# Detachment of Ice From Surfaces by Application of High Intensity Light

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A novel approach to the problem of detaching ice layers from surfaces is described. The primary problem is one of disrupting the bond of the frozen coating to the surface, at which point removal of the layer is a relatively simple matter. Some of the early methods that were examined at B. C. Research are described to show the progression which led finally to the subject technique. The use of high intensity light as the source of energy parallels the effect seen on a sunny winter's day, whereby, an ice coating exposed to the sun's rays experiences melting at the interface with the pavement surface. The advent of improved gas plasma arc lamps has provided the light intensity necessary to make this approach feasible for de-icing applications. A vehicle-mounted prototype de-icing unit that was field tested during the winter of 1977/78 is described and a brief discussion of the results and future prospects is presented.

## De-icing Background

Our organization began working in the field of de-icing technology in 1969 in response to a request from the British Columbia Ministry of Highways and Public Works to investigate methods of removing ice layers from paved road surfaces. More specifically, the problem was defined as that of determining the best method of removing a frozen layer of 13 mm (½ inch) maximum thickness - this being the residual coating which could not be readily removed by conventional plowing without damage to the pavement surface. No chemical means were to be considered.

A program involving both theoretical and experimental studies was initiated and several different approaches were condidered in the early work, viz.

### Simple Melting of the Layer

Technically, it would be possible to melt the entire coating using, perhaps, a gas-or oil-fired burner; however, the energy requirements would be enormous. A calculation was made to determine the fuel requirement, based on a maximum heat transfer efficiency of forty percent (40%), for 1 km (0.6 mi.) of a 3.66 m. (12 ft.) lane width and having a 13 mm (½ inch) coating of ice at -10°C (+ 14°F.) ambient temperature. A minimum of 1200 ℓ.(317 U.S. gal.) of fuel oil per kilometer would be required. Also, the resulting volume of melt water would be over 42,000 ℓ. (11,000 U.S. gal.) per km., which would present a formidable disposal problem.

This approach, then, was rejected for three main reasons; (1) high fuel consumption, (2) low traverse speeds, and (3) flooding and/or refreezing complications resulting from the melt water.

### Mechanical Detachment of the Coating

The work required to fracture ice is relatively little, so it is very tempting to try mechanical detachment methods. Our calculations showed that 75 watts (0.1 hp) would be needed to fracture a 13 mm (½ inch) thick ice layer along a 3.66 m. (12 ft.) lane width at a traverse speed of 24 km/h (15 mph). The fracturing was assumed to occur in 3 mm (1/8 inch) thick layers down to the interface with the road, but without separating the last thin film of ice residue from the base.

Other researchers[1,2] have shown that the physical strength of ice is often less than its adhesive force to other materials. In the case of an ice layer on pavement it has been found that using mechanical force on the ice coating will result in fracturing the ice, but not in separating it completely from the surface to which it is bonded.

Laboratory tests using a jack hammer with a spade tool and various narrower chisel-shaped tools showed that these were capable of chipping the ice away but, as predicted by theory, always left a thin film on the pavement surface. Over-enthusiastic use of the jack hammer removed the entire ice coating but not without damaging the underlying pavement. A compressive force applied normal to the ice surface through a blunt tool resulted in shattering of the ice in a flaking mode, but again left a thin layer of ice adhering to the pavement.

Because our tests indicated that the mechanical

approaches were not completely effective in removing the ice coating from the road surface, we turned our efforts in new directions.

Other Methods

Next, a number of more exotic techniques were considered and some tested experimentally; viz.,

Microwave Power. The possibility that microwave power would be effective in detaching the ice was examined. However, the known dielectric constants and very low loss coefficients of both ice and asphalt pavement showed clearly that a very high voltage gradient and very large displacement current would be needed to produce the desired effect. Under such conditions the efficiency of power transfer would be very low and the service life of the equipment would be very short. No experimental verification was attempted.

Electrical Discharge. Sudden electrical discharges are known to exert disruptive forces on many insulation materials. In a laboratory test a ½ μf capacitor was charged to 25,000 volts and discharged against the surface of an ice-coated block of asphalt pavement material. Even a thin ice coating (3 mm/ 1/8 inch) was sufficient to resist penetration - the discharge was dissipated over the ice surface without causing any observable effect.

Vibration/Ultrasonics. Vibrations originating from a jack hammer had been tried and found ineffective. Vibrations from an ultrasonic source at approximately 22,000 Hz frequency were applied through a conventional acoustic transformer to the surface of an ice-coated pavement specimen. For low contact pressures flaking occurred at the surface. However, there was no indication of any disruptive effect at the ice/pavement interface.

Infrared Heating. A considerable amount of work was carried out in utilizing various forms of infrared heating as possible means of removing ice. Examination of the radiation absorption characteristics of the ice/water system, however, indicates that radiation in this wavelength region (2-50 microns) will be almost totally absorbed at the ice surface and, as such, amounts to no more than a variation of the simple melting methods tried (and rejected) in earlier work.

Visible and Near-Visible Radiation. Published data[3,4] on the properties of ice suggested that electromagnetic radiation in the visible and near-visible regions of the spectrum could pass through ice relatively unimpeded, but would be absorbed strongly by pavement materials. The implication was that the interface between the ice and the pavement might be heated selectively by such radiant energy. If the energy could be supplied to the interface at a faster rate than it was conducted away, then the interfacial temperature would rise to the melting point of ice, resulting in disruption of the ice/pavement bond.

Several laboratory experiments were conducted on ice-coated pavement sections and these confirmed that the bond disruption occurred as predicted.

In view of the promising aspects of this latter approach, subsequent work (1970 and onwards) was aimed at studying and developing this method of de-icing.

Visible Light Experimentation

A program was begun to measure parameters and, hopefully, to optimize efficiency and rate of ice removal for an ice detachment system using visible light energy. The early phase of the program began with both theoretical and experimental procedures.

An initial mathematical model was created to represent a static condition, wherein radiation incident onto an ice-coated surface and the rate of temperature rise was expressed in terms of energy input, thermal conductivity of ice, and the interface temperature. The expression had the form,

$$Q = \frac{W}{t} = \frac{a\Delta T}{\sqrt{t}}$$

, where W is amount of energy input to the ice/ pavement interface required to raise the temperature to the melting point of ice,
a is a constant,
ΔT is the difference between the initial temperature at the interface and the melting temperature of ice,
Q is the rate of energy input to the interface, and
t is the time required to reach the melting point of ice.

The important aspect of this relationship was, that if good efficiency was to be achieved, then a high rate of energy input to the interface would be essential.

Later, a second and more complex model was conceived to introduce the effect of motion of the energy source over the surface of the ice and to incorporate a term for the energy required to melt a thin film of ice at the interface (latent heat). The relationship derived was,

$$Q = bV + c\ \Delta T\sqrt{Vx}$$

, where Q is the rate of energy input to the interface per unit length of source,
b and c are constants,
V is the traverse velocity of the energy source,
ΔT is the difference between the interface temperature and the melting point of ice, and
x is the distance travelled in the traverse direction.

From this model, calculations were made to obtain a range of values relating energy input rate at various interface temperatures and traverse velocities to thicknesses of ice melted at the interface. Up to a limiting energy input rate, we were able to verify these calculations in laboratory and field experiments using very high intensity quartz/halogen lamps.

A series of experiments was carried out to measure the energy transmitted through an ice or snow layer for visible energy sources and therefore determine what fraction of the energy would be effective in producing heat at the interface. These tests showed that the optical transmission of clear ice peaked at about 0.47 microns wavelength and was high throughout

the wavelength range 0.3 - 1.0 microns. Other experiments were conducted to verify theoretical relationships; such as, that the required input energy rate was a function of the square root of the traverse velocity. Still other tests showed that an ice coating was dependably detached from a pavement specimen when a 130 micron (0.005 inch) thick film of ice was melted at the interface and, also, that refreezing required more than five seconds after passage of the energy source for an ambient temperature of -15°C (+5°F). Gradually, the data were accumulated that allowed us to design an ice-removal process. At this stage[5] patent protection was sought (1974) and received .

During the course of these experiments it became evident that even the most intense light sources of the day did not have sufficient output energy density to enable our proposed machine to de-ice pavement at a high enough speed to be practical. Our prediction showed that 115 kw. of radiation was needed to reach the interface for each 30 cm. (1 ft.) of lane width in order to melt a 130 micron (0.005 inch) film of ice at 24 km/h (15 mph) traverse velocity and an ambient temperature of -15°C (+ 5°F). An extensive search for a suitable high intensity source failed to uncover anything that looked promising, so the project was temporarily shelved.

Within a few months hope was suddenly revived by the publication of data on a potentially very high intensity light, based on the principle used in plasma arc welding. Groups of workers in several physics laboratories had been developing gas plasmas - highly ionized gases that are electrically conductive and, in many respects, behave as metallic resistance heaters. An electric current passing through such a plasma will heat it up to a steady-state temperature which is dependent on the balance between heat input and heat removal. Temperatures beyond 30,000°C (54,000°F) have been reached in reported laboratory tests. The elimination of the tungsten filament and its replacement by a gas plasma; such as, ionized argon, has led to a many fold increase in the radiant energy that could be produced heretofore. We followed the progress in plasma arc lamps with eager anticipation and, in fact, we worked in cooperation with one group at the University of British Columbia to conduct initial de-icing tests in their laboratory. Important developments were made in stabilizing the light output and prolonging electrode life until, by 1976, at least two companies were offering gas plasma arc lamps for sale commercially. Finally, we were able to organize the funding for a program to field test the concept of de-icing pavement using a vehicle-mounted plasma arc lamp.

## A Prototype De-icing Equipment

During 1977 the construction of a prototype de-icing unit was completed in order to run field trials during the winter of 1977/78. The main components of the unit were, (1) the gas plasma arc lamp, (2) the downward facing water-cooled reflector, (3) the water-to-air heat exchanger, (4) the diesel-generator power supply and (5) the transporting vehicle. The lamp was specially modified for cold weather use and for transportability. The lamp length was 20 cm (8 inches) and required 100 kw of input power. The typical energy level emitting from the reflector was 20 kw approx. The reflector was contoured to focus the radiant energy in a line about 1 cm. (0.4 in.) wide at the road surface. The vehicle was a dump truck modified to operate at low speeds and to carry the arc lamp (with its heat exchanger) cantilevered out in front (see figure 1). The power supply was mounted in the dump box. A test site in central B.C. was selected and prepared for testing in the fall of 1977. Thermocouple wires were imbedded in the asphalt with the measuring junctions positioned half-buried at the surface.

Despite some initial difficulties, several test runs were made over the thermocouples at a variety of ambient temperatures with different coatings on the road surface for a range of traverse speeds. In each test run the temperature variations versus time were recorded.

Figure 1. Photograph of the vehicle-mounted prototype de-icing unit.

A comparison of measured and theoretical results revealed good correlation for clear ice coatings. Snow coatings, as expected, presented a more serious problem because of their inherently high reflectivity. A high percentage of the energy incident on the coating never reached the road surface, consequently the temperature rises recorded, even at very slow traverse speeds, were quite small (typically 20% of of those for a similar thickness of clear ice at the same traverse speed and temperature).

## Conclusions

If the correlation between theoretical and actual results holds for higher power levels incident onto the coating, then to detach clear ice from pavement at 24 km/hr (15 mph) would require at least 120 kw per 30 cm (1 ft.) of lane width. The lamp used in the prototype de-icer produced approx. 30 kw per 30 cm (1 ft.) width. It is expected, however, that this could be at least doubled merely through improvements in (a) reflector contour and (b) the reflectivity of the reflector surface. Increases in lamp emission can be expected as the techniques of electrode cooling improve and conversion to other gases (e.g. xenon) or gas mixtures for the plasma is made. Other possibilities for increasing the radiant energy onto the road surface involve the use of multiple lamps.

The need for an environmentally acceptable and energy conserving technique for de-icing surfaces; such as, roads, airport runways, ships decks, etc., makes the future of the subject method appear very bright (no pun intended).

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References

1. Raraty, L.E. and Tabor, D. The Adhesion and Strength Properties of Ice. Proc. Roy. Soc., Vol. 245A, No. 1241, 3 June 1958 pp. 184-201.
2. Stallabrass, J.R. and Price, R.D. On the Adhesion of Ice to Various Materials. Aeronautical Report LR-350, National Research Council of Canada, N.R.C. No. 6980, July 1962.
3. Lyons and Stoiber. The Absorptivity of Ice: A Critical Review. Dartmouth College (1959); AFCRC-TN-59-656, Sci. Rpt. #3.
4. Sauberer, F. Die Spektrale strahlungsdurchlässigkeit des Eises: Wetter und Leben, Jahrg. 2, Heft 9/10, pp. 143-197, (1950).
5. U.S. Pat. #3,964,183; Cdn. Pat. #980,846; (other patents pending) Method and Apparatus for Detaching Coatings Frozen on to Surfaces.