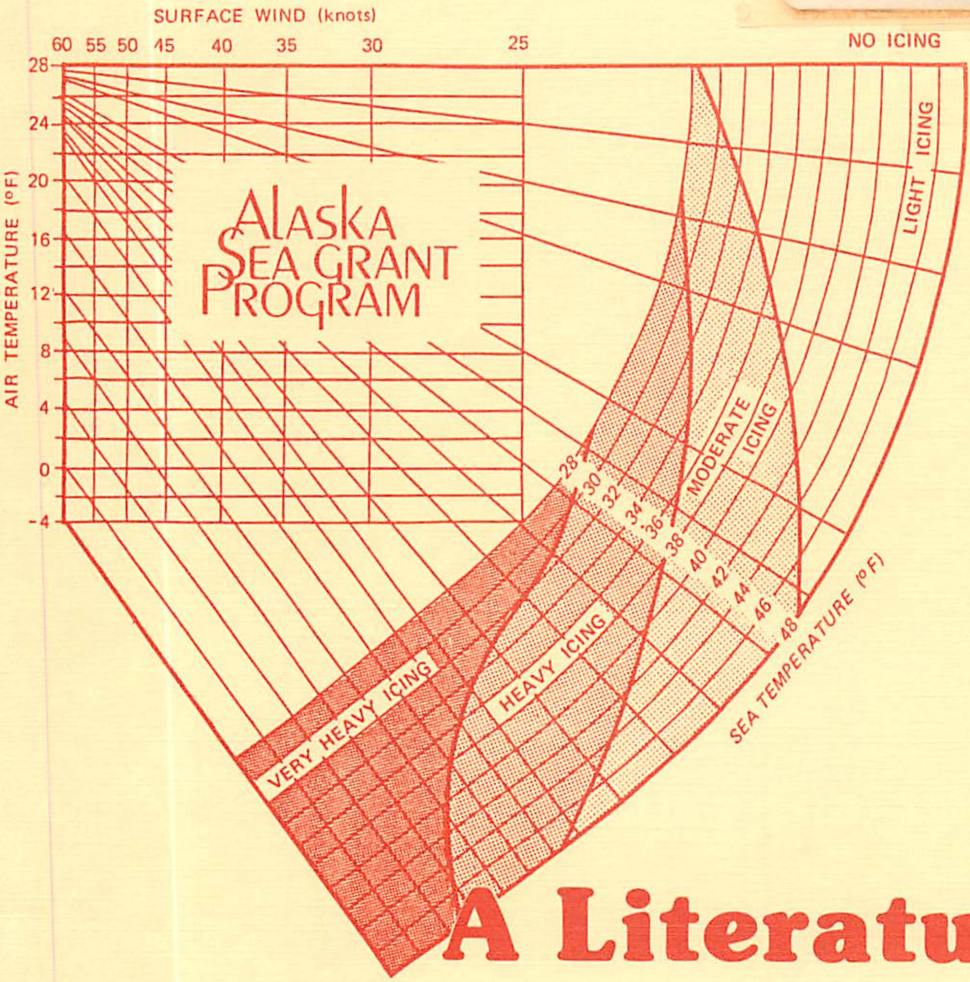

A Literature Survey of Spray Icing on Small Fishing Vessels

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A LITERATURE SURVEY OF SPRAY ICING ON SMALL FISHING VESSELS

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REPORT SUMMARY

INTRODUCTION

The impetus for this project came from an article by Ball (1978) which noted that "...vessel icing is one of the most dangerous phenomena a fisherman can encounter." Ball went on to indicate that icing can be costly, both in time lost avoiding or combatting the problem and, more seriously, in the occasional loss of a vessel. Although there seem to be several strategies for addressing the problem (including public education and development of an icing forecast network), little engineering research has been done to obtain cost-effective solutions through preventive measures or active de-icing.

Icing is not a problem common to all the world's fisheries, yet for those who use the polar fishing grounds during winter, it is a vital concern. The paucity of work in this area can be explained because it affects relatively few people, but the gravity of the problem speaks in favor of more study.

Wind-borne spray can freeze to any surface. If conditions are severe, a great mass of ice can accumulate quickly. Unless the skipper can hold a windward heading or run before the wind, the mass will be laterally asymmetrical; this shift of the center of bouyancy affects stability and handling characteristics. Asymmetries fore and aft can seriously weigh down the bow or stern, affecting steerage and speed.

OBJECTIVES

The objectives of this project were to determine state-of-the-art methods for dealing with ice accretion on small vessels, how well these methods work, where the focus of new research should be, and to prepare a plan for an engineering study of alternative strategies for reducing the icing problem.

WORK PLAN

At the beginning of the project, several comprehensive studies were available (Itagaki 1977; Minsk 1977; Ackley and Templeton 1971; Stallabrass 1970). Because of their completeness and accessibility, it is unnecessary to report a complete review of the general and technical aspects of the problem.

It was necessary, however, to get some idea of current icing studies. Computer literature searches were helpful in this area. We also contacted embassies of nations with northern fishing interests and asked about research pertinent to icing. These answers are summarized in the correspondence section. We also contacted people familiar with icing in Alaska. The U.S. Coast Guard; J.L. Ball, marine advisory agent in the University of Alaska's extension program; and the staff of the Alaska Sea Grant College Program were particularly helpful.

The resulting literature review is two-part: a briefly annotated bibliography, and brief summaries of 13 reports judged most helpful in determining a practical icing solution.

We found no practical economical anti-icing device described in either the literature or the correspondence from circumpolar nations. Theoretical research has been sponsored by several countries. The British, when they were fishing in Icelandic waters, made progress toward a practical solution; these efforts ceased when they permanently left these dangerous waters. The British tests and the more theoretical work can provide background for developing a prototype.

Three publications have resulted from this study: this report, a master's project report by Nisai Palanukorn, and a technical paper for the IAHR International Symposium on Ice, Quebec, 1981 (Carlson, Zarling and Hok). The papers' abstracts appear in Appendix I.

RESULTS

Fishing vessel icing in Alaskan waters occurs almost annually. Vessels can be lost, damaged, or made inoperative because of it, and a considerable amount of crew time is expended avoiding or recovering from each episode. It is a hazard that Alaskan waters have in common with other circumpolar fishing grounds.

The preliminary study of the readily available literature indicated four approaches to the problem. First, an increased understanding of the icing process and of the ice cover's molecular structures could lead to improved ship design, maintenance, and operation. Second, improved understanding of meteorological aspects could lead to better icing advisory forecasts (permitting avoidance maneuvers). Third, a number of active or passive anti-icing (preventative) methods have been studied; these could decrease the threat of an ice build-up. Finally, a number of active or passive de-icing techniques have been used with varying degrees of success.

We reviewed articles dealing with any aspect of vessel icing. Minsk (1977), Stallbrass (1975) and Ball (1978) give a complete summary of nearly all important aspects of the problem. Minsk's work describes many technical features of the problem, concentrating on the ice growth processes. Although aimed at ocean structures in general, most of his report is drawn from and is directly applicable to vessel operation. Stallabrass's work reports on his own extensive laboratory and field studies and also draws heavily on the published literature. It is extensive, complete, and well done in every aspect. Ball draws together important features of the problem as it applies to Alaskan waters.

After reviewing the work of others and relating possible solutions to Alaskan conditions, we feel that active de-icing concepts hold the most promise. De-icing methods tried elsewhere will not work in the Alaskan fleet unless some modifications are made. This is where engineering and research efforts should be concentrated.

The Alaskan fishing fleet is for the most part small, and the boats are owner-operated. Many of the vessels are heavily used, fishing for several species throughout the year. Most have small crews and carry modest, though adequate, communication equipment. The most important feature, of course, is that the fleet operates during the winter under stormy conditions that often cause severe icing.

These fleet characteristics should be considered when designing de-icing equipment for Alaskan waters. Since most vessels are already built and outfitted, a de-icing device would have to be readily adaptable to existing conditions. The equipment must be fairly unobtrusive, but ready to operate after long periods of non-use. Because icing usually occurs in heavy seas under emergency conditions, the device would have to be semi-automatic and operable by remote control. Finally, it should be inexpensive to install, operate, and maintain.

Of the 20 or so techniques and devices mentioned in the literature, several appear to have promise and should be considered in the preliminary aspects of an engineering and development program. Pneumatic inflatable membranes seem to be the only successful field-tested device and should be a prime candidate for further consideration. Thermosiphons have a great deal of conceptual appeal and are especially attractive for using waste engine heat. High pressure sea water ram jets have been tried and would readily adapt to existing vessel equipment. The one universal removal technique, brute force hammering and axing, could be greatly enhanced with pneumatic and mechanical vibrating hammers. Improved ship design should still be considered for new or rehabilitated vessels to include de-icing measures.

CONCLUSIONS

Of the more promising methods addressed above, considering the characteristics of Alaskan vessels and the means available to a university engineering research program, four appear to have promise: adaptation of pneumatic or hydraulic inflatable membranes, improved high pressure jetting, improved mechanical or pneumatic hammers, and a device to vibrate a surface vigorously enough to sever the ice-surfaced bond. Each has its inherent limitations and advantages, would address different aspects of the problem, and would appeal to different types of vessel design and operation.

Because pneumatic inflatable membranes are the single proven de-icing device, research should be directed toward examining the availability of manufactured components and the cost and feasibility of adapting them to fishing vessels.

High pressure jetting has been mentioned in several references as holding considerable promise. The technique has the advantages of extending the mechanical reach of the operator and using the nearly limitless heat supply of fresh ocean water. In certain cases, the jet nozzle could be built in and remotely operated.

The research program devoted to an improved mechanical pneumatic hammer builds on the well-established brute force method of ice removal. A research program could lead to an array of devices which would be portable and effective.

The principle of breaking up the ice by shattering it from the outside ice surface leads to the concept of applying mechanical energy directly through the boat surface itself. Little mention has been made in the literature of this idea. Occasional mention has been made of the lack of buildup on vibrating stays and the use of flapping membranes of various types.

Each of the four approaches could be carried out as a part of an integrated research program. Some features would include involvement of engineering students, graduate or undergraduate; close contact with the marine advisory service and vessel operations; continued collaboration with and literature assessment of work of others; and a possible close cooperative program with Dr. Minsk of the Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

SUMMARIZED REPORTS

ACKLEY, S. F. and M. K. Templeton. 1979. Computer modeling of atmospheric ice accretion. U.S. Army Cold Regions Research and Engineering Laboratory: Hanover, NH. Report number 79-4. 37 pp.

This report presents a development model which computes the amount of ice that will accumulate under a variety of conditions. The results indicate accretion is related to air velocity, droplet size, cloud liquid water content, and air temperature when considering a cylindrical object. The primary model basis is the fluid-day flow field and the thermodynamic reaction as the droplet size approaches a solid body.

Conclusions

The model helps to accurately compare theory and experimental results by including time dependence in a measurable way. With it, time dependence can be evaluated for a number of case histories. It is important to ice accretion work because it provides a solid theoretical background for the more difficult physical aspects of the problem. Because it is a computer model, theoretical assessments of experiment results can continue.

Use For The Alaskan Fleet

There is no direct use for this model in the fleet.

Miscellaneous Information Included

The report includes 25 references and 16 figures. The appendix includes a program of the numerical simulation model.

DEANGELIS, R. M. 1974. Superstructure icing. Mariners Weather Log 18:(1):1-7.

This report is a magazine-type description of the nature of icing on a fishing vessel. It contains a vivid description of various histories of icing. Primary icing potential exists when temperatures fall below -2°C and winds blow at 13 knots or more, with a probable accumulation of up to 3 inches per hour. Severe icing potential exists when temperatures are -9°C or lower and winds are 30 knots or more. Excellent photographs are included in the article with a discussion of the potential for superstructure icing in the North Atlantic Ocean from November to April. Several tips are included to minimize icing hazards on fishing vessels. This report is a succinct yet complete description of the practical nature of the icing problem.

Miscellaneous Information Included

Includes 15 references and five figures.

HICKMAN, D. 1969. De-icing radar scanners. Decca Radar Limited, Environmental Laboratory: Chessington, Surrey, England. RD.ENV.P.101. 7 pp.

This paper reports the results of field tests on various devices used to reduce icing around the radar scanner. It is particularly important to keep the scanner clear during severe weather.

The Boston Phantom experiments included trying to use anti-icing fluid on the scanner. Crew members found it impossible to put the fluid where it was needed. Another proposal was to cover the scanner with a fiberglass window to improve its shape. Additional devices included a polyvinyl chloride envelope slipped over the window and putting polyethylene bags over the scanner. The basis of this system is to create a surface that flaps in the wind and throws off ice as it accumulates. A heated window was also considered.

A pneumatic system was also used. An inflatable device around the radar scanner functioned successfully. The inflator worked with up to 4 inches of ice.

Conclusions

The pnuematic de-icer has proven the most satisfactory technique for radar scanner de-icing. Operation is simple and requires little modification. It is easily adaptable to a fishing vessel. The author recommends that such facilities be used in scanners operating in northern seas.

Use For The Alaskan Fleet

This report is one of the few which particularly focuses on the problems of radar scanner icing. The suggested pneumatic de-icer appears to have been successful in both field trials and climatic chambers and quite likely could be directly adapted to radar scanners used in the Alaskan fleet.

Miscellaneous Information Included

No references are provided. Four photographs show various trials with the inflator in an environmental chamber.

ITAGAKI, K. 1977. Icing on ships and stationary structures under maritime conditions: a preliminary literature survey of Japanese sources. U.S. Army Cold Regions Research and Engineering Laboratory: Hanover, NH. Report 77-27. 22 pp.

This report is a literature survey of Japanese sources relating to the problem of icing on vessels and marine structures. Most of the information in the report is related to ship icing with few references to stationary marine structures.

A number of references are made to field studies, particularly that of Tabata, et al. 1963, including descriptions of icing growth rates, the structure of accreted ice, how accreted ice changes a ship's center of gravity, and a questionnaire system used in the Japanese maritime industry.

A succinct summary of several reports from endangered ships is given including the Shomei Maru (1967), the Jujo Maru, and the Keifu Maru (1973).

The method of forecasting icing is given. Two main criteria are surface to 850 millibar temperatures lower than -4°C and winds exceeding 8 to 9 knots.

Conclusions

The author cites data collected by moving ships and concludes that ice accumulation is highly dependent on the size and structure of the ship. Small ships with a lower freeboard will accumulate more ice. Icing rates on stationary structures may not be similar to that of ships. There is need for a good theoretical understanding of the problem.

Use For The Alaskan Fleet

This report is rather short and has limited application, particularly from the standpoint of ice removal. Its main contribution is its rather thorough coverage of Japanese problems in the general location of the North Pacific.

Miscellaneous Information Included

Eight references are given along with four tables and 15 figures. This report is one of the few which relate directly to stationary structures. One figure includes a theoretically calculated icing rate as a function of wind speed and air temperature.

LANDY, M. and A. Freiberger. 1968. An approach to the shipboard icing problem. Naval Engineers Journal (Feb):63-72.

This report describes a program in an environmental chamber which examined the process of ice adhesion to various kinds of surfaces.

A brief history of the icing problem is given. Ideal methods of ice removal would depend on the use of a coating to which ice cannot adhere.

Various methods of testing the strength of ice adhesion were conducted, including tests of water purity, freezing rates, extent of interfacial area, and test temperature. An extensive series of 70 tests included four different surfaces and 45 different coatings. For each combination, the ice adhesion in pounds per square inch was determined.

Conclusions

Several formulations are given which may help solve the icing problem.

Various factors which affect ice adhesion between molecules of ice and the substrate surface include: number of bonds per unit area, flexibility of the bulk substrate, test method, purity of water, interfacial area, temperature, age of the ice, substrate joint, and rate of stress application. Two materials which showed promising de-icing properties include Corning Corporation's silicone resin and Dupont's Teflon.

Use For The Alaskan Fleet

This paper is one of the few which presents a complete description of the ice adhesion process on different surfaces. It probably has limited application to the Alaskan fleet because it may be very difficult to install a special surface on the working fishing vessel.

Miscellaneous Information Included

Report includes 23 references and six figures.

LOCK, G.S.H. 1972. Some aspects of ice formation with special reference to the marine environment. Transactions of the Northeast Coast Institution of Engineers and Shipbuilders 88:(6):175-84.

This paper is a literature review of the problem of ice formation on fishing vessels. It repeats much of what has been stated in other reports; nonetheless, it does have a concise description of the process, the problem, and some means of its control.

The nature of the problem and research which has been done by other agencies is described with particular emphasis given to the work by Japanese investigators and Stallabrass. The theoretical nature of the process is described with particular emphasis on a parametric analysis of the accretion process.

Various experiments with accumulation of ice on structures are described with particular emphasis on an experimental program carried out at the University of Alberta freezing process tunnel.

A good discussion is given on a number of aspects of icing, including effects of wind and spray, sea surface temperature, and vessel geometry. Brief mention is made of controlling vessel icing. The discussion is in two parts, one of anti-icing measures, and one of de-icing measures. The primary de-icing method is mechanical, using hammers and other devices. The most prominent new method uses pneumatic inflation device, particularly on critical areas such as the radar scanner. Chemical de-icing offers little promise for both theoretical and practical reasons. Thermal siphons could use available heat and move it to mast and railing areas. Sea water jets, particularly those which may be slightly raised in temperature, may be useful.

Miscellaneous Information Included

Work includes 29 references and 10 figures.

MAKKONEN, L. 1979. Huurteen, kuuran ja iljanteen muodostuksesta merellä. M.Sc. thesis presented at the Institute of Marine Research, Helsinki, Finland.

This work stems from a master's thesis in meteorology. We learned of it through a letter from P. M. Malkki (Institute of Marine Research, Helsinki, Finland). Malkki stated that icing had interested Finnish investigators for the past 10 years. A preliminary literature survey was made in 1973, the results of which were published by Lindquist and Uden in 1977. L. Makkonen covers several aspects of vessel icing formations, statistical information on meteorological conditions, chronological results, and a discussion of de- and anti-icing methods in his thesis.

This paper includes 150 references and is of primary interest to present investigators. It may be the only recent work with a complete literature search that concentrates on eastern European sources.

Malkki also states that Makkonen has continued his work. A paper he prepared on ice formation was presented in May 1980 at a Nordic meeting of meteorologists.

Use For The Alaskan Fleet

We believe this thesis could be of major importance in studying icing with regard to the Alaskan fishing fleet. It is written in Finnish and Russian, however we feel the information is important enough to warrant translation.

MINSK, L. D. 1977. Ice accumulation on ocean structures. U.S. Army Cold Regions Research and Engineering Laboratory: Hanover, NH. Report number 77-17. 47 pp.

This report is based on an extensive literature search of Soviet, Japanese, British, American, Canadian, and Icelandic sources.

Shipboard icing is a relatively recent research topic. The earliest work started in 1955. Two primary research efforts exist. The Intergovernmental Maritime Consultive Data Organization (IMCO) began work through its subcommittee on Safety of Fishing Vessels in 1969. The World Meteorological Organization (WMO) prepared a comprehensive review in 1974 through its Commission for Marine Meteorology (CMM).

General engineering data on ice accumulation is difficult to extract from the literature since station reports and field control experiments are specific for ship type.

Icing occurs when water is exposed to some process which extracts enough thermal energy to form ice. Major sources are direct shearing of droplets from wave crests and spray from waves the ship hits. Wave action on horizontal surfaces is not usually a cause of icing unless the water cannot drain freely. Almost all icing results from sea spray hitting the superstructure and upper deck.

Some pertinent observations on icing include the following. Of 3,000 cases of ship icing, 89 percent are caused by spray from ocean water. Icing usually does not occur when air temperatures are greater than -3°C. Strong icing occurs when air temperatures are between -3°C and -15°C. Icing on the structure varies with the ship's construction. Ice is loosely bonded in the first hour to an hour-and-a-half of accumulation and can be easily scraped or knocked off. The greatest accumulation of ice occurs when the ship is heading into the wind at angles between 15° and 45°.

To predict icing intensities and rates, investigators use empirical formulas devised from laboratory experiments. A key concept, collection efficiency, has been proposed by Stallabrass and Hearty. It is the fraction of droplets which strike a surface, freeze, and are retained. Icing efficiency is a product of the collection efficiency and the freezing fraction.

Controlling and avoiding icing are primary concerns. No completely effective methods of removing ice have been found. Mechanical methods are the most common, but experiments have also been done with heated surfaces, ice phobic surfaces, deformable surfaces, and freezing point depressants. Literature reports the use of baseball bats, sledge hammers, axes, hammers, picks, and other instruments to remove ice. De-icing methods can also include (in order of effectiveness) pneumatic de-icers, freezing point depressants, rubber surfaced plastic foam, grey deck paint on wooden panels, spar varnish on wooden panels, and other combinations of coatings. Tests are very qualitative and cannot give quantitative engineering results.

Suggestions for reducing icing hazards include heading for warmer water, stowing gear below deck, lowering cargo booms, covering deck machinery, fastening storm rails, removing gratings, making the ship more watertight, ballasting with sea water, and establishing reliable two-way radio communication.

Conclusions

The most common cause of icing at sea is sea spray generated by waves hitting the structure, and to a lesser degree, droplets sheared from breaking waves. Icing does not generally begin until the air temperature drops to -3°C. Icing is not strongly related to water temperature. Icing increases as one approaches more on the beam between 15° and 45°. Spray does not become a factor until wind speed reaches about 17 knots. Small surfaces will accumulate ice more rapidly than large cylinders or flat surfaces. Distribution of ice accretion on a ship is erratic. Accumulated ice is only loosely bonded at the surface, but increases its adhesion in the first one-and-a-half to two hours. Icing occurs most frequently in the rear of a low pressure system. Icing is likely to occur in a cold trough, with temperatures falling from -15°C to -18°C. No completely effective methods of ice removal have been reported.

Miscellaneous Information Included

Minsk's report includes a selected bibliography of 67 items, 15 figures, and nine tables. The report is 42 pages long and is readily available from the Hanover office of the Cold Regions Research and Engineering Laboratory.

MOTTE, R. 1975. Superstructure icing. Safety of Sea International (June):10-14.

This magazine article recommends the usual ways of avoiding icing: heading for warmer water, reducing the amount of equipment on deck, establishing two-way radio contact, and setting a course to minimize spray.

Conclusions

Fishing vessels are particularly susceptible to icing. Motte concludes that although a number of de-icing devices have been introduced, they have met with only limited success. It is difficult for any of the current methods to help clear ice from riggings and exposed upper areas. The most prudent course for any ship is to avoid conditions that will produce severe icing.

Use For The Alaskan Fleet

The main value of this report to the Alaskan fleet is its discussion with regard to fishing vessels.

Miscellaneous Information Included

Report includes eight references and several photographs of icing and de-icing equipment.

SHELLARD, H. C. 1974. The meteorological aspects of ice accretion on ships. United Nations World Meteorological Organization Marine Science Affairs: Geneva, Switzerland. Report number 10. 34 pp.

This report reviews shipboard ice accretion literature up to 1974. Emphasis is on meteorological elements of ice accretion, with particular application to reporting and forecasting icing conditions. The review includes material generally available in the meteorological, scientific, and engineering literature. It also includes documents issued by the Intergovernmental Maritime Consultive Data Organization in connection with its work on fishing vessel safety. IMCO commissioned a study and this literature review because of vessel and crew losses to icing since 1950.

Causes of icing and their relative importance are briefly reviewed. The major cause is sea spray, encountered as the ship meets oncoming waves and as the wind blows water off wave tops. Climatic chamber tests on a 1/12 scale trawler model are summarized. Also included are summaries of Japanese literature and various other reports available on the subject.

The report notes that the major effect of icing is to add weight to the upper part of the structure. This reduces the freeboard and modifies the stability of the ship, since the weight will collect unevenly.

The effect of various meteorological conditions on icing is also discussed. Included are wind speed, air temperature, sea temperature, sea conditions, and salinity. Conclusions indicate that icing hazards are more serious as wind speed increases and air temperature falls below -4°C.

Ways to avoid icing are briefly discussed. These include heading for warmer water, seeking shelter in lee of land, and running before the seas to reduce spray.

Conclusions

The most common cause of icing at sea is spray, with minor contributions from direct precipitation, fog, and sea smoke. Ice accretion is particularly hazardous to small boats and may pose problems for large ships where icing of upper structures is quite dangerous.

The most important meteorological elements affecting ice accretion are wind speed and air temperature. There seems to be no limiting lower air temperature, as has been suggested in the past. Sea surface temperature is not really important, particularly if the air is not below 0°C.

More information from icing cases is needed. More research is needed on forecasting icing conditions.

STALLABRASS, J. R. 1975. Icing of fishing vessels in Canadian waters. National Research Council of Canada, Division of Mechanical Engineering DME/NAE Quarterly Bulletin 1:25-43.

This report presents the results of laboratory tests, a summary of field observations and some literature observations.

Vessel icing is a perennial hazard faced by crews fishing in northern waters. Conditions for ship icing are generally accepted to be the simultaneous occurrence of an air temperature of -2°C or lower, water temperature of 6 to -2°C, and a wind speed greater than 20 knots. The vessel speed and relative heading must be such to produce significant amounts of spray. A review of the present knowledge of the causes and physical processes involved and an assessment of the problems related to Canadian fishing fleet are included.

Summaries of the frequency and severity of icing conditions encountered by fishing vessels off Eastern Canada were made from field observations by vessel captains over a six year period. The results indicate that the icing season around the Newfoundland Banks can extend from the middle of December to the latter part of March with the most severe conditions occurring in January and February. Ice pack edges form the northern limit of significant icing since wave action and spray are inhibited by the ice cover. South of the 50th parallel, ice conditions are confined to the continental shelf with more dangerous conditions nearer land where colder water and air temperatures are prevalent.

General icing conditions in the area last two or three days at a time, and are usually the result of intense cyclones. One episode in late January or early February 1972 resulted in icing rates in excess of 1/4 inch per hour with one stern trawler (630 gross tons) reporting an accumulation of 200 tons of ice, sometimes in thicknesses of up to 20 inches.

Several measures have been developed to combat the icing problem. First, of course, is to avoid icing conditions, but often some means of combatting the ice are necessary. These may be divided into two categories: de-icing and anti-icing. Popular de-icing methods include use of steam, water hoses, mallets, and axes. These are hazardous and often impossible when conditions are most severe. These methods are not useful in de-icing the upper part of the superstructure. Preferred methods should keep crew members off deck and be semi-automatic. Several proposals include using plastic foam, inflatable rubber de-icer blankets, and electric impulse methods. Cost will prevent extensive use of electric heat for de-icing. As a result of the author's work at the National Research Council, inflatable rubber de-icing on both cylindrical and flat surfaces has shown remarkable effectiveness. Some anti-icing methods include freezing point depressants and certain chemicals which create a ice phobic surface.

Use For The Alaskan Fleet

This report presents a succinct summary of conditions which appear to be analogous to those of the Alaskan fleet. This paper is a more general summary of the author's very extensive laboratory work in this area.

Miscellaneous Information Included

Thirty-five references are given. An appendix describes the collection efficiency of cylindrical bodies. Seven figures are given in the report including a sample ice shipping report, spectacular photographs of an icing event in January and February of 1972, and a brief description of a two-phase thermosiphon device which may be used in railings and masts.

STALLABRASS, J. R. 1970. Methods for the alleviation of ship icing. National Research Council of Canada: Ottawa. Mechanical Engineering report MD-51. 30 pp.

This report presents the results of laboratory tests and various proposals for the alleviation of icing on superstructures of ships.

A number of tests were made of icing conditions in an icing wind tunnel and at an outdoor test site. Specific de-icing methods examined included pneumatic de-icers, plastic foams, paint and varnish on a wooden bulkhead, distribution of freezing point depressants over bulkheads, and parallel filament ropes for use as stays.

The test facilities include a 4 1/2 ft^2 wind tunnel which is capable of speeds up to 180 mph and a temperature range from -30°C to room temperature. The outdoor test site consisted of a 20 ft square, 3 ft high platform on which equipment for testing could be mounted. The outdoor facility was restricted to ambient temperatures.

Methods and devices evaluated included a pneumatic de-icer. It is essentially a series of tubes built into a rubber mat. When the tubes are inflated, the mat surface heaves and stretches and in doing so breaks down the adhesion of ice to the mat surface. Mats of plastic foams applied to hull, bridge front, and breakwaters were tested as the result of reports in Japanese literature. Some tests were conducted using varnish and grey deck paint on wood and steel panels. Freezing point depressants were used, including ethanol glycol, which was distributed over one area of the outdoor test stand. The glycol was discharged through a series of holes, then flowed down to the panel surface. Parallel filament rope was tested in comparison to steel cable.

A qualitative evaluation of methods for alleviating ship icing was made, although test conditions did not necessarily resemble actual de-icing conditions.

The pneumatic de-icer proved to be most effective, both as a mass and flat surface de-icer. Pneumatic de-icers are apparently ideal for the upper parts of masts and reducing large ice accumulations caused by spray from the ship's bow. Ethelene glycol reduced the strength and adhesion of ice on surfaces and may prove useful on radar components and inflatable life craft containers. Its disadvantages include a slippery residue which might contaminate the iced fish catch if not washed away.

The various coatings and finishes tested were not effective de-icers. The most promising was rubber-coated plastic foam. This formable substrate made it fairly easy to break off ice. Ice didn't adhere as well to the smooth rubber surface as to the pebbled surface of bare polyethylene foam.

Little difference was observed in ice removal between polyethylene rope and steel cable.

Use For The Alaskan Fleet

This report represents the main conclusions of extensive laboratory tests conducted by the author. Tests indicate that pneumatic de-icers effectively expedite ice removal from shipboard surfaces. They may be adapted to the Alaskan fleet if economical and if they do not hamper normal fishing activities on the vessel.

Miscellaneous Information Included

The report includes four references and extensive tables on the conditions of the tests. Figures include a number of extremely good photos of the testing apparatus, and particularly the effects of the pneumatic de-icing equipment.

WHITEFISH AUTHORITY. Date uncertain, 1969 likely. Trials of de-icing equipment on the Boston Phantom. Technical Memo 52, Industrial Development Unit.

This report is based on experimental observations by the side trawler Boston Phantom. It evaluates the effectiveness of pneumatic de-icing in an actual icing event.

In response to a storm near Iceland in February 1968 which resulted in the loss of the Ross Cleveland and the County to icing, the Whitefish Authority undertook a research program in cooperation with Palmer Aero Products, Ltd. and Boston Deep Sea Fisheries, Ltd. The side trawler, Boston Phantom, (a conventional 430 ton side trawler) was fitted with pneumatic equipment to test its suitability for de-icing the bridge front and other parts of the craft. The pneumatic de-icing device is a series of tubes which can be flexed, breaking the ice from the surface.

The de-icing equipment was fitted to work the bridge front, port and starboard mainmast and stays, radar scanner, and well deck. A control system was fitted to allow semi-automatic operation of the inflatable de-icers.

The ship was also equipped with a mainmast forestay and two mizzen mast backstays made of parafill rope for assessment on the trial voyage. Parafill rope is a twistless rope based on a parallel fiber cone encased in a sheath.

During the trial, the Boston Phantom experienced severe icing in January 1969. The boat quickly accumulated approximately 1 inch of ice over most of the boat with up to 3 inches on rails and stays. All wires and halyards were heavily iced, up to 3 inches to the half mast height. Ice was allowed to build up to a thickness of 1/2 inch before the pneumatic de-icing equipment was inflated. The ice broke away cleanly and the majority immediately fell overboard into the wind. The radar scanner de-icer freed the ice adhering to it and the radar picture was noticeably improved. The controls of the de-icers were on the bridge, so operation was simple.

The pneumatic devices were effective in keeping the protective surfaces clear of ice, and did not interfere with the ship's normal routine.

De-icing equipment was fastened top and bottom by metal bands. The bridge front equipment consisted of small panels rather than large sections. Experiments attaching de-icing panels to the bridge surfaces with an adhesive failed. Performance of the parafill rope was inconclusive but apparently did not add much de-icing capability.

Calculations indicated approximately 7 tons of ice accumulated during the storm and that a further 2 tons would have been added had the de-icers not been operative. Virtually no ice was formed on the main deck during the trials because the area was being washed by sea water at .3°C. The de-icing equipment may have given the skipper almost three hours more time to take evasive action had he needed it.

Conclusions

Pneumatic icing equipment is fully effective for removing ice. It was easy to operate and did not interfere with the ship's operation. Further development is needed so the system can be used on the higher surfaces of the vessel. The radar de-icer was particularly effective, removing ice that collected on the scanner. Parafill rope worked best when under tension from the natural vibration of the ship. Good seamanship was also a good anti-icing measure.

This report includes one of the few quantitative records of the rate of ice accretion on an operating fishing vessel.

Use For The Alaskan Fleet

Because this research is based on observations made from an actual fishing vessel, it is useful for determining further development of the pneumatic system.

Miscellaneous Information Included

Two references are included in the table giving various calculations on the stability of the vessel. The appendix includes the trial and log of the vessel, and the recommended stability criteria for fishing vessels developed by the National Maritime Consultive Organization. Also in the appendix is a brief history of de-icing fishing vessels. This includes three references and 12 figures, and some good pictures of the de-icing panels during the trials and a series of graphs determining the nature of icing danger for various conditions.

CORRESPONDENCE SUMMARY

Assessment of research on ice accretion in all circumpolar nations began with a personal literature review and a computer literature search on three national data bases. These yielded few citations on the topic. A subsequent letter writing effort, starting with some known sources and general inquiry to embassies of northern countries, is summarized. Anyone wishing to pursue the issue should be able to find some appropriate contacts in this listing. Note that southern hemisphere countries were not contacted; they may have information that we have not located.

1. Alaska Senators Ted Stevens and Mike Gravel were contacted for information on possible government research. Each provided literature searches from the Congressional Research Service. Neither of these led to any new references or sources.

2. Alaska Representative Don Young responded with the addresses of the director of the National Science Foundation (NSF) and of the administrator of the National Oceanic and Atmospheric Administration (NOAA).

3. Dr. Richard Frank of NOAA cited a NOAA contracted report that was recently completed by the University of Alaska's Arctic Environmental Information and Data Center. This report was subsequently obtained.

4. Dr. Francis Johnson of NSF suggested two information sources, a design engineering firm in Boston (no address given) and Dr. R. Elsner of the University of Alaska's Institute of Marine Science, who co-authored a design study for a polar research vessel. Since Dr. Elsner was on sabbatical leave, the portion of the report dealing with spray ice problems was reviewed and further inquiry made of another co-author, Mr. J. Dermody, presently of ESCA-Tech Corporation in Federal Way, Washington. Several articles and some further contacts were suggested. Most of the reprints are in hand, and some contacts were made.

5. A search through the National Sea Grant Depository in Rhode Island showed that Sea Grant has never funded research on this topic.

6. The Belgian Embassy in Washington, D.C. replied that Belgian fishing vessels travel only as far as the North Sea, and do not have spray icing difficulties.

7. General inquiry directed to the People's Republic of China seems to be caught in a tangle of identification problems with Taiwanese. The reply we received stated that there was no such research conducted in Taiwan. If the project continues, we will again attempt to query the People's Republic of China.

8. From the office of Admiral John Hayes, U.S. Coast Guard, we received two citations through their ship design section and a promise to share relevant information they were to receive soon. This information was sent following a March phone call of inquiry.

9. The embassy of the Federal Republic of Germany referred us to Dr. Gerhard Zickwolff of the Deutsches Hydrographisches Institut in Hamburg.

10. The Royal Norwegian Embassy referred us to the Norwegian Fisheries Research Council (Norges Fiskeriforskningsrad). Dr. Tore Jorgensen is currently preparing a report on this topic and intends to forward a copy when it is completed.

11. A similar request to the Icelandic Embassy was forwarded to Dr. Hjalmar Baroarson, State Director of Shipping, who summarized the Icelandic approach to the problem in his reply. He also directed us to contact the Intergovernmental Maritime Consultative Organization (IMCO) in London. Studies of this problem have been collected by their Subcommittee on Safety of Fishing Vessels, which he has chaired.

12. L. Kobylinski, technical officer of the Sub-Division for Technology of IMCO, sent five reports (two submitted by the U.S.S.R., two by Canada, and one by Norway). He also included the "guidance" relating to ice accretion, an extract of an attachment of the Torremolinos Convention for the Safety of Fishing Vessels, and he made reference to two other Canadian articles, both of which we obtained.

13. The Canadian Embassy forwarded our request to the Dynamics and Ship Laboratory of the Canadian National Research Council (NRC), which in turn forwarded it to NRC's Low Temperature Laboratory. Dr. E. C. Smith, acting director of Ship Safety, was our next correspondent; he referred us to both the IMCO and to Dr. J. R. Stallabrass of the NRC's Division of Mechanical Engineering. These contacts had already been made.

14. Our inquiry to the British Embassy was directed to the Department of Trade (DOT) in Longer, which replied to the embassy that they have no projects concerning icing problems. Further inquiry by the embassy in our behalf led to a response from the DOT's Marine Division suggesting we contact the Industrial Development Unit of the Whitefish Authority in Hull. Mr. J. F. Foster, principal naval architect with the authority, sent several reports very pertinent to the question and a short history of Britain's concern, which has lessened since they have accepted the Icelandic 200 mile economic zone and no longer fish in waters having icing conditions.

15. The Finnish Embassy furnished two addresses for our use. One, Oy Wartsila Ab, is the world's leading manufacturer of ice breakers and has built several other ships for arctic conditions. Their response was twofold: an acknowledgement from the manager of the arctic design and marketing department that they have been studying the problem but couldn't send any reports because they had published none of use to our study, and a general company information letter from the head of the consulting department.

16. The other address was for Helsinki University of Technology Shipbuilding Laboratory in Espoo. They referred us to the Maritime Administration in Helsinki. A report (in Finnish) was received from

them. They also forwarded our request to Mr. Kari Ahti of the Finnish Meteorological Institute, who sent a paper of his own dealing with rime ice and a summary of another paper that he will be publishing.

17. An inquiry sent to the director of the Ocean Engineering Information Centre of Memorial University of Newfoundland netted no direct results. Our letter was passed on to Ms. Judith Bobbitt of NORDCO, who has been interested in the problem of ice accretion on offshore structures. Ms. Bobbitt has not replied. The Information Centre has also received an inquiry similar to ours from the Institute of Marine Research in Helsinki; they responded to our inquiry with an informative letter and a copy of the bibliography of a recent master's thesis on the meteorological aspects of the question.

18. We have received no replies from the Danish, Swedish, Polish, South Korean, West German, or Soviet embassies; the director of the U.S. Air Force Office of Scientific Research, the director of the U.S. Army Research Office, Dr. Seiiti Kinosita of the Institute of Low Temperature Science at Hokkaido University, Dr. Ken Croasdale of the design engineering production department of Imperial Oil, Ltd., of Canada (address suspect), or from Dr. Torkild Carstens of Trondheim, Norway, who travels widely.

19. An inquiry sent to Mr. Lorne Gold of the Canadian National Research Council's division of building research was forwarded to Mr. J. R. Stallabrass of the NRC's division of mechanical engineering. His reply was most helpful, and included five reports that he published. He also referred us to Mr. L. Wilson of the Atmospheric Environment Service in Ontario, who had been working in support of the oil drilling operations in the Beaufort Sea. He did not replied.

20. An inquiry sent to the Royal Netherlands Embassy resulted in a referral to the Netherlands Institute for Fishery Investigations; however, there was no response from them.

21. The U.S. Office of Naval Research sent three referrals, one of which we had already contacted. Letters were sent to the others: the commandant of the U.S. Coast Guard Research and Development Center, and Dr. Tadashi Tabata, Head of the Sea Ice Laboratory at the Institute of Low Temperature Science at Hokkaido University. Neither replied. (Dr. Tabata has published on the subject.)

22. The Embassy of Japan referred us to Mr. T. Kuriyama, director of the technology division of the Ships Bureau, Ministry of Transport, even though they assured us that Japan does not face the problem. They use only large vessels in northern waters and these do not develop icing problems. Mr. Kuriyama did not reply.

23. Dr. L. D. Minsk of the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire, mentioned Dr. Stallabrass and some possible work that might be started at NOAA's Pacific Marine Environmental Laboratory, Seattle. Dr. Minsk, having published on the subject, was most helpful in offering to open his files to us. He also referred us to the CRREL bibliography, which we were

not able to obtain until much later. In response to subsequent inquiry, Dr. Minsk has sent specific titles of reports issued by the now-defunct U.S. Naval Applied Science Laboratory. He has offered to send copies, and this will be pursued if the project continues. One other report he cannot send, as it is "For Official Use Only". A request will be made for this important reference through official channels if the project continues.

24. This project was first prompted by an article in Alaska Seas and Coasts by Mr. John Ball. He also referred us to Mr. Al Comiskey, (previously with the National Weather Service and now with the Arctic Environmental Information and Data Center in Anchorage) who has constructed an icing nomograph, and to Dr. Bruce Adee (associate professor of mechanical engineering at the University of Washington) who is associated with marine safety and, in that capacity, maintains a vessel accident reporting service.

25. Mr. J. L. Wise answered for Mr. Comiskey. Following some correspondence, he copied and sent icing records for 20 Alaskan case histories and for the semi-submersible drilling platform Ocean Bounty.

26. Mr. Adee, having heard of this project, took the initiative and called. He was very supportive and, among other suggestions, referred us to Mr. W. A. Cleary, Office of Merchant Marine Safety, U.S. Coast Guard. Mr. Cleary replied with four enclosures and referred us to a private engineering consulting firm experienced in marine icing problems (Arctec Canada, Kanata, Ontario; and Arctec, Inc., Columbia, Maryland). Their program manager, I. F. Glen, sent some references and suggested we contact Dr. Stallabrass and the Newfoundland Department of Fisheries Technology. This will be pursued if the project continues.

Obviously, the correspondence file is still an active portion of the project. Some very helpful contacts have been made and interesting material received. While more responses are pending, we believe that we have received most of the forthcoming information.

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APPENDIX I

ENGINEERING FOR VESSEL ICE ACCRETION WITH PARTICULAR REFERENCE TO THE ALASKAN FISHING FLEET

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ABSTRACT

Ice accretion on fishing vessels in northern waters has been a persistent long-term problem, contributing to vessel damage, loss of productive time, and occasionally loss of vessels and life. Past research (which has been sporadic, widely dispersed, and often in response to disasters) has pointed out several useful paths for engineering solutions. Key strategies suggested by these investigations include increased education of vessel operators about the general nature of the problem, understanding the meteorological conditions required for ice accretion, the physical mechanisms of drop deposition and ice growth, ship design modifications, active and passive anti-icing and de-icing measures, and well-publicized systems of forecasting icing conditions and advising evasive action.

Existing methods dealing with ice accretion were examined, with emphasis on adapting them to the Alaskan fishing fleet. Relevant design criteria include adaptability to retrofitting, semiautomatic operation usable in an emergency, and usability in dangerous situations. Methods that appear to hold promise include pneumatic inflatable membranes, thermosiphons using engine waste heat for masts and railings, high-pressure seawater jets, and methods of surface vibration. The best engineering strategy will likely be a combination of improved vessel design, judicious use of weather forecasting, good seamanship, and use of active de-icing devices.

SHIP ICE ACCRETIONS

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ABSTRACT

Ship icing in northern waters is very dangerous to small vessels. It develops when air temperature is below the freezing point of sea water. Ships active in winter months will experience ice build-up. The rate of ice build-up depends on hydrometerological conditions together with size, configuration, speed and position relative to wind and waves. Mathematical equations have been developed to predict ice growth rate on ships and to help researchers with ship design. A variety of methods are used to reduce the adhesion force of ice to ships' surfaces; some methods even prevent ice formation. Mechanical devices that allow fast and easy removal of ice seem to be most reliable and not to require much labor. Pneumatic de-icers are a case in point. Forecasting often warns those ships that engage in winter activity ahead of time about ice conditions. Graphs, data, and calculations which require comparison with actual past experience at sea should be made for each geographical location for forecasting. More research and experiments should be conducted to develop reliable and effective methods of preventing hazards to ships from ice accretion.