanism is proposed.

KEY WORDS: Frazil Ice, Measurement, Quantity, Calorimetry, Tests

INTRODUCTION

The presence of frazil ice in river water precedes some periods of ice accumulation. These periods are important in modelling, forecasting and controlling rivers in winter conditions in Canada (Burrell 1984; Calkins 1984). A measure of the concentration of frazil ice is needed as an input to the models and control criteria. J.G. Lockhart, Environment New Brunswick, after consultation with Dr. K.S. Davar, University of New Brunswick and B.C. Burrell, Environment New Brunswick, requested that the National Water Research Institute, Environment Canada, respond to the need (memo Lockhart to Dr. G.K. Rodgers, July 1981). A recorder has been designed, built and tested to measure frazil ice in a river. The device is described and some results of laboratory and field trials are given. From the amount of field data gathered so far, it is clear that the system has potential for detecting and recording frazil ice events. Some improvements should be made to future models, however.

DESCRIPTION

A bullet-shaped body is anchored to the bottom of the river on a stand. An intake, in the nose-cone, is about one half metre off the bottom and faces upstream. Ice and water are drawn in the cone with a pump and agitator which breaks up the ice clusters to lower the probability of plugging. Heat is applied to the mixture so that the ice melts as it passes through the body. The water temperature is measured at the intake and again at the exit from the mixing section. The resulting temperature difference between the intake and exit is indicative of ice content. The presence of ice will lower the difference because it absorbs heat as it is melted. The ratio of ice to water is easily determined from the temperature differences.

The governing equation (Ford 1982) is

$$[1] \qquad n = \frac{2 \cdot F \cdot L}{S \cdot R \cdot V} - (T_2 - T_1) \cdot \frac{C}{S}$$

where n is the volume or mass ratio of ice to water depending on the units of C and S; F is the heat flux into the heater tube in power per unit area; L is the length of the heater tube; T_2 and T_1 are the exit and intake temperatures respectively when ice is present; R is the radius of the heater tube; V is the speed of the water through the tube; C is the heat capacity of water; and S is the heat of fusion for ice.

It can be shown, with the aid of Figure 1, that part of the first term on the right in Equation 1 is related to the temperature difference when no ice is present:

[2] $$\frac{2 \cdot F \cdot L}{R \cdot V} = (T_4 - T_3)C$$

where T_4 and T_3 are the exit and intake temperatures respectively when ice is not present.

The volumetric ratio of ice to water simplifies to:

[3] $$n = \frac{C}{S}((T_4 - T_3) - (T_2 - T_1))$$

with a short form:

[4] $$n = \Delta(\Delta T)C/S$$

where Δ signifies the differences in temperatures.

Providing there is no change in pumping or heating rate before and during a frazil formation period, the concentration of frazil can be measured from the time series record of the temperature differences only.

DESIGN

Several iterations in the design were made after laboratory testing to arrive at the present model. Considerable attention was paid to stable pumping, anti-clogging and replacement costs. Figure 2 shows the sensing head with the outer nose-cone removed.

The pump is the progressive cavity type which features a positive displacement action with the ability to pass moderate amounts of debris. The pump is driven by a synchronous motor through a 5:1 speed reducer. The heat is provided by two, 125 watt band-clamp heaters through a section of stainless steel pipe. The temperature sensors are physiological, hypodermic thermistors. Custom designed signal conditioning electronics give a one volt per degree celsius output for each thermistor.

Four #18 wires in a shielded, waterproof jacket carry the power to the sensing body (approximately one kilowatt). The AC power to the heater is regulated with a saturable transformer and is carried by one pair of wires while the motor power, on the other pair, is not regulated. The signals leave the body by seven, #18 wires in a similar cable.

On the bank of the river, the signals are received, processed and recorded in the control cabinet. A multipoint recorder provides the record of the intake and exit temperatures, the difference of temperatures, the heater and pump amperage, and any occurrence of an alarm condition such as overheating. If an alarm condition occurs, the power to the body is turned off automatically. The alarms can be overridden for test purposes. Ground fault interrupters provide protection for the public and personnel from all AC power leaving the control cabinet.

LABORATORY TESTS

One important set of tests was done to demonstrate the ability of the sensing body to resist plugging with frazil ice. Several intake and agitator shapes were tried. The best shapes were a funnel with a helical spiral turning at 360 rpm inside to to break up the frazil clumps and draw them into the heater section. The rate of rotation was chosen experimentally. The work of Michel et al. (1984), with their studies of ice accumulation on propeller blades rotating at different rates, was reassuring. Their Figure 11 showed that a propeller blade, rotating at 430 rpm, had iced up only at the hub. In our case the rate of rotation may be still too low to keep the ice from sticking to the agitator.

Another important series of tests was the calibration runs. A special bath had to be made up because frazil could not be formed in sufficient quantities in the ice flume. The dimensions of the bath were 90 by 56 centimetres and filled to 12 centimetres. The nose of the body protruded through one wall at mid-depth. This bath had a problem because the stirring was insufficient to overcome the stickiness and buoyancy of all the clusters and keep the bath well mixed. This was alleviated by adding salt to the water which assisted in keeping the frazil in smaller clumps at the higher concentrations.

The concentration of the frazil ice was measured independently with a grab-sample method. A dewar flask was used to dip out a sample of the ice and water. The temperature was measured then a 100 gram block of aluminum was transferred from boiling water to the flask. The contents were mixed with a magnetic stirring bar until the final temperature was reached. By correcting for the barometric pressure, the heat through the walls of the dewar and the salinity, a measurement of the frazil content could be made. Eleven blank runs showed that the bias was 28 ppm with a standard deviation of 100 ppm in the ice-to-water mass ratio. From this it could be concluded that the uncertainty in a single grab-sample determination is ±7 ppt ice to water by mass with a 95% confidence. Unfortunately the non-uniformity of the ice and water mixture, which is a function of water agitation, makes the uncertainty much greater at higher concentrations of ice.

Figure 4 gives an example of a calibration run. The intake temperature is well below zero because of the salt content. The exit temperture is about 2.25°C higher than the intake when the agitator is off and no ice is being sampled by the recorder. When the agitator is on, the exit temperture drops 0.75 degrees indicating about 0.91% ice by mass. The non-uniformity in the ice mixture can be seen in the noisy trace and especially when the dewar is used to withdraw a sample from the bath because of the extra agitation it introduces.

Several calibration runs are summarized in Figure 5 where the recorder's readings are calculated with Equation 4 and compared to the grab-sample determinations. There is a definite bias at higher concentrations because the dewar tends to sample more of the surface water than the recorder does. The correlation coefficient for the comparison is 0.79.

FIELD TRIALS

Five field trials were made with the logger in the winters of 1984 and 1985. One was a simple endurance test for the anchor, stand, sensing body and cables. A dummy setup was placed in the Nashwaak River near Stanley Bridge. The equipment remained in place without damage over the winter of 1984. However, the ice cover did not move out en masse as it sometimes does, so the survivability test was not fully representative.

The other four trials were done with an operating system. Two were done in Ontario late in the winter of 1984-85. Both trials ended with leaks in the sensing body. Valulable experience was gained in deploying the system and learning that the sensing body can operate well with a 250 metre cable to the control cabinet.

In the winter of 1985, two more field trials were made with the system. In late November, the field trials in the

Nashwaak River were ended by an operator mistake while the safety interlocks were defeated. Even though repairs were made quickly, further trials at that site were called off because a stable ice cover had formed on the river.

In the final trial for 1985, the system was installed in the Trent-Severn Waterway at the Sills Island Generating Station. The sensing body was placed in about four metres of water about three metres ahead of the trash racks for the generator. The installation went well with about an hour lost in generating time. The depth of the installation was a disadvantage because much, if not all, of the conglomerated frazil ice would be missed as it floated toward the surface.

Figure 6 gives three events in the recorder's traces. Time runs from the bottom of the page. The first event was unexpected. A rise in exit temperature indicated partial plugging of the intake. Ice did not seem to be the cause because at least part of the record would have indicated its presence with the lowering of the exit temperature. When the body was retrieved, several leaves were found clinging to the intake thermistor which may account for the problem. The thermistor has been relocated since.

Two other events are recorded in Figure 6. They indicate the presence of frazil ice in very low concentrations (0.13% by mass). During these events the generators were affected by icing conditions. The low concentrations suggest that the body was sampling frazil in the flake form that likely mixed to the bottom before clustering began. Once clustering began, the water turbulence was not strong enough to keep the ice down where the body was able to sample it. Visual observations confirmed that clusters arrived at depths of one to two metres but it was not possible at the time to confirm deeper clusters. Note also that the exit temperature did not return to normal after the second event. This might indicate partial plugging of the intake with ice.

FUTURE IMPROVEMENTS

The long term stability of the pump has been a disappointment. To overcome general drift in the baseline of the record, a third temperature record must be kept. This temperature will be a final temperature of the water after it has absorbed the waste heat from the motor. The difference between the final and the exit temperatures will indicate the actual flow through the body which can be used to compensate the frazil ice readings when required. Eventually a microprocessor should be used to make the compensations.

Further flume trials are recommended to make sure that ice does not plug the intake. If it does, the speed of the agitator must be increased.

Finally, the single point measurement in a river may not be enough to give a sufficient picture of all the frazil production. Placing the body in the best location, to sample frazil ice in an unbiased manner, will demand considerable skill from the monitoring system users. Therefore, a profiling mechanism should be considered in future designs. The addition of a depth sensor, a hydraulic ram and some servo controls would make it possible to automatically raise and lower the body to get a profile of the frazil ice. If a profiler is not used, careful consideration must be given to the site selection where the depth remains reasonably uniform, the water is well agitated, the frazil is fully formed but not yet reached the surface and where ice pans are unlikely to tip up and damage the body.

CONCLUSIONS

A working system has been demonstrated and tests have shown that it works according to theory.

The field experience has been very brief but valuable in the development of the recorder.

Some improvements seem necessary. These may be added as further testing and field trials confirm the suspected deficiencies.

ACKNOWLEDGEMENTS

We are grateful for the encouragement provided by personnel of the Environment New Brunswick, the Water Survey of Canada and the National Water Research Institute, especially N. Elhadi, B.C. Burrell, P. Hiltz and F. Roy. The contributions of field and diver support from the Water Survey of Canada, Parks Canada and the National Water Research Institute were excellent and we are especially grateful to P. Hiltz, B. Kitchen, B. Warwykow and H. Don. Sincere thanks are given for the assistance and full cooperation from Ontario Hydro through D. Hoffman and his people. The patient and dedicated work from our Machine Shop is acknowledged especially J.G. Ford, who must have shaped a dozen agitators for us. M. Pedrosa provided the much needed electronics support for this project. We are indebted to Dr. T.M. Dick who backed the project even at times when we appeared to be failing.

REFERENCES

Burrell, B.C. 1984. New Brunswick's subcommittee on river ice. Proceedings Workshop on Hydraulics of River Ice, University of New Brunswick, Fredricton, New Brunswick, p. 409.

Calkins, D.J. 1984. ibid., p. 247.

Ford, J.S. 1982. An engineering proposal for a frazil ice recorder. Technical Note, Hydraulics Division, National Water Research Institute, Burlington, Ontario, p. 5.

Michel, B et al. 1984. Measurements of frazil and drifting ice in the Lachine Rapids. Proceedings Workshop on Hydraulics of River Ice, University of New Brunswick, Fredricton, New Brunswick, p. 325.

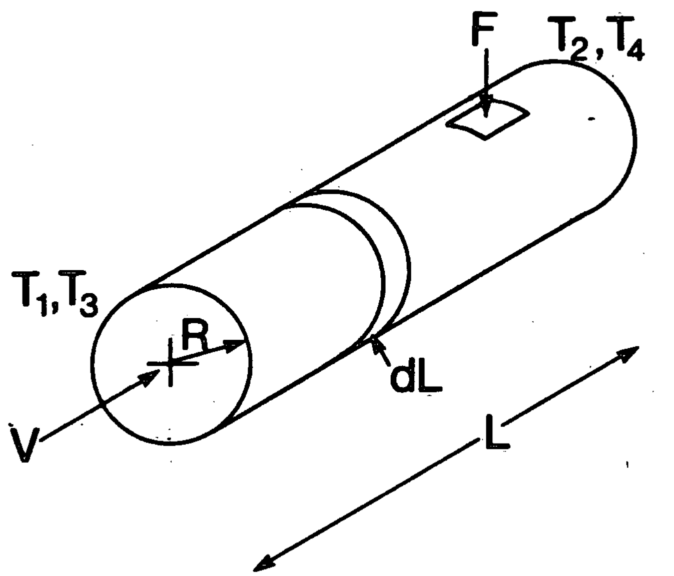

Figure 1 DIAGRAM OF HEAT AND WATER FLOW IN HEATER TUBE.

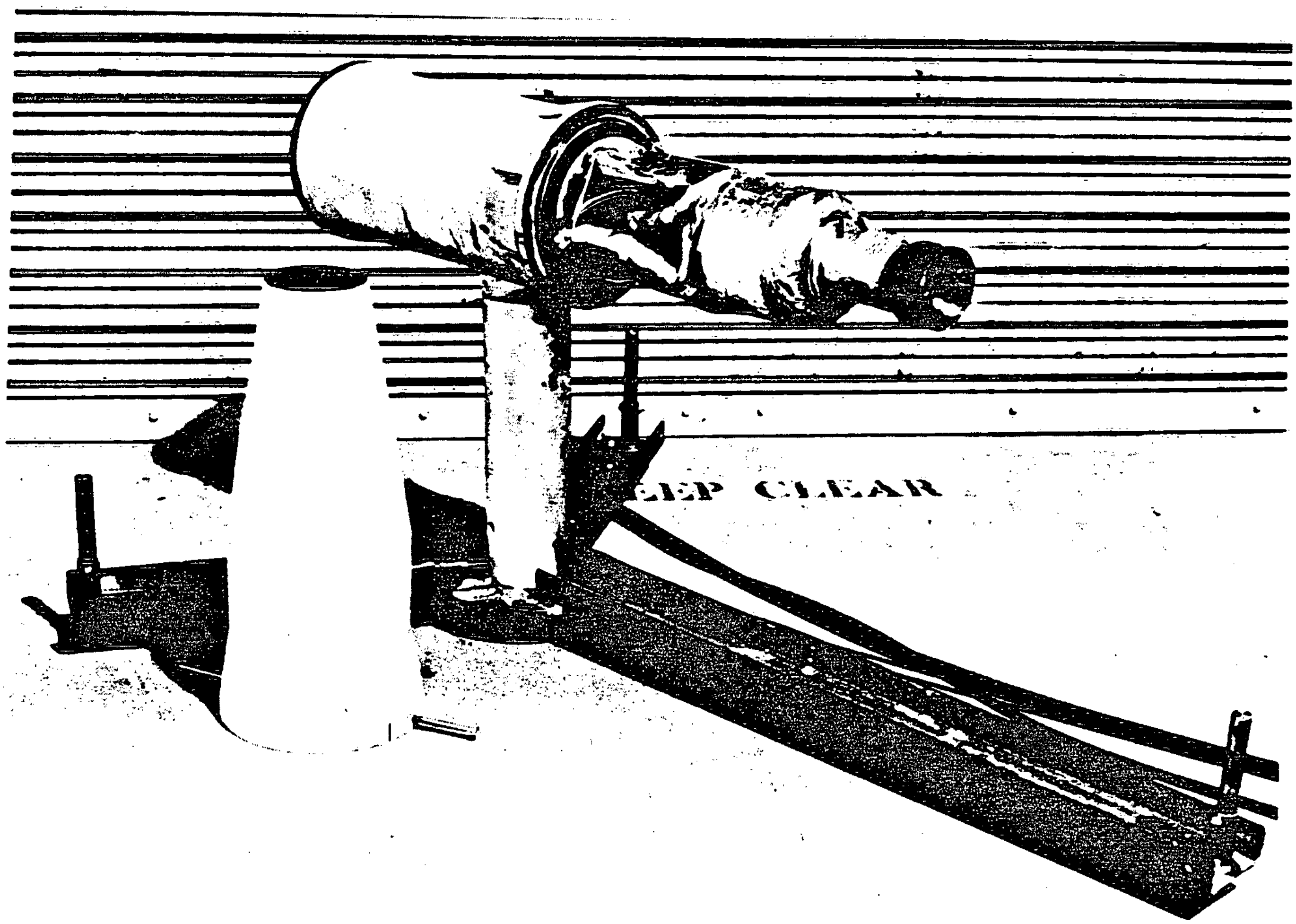

Figure 2 Sensing Body with Nose-Cone Removed

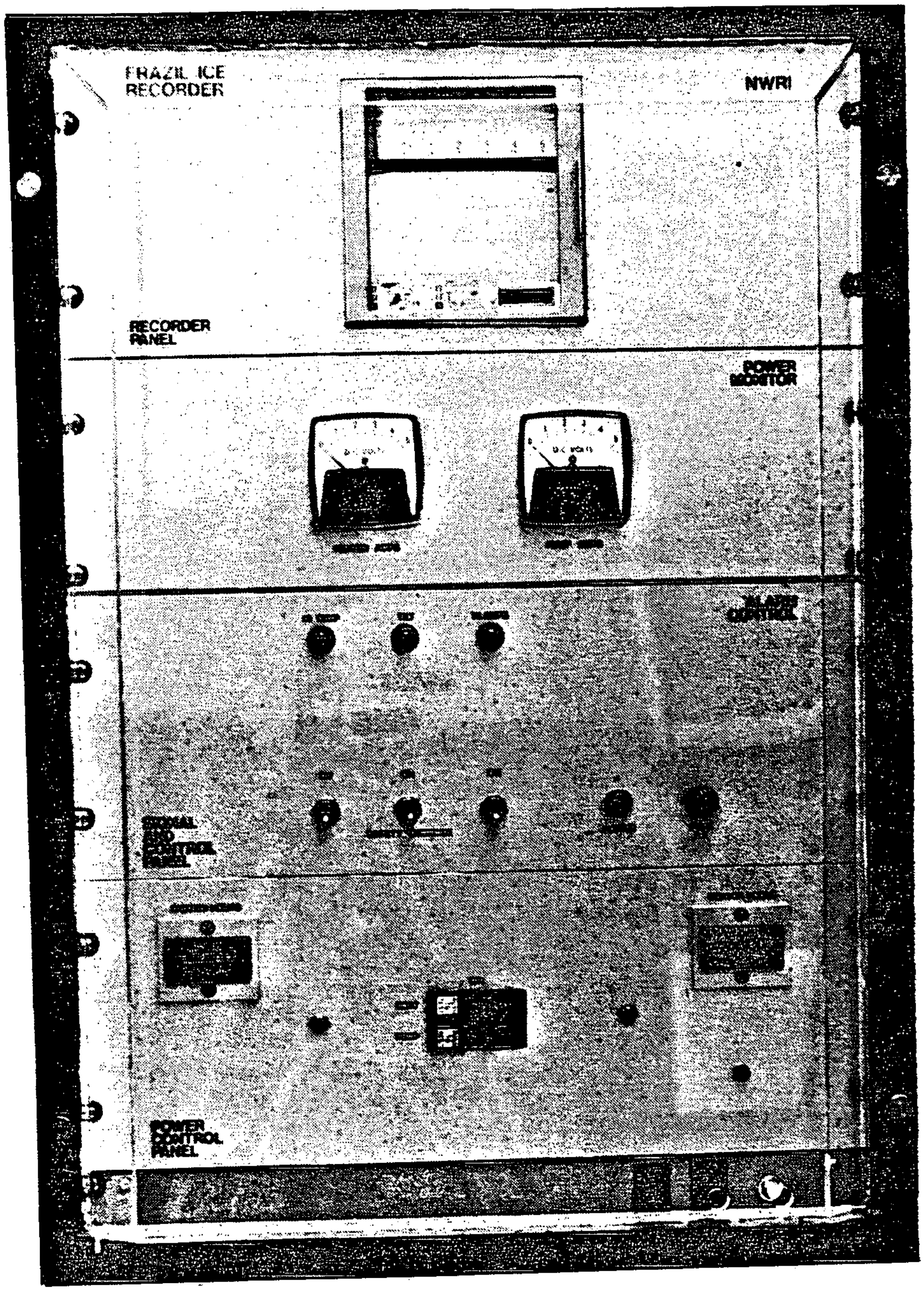

Figure 3 Control and Signals Cabinet

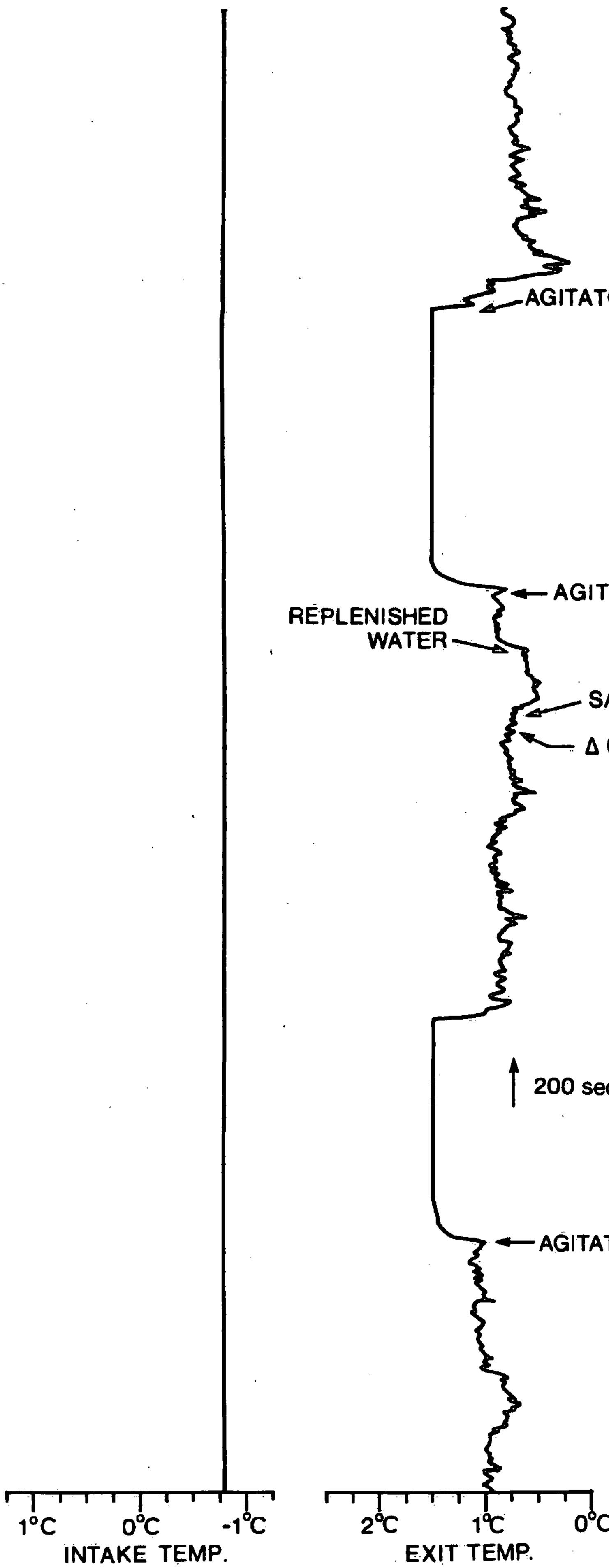

FIG. 4 SALTED WATER CALIBRATION

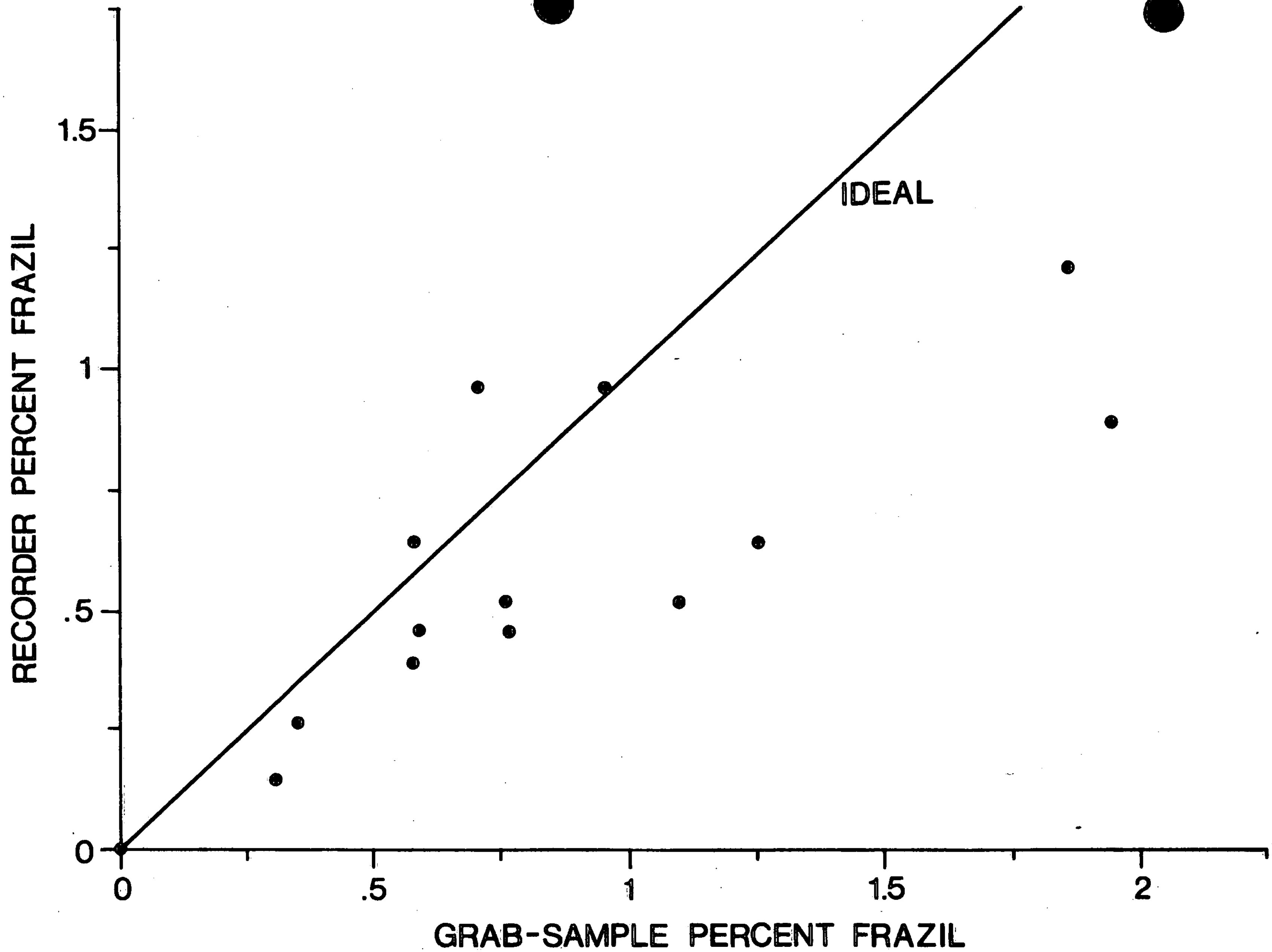

FIG. 5 CORRELATION-INSTRUMENT OUTPUT TO GRAB-SAMPLE

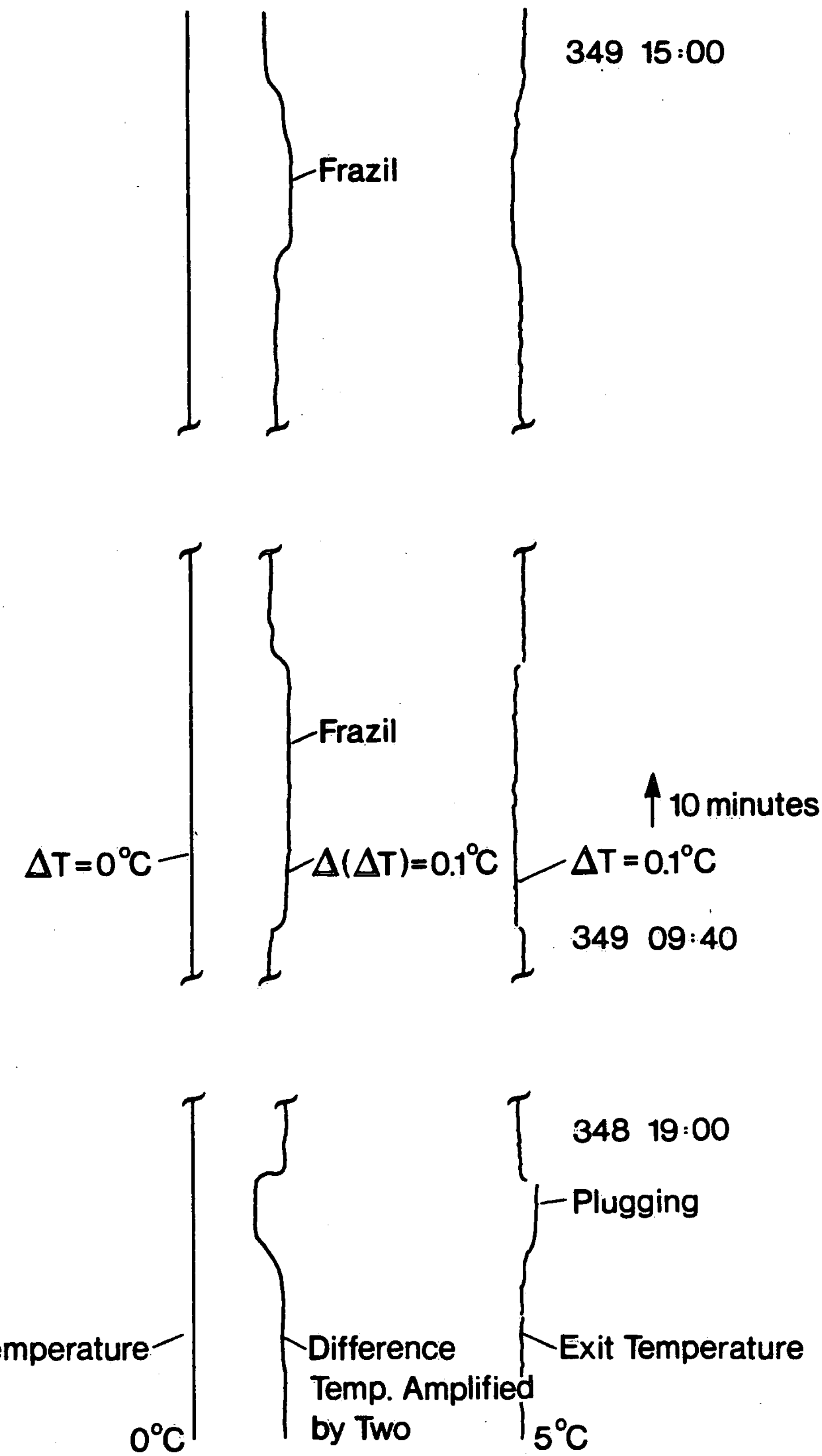

Figure 6 EVENTS FROM FRAZIL ICE RECORDER TRACES