Where, however, the insulation to metal surface joint is that point on a refrigerant pipe where the insulation ceases—for instance, near the compressor or around a valve spindle, it is not possible to keep the metal ice free actually on the normal line of contact. It has been suggested that by arranging for a false or secondary line of contact, ice formation can be avoided (Fig. 5, p. 544).

Here the cone of metal must be sufficiently large to pick up enough heat, so that the new line of contact is above freezing point and considerable research would be needed to arrive at the correct areas of heat pick up for varying pipe and ambient temperatures.

ICING PROBLEMS ON SHIPS

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The following remarks are derived mainly from the experiences of ships of the Royal Navy serving in Arctic waters. Icing was encountered by our submarines operating in the Baltic Sea in the 1914–18 war and by the warships of all types which crossed the Greenland and Barents Seas as escorts or covering forces for North Russian convoys in 1941–45, but in peace the phenomenon may still be encountered in any winter by the ships of the Fishery Protection Flotilla or the frigates on the America and West Indies Station. A certain amount of experience of icing is also gained during special cruises; for example, by the ships participating in the Cold Weather Cruise in February 1949. These experiences, however, merely display in somewhat heightened form the problems which confront any steel ship in high latitudes.

In point of fact, in the Cold Weather Cruise of 1949 far more rough weather was encountered than cold weather, and heavy icing never occurred. This seems to be fairly typical of experience in near-Arctic regions, which can be traversed time after time without experiencing icing. The weather conditions which give rise to this phenomenon are a strong wind, a cold sea, say 29° to 32° F. (1·7° to 0° C.), and a low air temperature, say 5° to 20° F. (−15° to −6·7° C.). Incidentally, these air temperatures are low for the open sea clear of land masses or ice. In strong winds continuous masses of cold spray are flung at the ship at a temperature just above freezing point; the low air temperature chills the steel and the spray freezes immediately on impact. With these conditions a film of ice builds up on the steel. This tends to become a sheet and the sheet a block. There is no apparent limit to the process, which continues while the weather conditions persist. In general the ice formed in this way binds tenaciously to the steel. If an opportunity comes to remove the ice a considerable physical effort with ice picks and similar implements is required.

All the above-water parts of the ship which are not perceptibly warm are liable to accumulate ice when the weather conditions are suitable. In time the weather surfaces of the ship and its superstructure and deck equipment disappear under the icy envelope. This has two effects:

(*a*) The deck equipment will, in the absence of special measures, become locked with ice and unworkable; and

(*b*) The weight of ice which is being continuously added to the topsides of the ship will reduce and may even endanger the stability of the ship.

The effect of icing on the superstructure of a ship is thus a progressive wearing down of the resistance of the ship to capsizing. In a beam wind one side of the ship would be iced and the ship would heel to that side, and, with the deck edge brought nearer to the waves, the rate at which ice is deposited would be accelerated.

Warships are likely to suffer more from icing than merchant ships. Only one case of a warship being lost in 1939–45 as a direct result of icing can be recalled, although photographs of iced up ships suggest that the margin of safety must often have been small.

The obvious method of attacking ice as it forms is with heat, but to attempt to heat all the weather surfaces of a ship would involve first cost, permanent weight and fuel consumption which are prohibitive. The use of heat is therefore confined to certain items of equipment which must be kept workable. As an example, the steel screen doors which give access from the superstructure to the decks of warships must be capable of being opened at any time; this is usually ensured by encircling the door with a small bore steam pipe which keeps the steel plating warm enough to prevent ice forming between screen and door. An auxiliary steam range encircling the ship can fairly readily be tapped for this sort of duty. Again certain instruments have electric heaters built into them to maintain the functioning of the instrument. These applications are, however, necessarily local and in general it has to be accepted that icing will occur when the weather conditions are appropriate.

What can be done about icing while it is in progress? Here is an account by one who has been at sea in icing conditions:

> "Spray icing comes very fast—although 3 days a month has been quoted as the odds, to anyone who is trying to keep the sea it is more like 30 days. The average relative wind velocity between the months of October and May was certainly 50 knots and seldom less than 30. Under these conditions you get a good deal of spray and it does stick at once, getting thicker and thicker until you get into harbour. As for *ad hoc* action of the ship's company, either chipping or breaking ice is normally not practicable because the sea is too rough. You cannot get on to these exposed surfaces and normally you have to wait until you are in harbour. There is very little you can do at sea once ice has formed."

Naturally every advantage is taken of any permissible change of course which reduces icing, and of any lull which allows some ice to be cleared.

The major advance in de-icing methods in recent years has been the development of means of preventing ice from binding tenaciously to steel and so making the chipping and removal of the ice easier. This is effected by the prior application to steel surfaces of certain dressings. There is a variety of these dressings available suitable for brush, spray or smear application. In essence they merely interpose a greasy film between the ice and the steel and as a result the effort required to remove the ice is considerably reduced. This sounds simple enough, but it must be remembered that the ideal dressing should be easy to apply but capable of resisting the attrition of wind, spray and rain, possibly for weeks before ice forms. It should facilitate the removal of the ice at a low temperature and should then be in a state to function satisfactorily again if icing recurs; it should not be unreasonably obnoxious to the crew as regards odour and stickiness; should be transparent and colourless so as not to interfere with camouflage colour schemes, and must be non-poisonous and non-corrosive. Besides these surface dressings there is a need for a luting compound which can be worked into clearances in mechanisms to prevent the intrusion of water which, on freezing, would lock the mechanisms. If this locking is avoided and if proper low temperature lubricants are used, deck machinery may be expected to function quite satisfactorily.

In the matter of equipment steel wire rope in general behaves very well in icing conditions and if treated with de-icing paste should give little cause for concern. With hemp and manilla rope there is often a tendency to stiffen which is not easily countered. This makes the use of signal halyards difficult—a matter of some importance in convoy work. One proprietary make of rope has a core impregnated with a de-icing agent. Nylon rope can also be used. For freeing small iced-up fittings there are portable heaters similar to blow lamps. It can be said that the icing of deck equipment is not a major problem.

It will be realized from the foregoing summary that icing in ships, particularly small ships, can still be a serious matter. Counter-measures on a much more ambitious scale than are at present attempted are entirely feasible, but would hardly be justifiable unless the ship concerned was being designed exclusively for Arctic or Antarctic work.

DISCUSSION

The CHAIRMAN opened the meeting for discussion.

Dr. VINCENT SCHAEFER (General Electric Company, U.S.A.) said that a few years ago a very interesting method of changing a super-cooled cloud to one of ice crystals was found. Mr. Hardy had referred to that briefly and he would therefore like to describe some of the things that had been learned about supercooling.

Basically, water could be cooled, as far as was known, to a temperature of about $-38\frac{1}{2}°$ C. The only thing which prevented this degree of supercooling was the presence of foreign particles and frost crystal nuclei.

In the atmosphere there were natural nuclei of foreign particles which served to form snow. As far as he was aware this normally occurred at a temperature of about $-12°$ C. threshold temperature, and perhaps as low as $-36°$ C., depending on the particular particle. A certain spore had served as an ice nucleus and had been known to form a snow crystal at a temperature of $-36°$ C. So far as was known, bacteria did not form nuclei within a temperature of $-39°$ C. A small piece of clay had served as a nucleus at a temperature of $-15°$ C. A smoke cloud did not form nuclei but graphite had been known to do so under certain conditions.

A still different type of ice nucleus effect was that produced by freezing nuclei, called frazil ice, which formed thin, rounded discs in supercooled streams. These often developed when the air temperature was only a few degrees below 0° C. and often created a serious problem where hydro-electric plants utilized such water. A complete shut-down of a 30,000 kW. power plant had been observed less than an hour after such ice began forming.

Since January 1948 at the summit of Mt. Washington in New Hampshire, U.S.A., more than 8000 observations had been made of the concentration of ice nuclei in air samples. It had been found that the values varied by a factor of at least a million-fold. For example, about 50 per cent of the observations had shown a concentration of ice nuclei of less than 500 per cubic meter of air. All observations had been made with the air sample cooled to about $-18°$ C. About 42 per cent of the observations had shown the concentration to be in the range of 5×10^2 to 5×10^5 per cubic meter of air. The remaining 8 per cent had shown values between 5×10^5 and 1×10^7 per cubic meter. It was believed that about 10,000 ice nuclei per cubic meter were necessary if effective modification of a supercooled cloud was to occur within about thirty minutes. This variability of ice nuclei concentration was believed, to be one of the most important factors related to the difficulty of predicting the occurrence and persistence of supercooled clouds.

The result of being able to change a supercooled cloud to ice crystals was that it was also possible to modify its path in the atmosphere. One gram of dry ice could be used to produce 10^{16} ice crystals. Large areas of super-cooled cloud had been cleared over North America and it was technically very easy within a few minutes to clear two or three hundred square miles if the clouds were suitable for modification.

It was now thought that it would be reasonably easy to modify destructive storms, and one day it might be possible to tackle the hurricane because, as far as could be seen, destructive storms were bound up with super-cooling and if super-cooling could be prevented in the early stages, it should be possible to prevent the storms.

Mention had been made by Mr. Hardy of frost on refrigerator surfaces. The speaker believed