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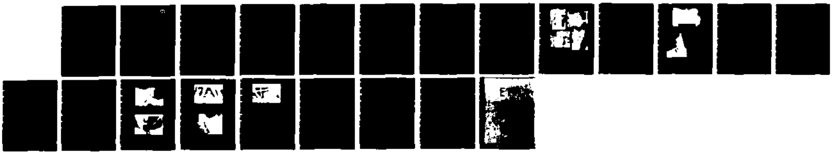

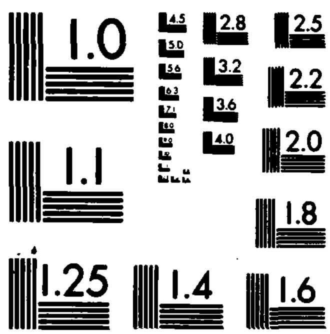

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February 1984

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Ice observation program on the semisubmersible drilling vessel SEDCO 708

L. David Minsk

Prepared for
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A semisubmersible drilling vessel (SEDCO 708) was equipped with ice detectors and ice accretion measurement devices, and observations were conducted while it drilled an exploratory well on the North Aleutian Shelf. One significant storm occurred 3-8 January 1983, which resulted in light spray ice accretion, estimated at 30 tons and a maximum thickness of 5 in. on understructure diagonal trusses. Only minor icing (less than 1 in.) occurred on the windward main columns (30 ft diameter). Comparison with the 1979 Ocean Bounty icing event suggests that wind speed is the significant parameter influencing icing severity,

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20. Abstract (cont'd)

and that light icing will occur at average speeds around 30 knots and heavy icing around 88 knots, with undefined severity within the range. Four ice-phobic coatings were exposed on test panels; one was effective.

PREFACE

This report was prepared by L. David Minsk, Research Physical Scientist, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this study was provided by ARCO Alaska, Inc., as operator for an industry consortium, and by the Minerals Management Service, U.S. Department of the Interior, under authorization number 2LA6000-1077.

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These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric Practice Guide (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	By	To obtain
inches	25.4	millimetres
feet	0.3048	metres
pounds (mass)	0.4535924	kilograms
tons	907.1847	kilograms
knots	0.5144444	metre per second
degrees Fahrenheit	$t°C = (t°F - 32)/1.8$	degrees Celsius
pounds (force) per square inch	6894.757	pascals

ICE OBSERVATION PROGRAM ON THE SEMISIBMERSIBLE DRILLING VESSEL SEDCO 708

by

L. David Minsk

INTRODUCTION

Ice accretion on ocean structures can seriously affect their performance and in the extreme create a hazardous condition on manned structures. The icing event on the Ocean Bounty in December 1979, in lower Cook Inlet (near Shelikof Strait) at latitude 59°N, longitude 153°30'W, during which an estimated 400 tons of ice was accreted on the semisubmersible drilling vessel, demonstrated the danger that could arise from a combination of high winds, high seas and subfreezing temperatures (Fig. 1). Though there was reportedly no immediate danger to the vessel and its crew, it was necessary to jettison drilling mud as a precaution to maintain trim and stability (Nauman, in prep.).

Semisubmersible drilling vessels have a large sail area for accreting ice from two sources: water droplets in the atmospheric boundary layer, and water droplets arising from wave action in the spray zone. In the former case the derrick and other structures on and above the main deck are the accreting objects, whereas spray generated by wave shearing or wave crashing will generally only affect the understructure, though as demonstrated in the Ocean Bounty icing event, the main deck and its appurtenances can also receive a large amount of spray. Since the higher that ice forms on a vessel the greater the overturning moment for the same mass, it is necessary either for vessel designers to accommodate this extra load by reducing the metacentric height or for operators to control the amount of ice accreted.

There is a paucity of usable data on spray ice accretion rates and intensities that can be applied to semisubmersible drilling vessels or other platforms since ice accretion is highly dependent on the geometry of the structure. The icing data that have been accumulated are from ships, generally small fishing trawlers, that have low freeboard and many small deck objects subject to ice accretion. The lack of reliable, detailed

Figure 1. Ice accretion on the Ocean Bounty in lower Cook Inlet, December 1979.

observations during ship icing events is understandable when a crew is fighting to remain afloat. Information such as wave heights, water temperature, air temperature, wave heading and accretion rates on various structures as a function of height above some reference level, all of which would be useful for planning operations in icing areas, is not generally available.

Thus operations planned for offshore areas can make use of only very general meteorological information influencing icing. Prudence dictates assuming a high probability of occurrence of extreme events. These considerations led the operator, ARCO Alaska, Inc. (as principal for 18 companies) to include an ice accretion observation program during drilling of a Continental Offshore Stratigraphic Test (C.O.S.T.) well on the North Aleutian Shelf at latitude 56°16'27.21" N, longitude 161°58'34.32" W by the semisubmersible drilling rig SEDCO 708 during the fall and winter of 1982-83. Also included in the program was an evaluation of several coatings intended to reduce the strength of ice adhesion and thereby enhance the self-shedding of accreted ice, or to make it easier to remove by the crew.

OBJECTIVES AND APPROACH

The three principal objectives were to:

1. Measure atmospheric icing on the derrick.
2. Measure spray icing between the waterline and deck.
3. Evaluate the effectiveness of icephobic coatings.

Measurement of atmospheric icing was deemed important because of the lack of concrete information on the frequency and intensity of freezing rain events along the North Aleutian Shelf, and also because ice accreting on the derrick would increase the overturning moment as a consequence of its height (the derrick crown is 180 ft above deck).

Atmospheric icing measurement

The model 872DC Rosemount ice detector was chosen to monitor occurrence, and to estimate intensity and rate, of atmospheric icing. This device (Fig. 2) was originally designed to monitor ice accumulation in turbines, but it has been adapted to aircraft and structure icing. It is the only commercial ice detector currently available, and four CRREL units were used for the study. The detector consists of a strut mounted on a cylindrical electronics housing and supporting a probe consisting of a closed tube that can be caused to oscillate axially by a magnetostrictive oscillator. Ice accreting on the surface of the probe will increase its mass and change the frequency of vibration. When the difference between a stable reference frequency and the frequency of the iced probe reaches a

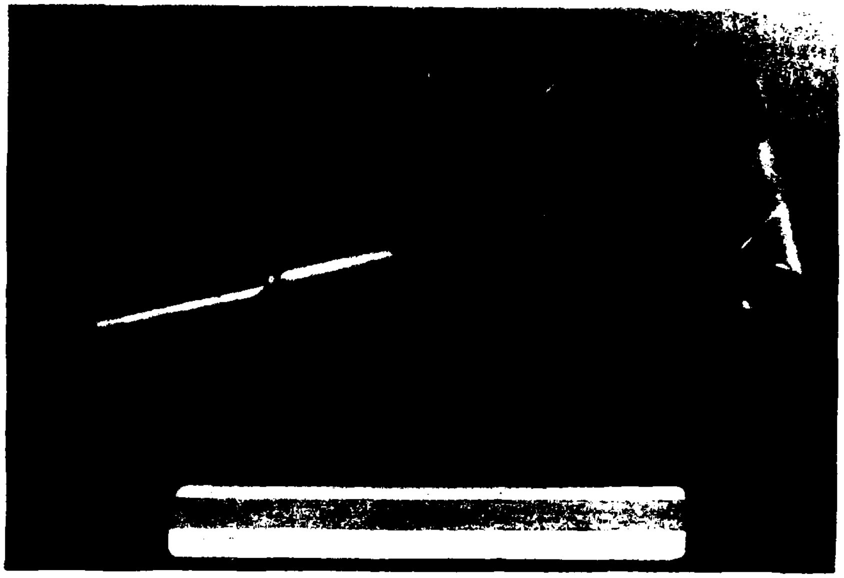

Figure 2. Rosemount ice detector.

Figure 3. Locations of Rosemount ice detectors on derrick. Heights (above deck) are 1 - 180 ft; 2 - 120 ft; and 3 80 ft. Number 4 is on the railing above the diving bell area, a, ɔut 20 ft above deck.

preset value (normally factory-set at 400 Hz, which represents a thickness of 0.02 in. of ice) a relay is closed that actuates an alarm and initiates a deicing cycle. A 310-W heater in the strut is energized to melt the ice on the probe; it is on for 5-7 seconds, but an additional 5-8 seconds is required before the probe has cooled below freezing and the next icing cycle starts.

Three of the ice detectors were located on the derrick at heights above the deck of 80, 120 and 180 ft (Fig. 3). The fourth detector was mounted on the railing on the roof of the diving bell storage area, about 20 ft above the deck.

Spray icing measurement

The amount of ice from spray sources was expected to be greater than atmospheric icing because of the certainty of wave action against the floating structure; the higher rate of accretion and the potential for corrosion or electrical malfunctions militated against the use of the Rosemount detector below the main deck. Arrays of 1-5/16-in.-diameter by 8-in.-long cylinders were used to measure spray ice accretion. (The preferred diameter of the cylinders is 1 in., since in general droplet accretion is greater the smaller the diameter of the accreting object. The steel pipe from which the cylinders were fabricated was available only in 1-5/16-in. o.d. on board the SEDCO 708, but this was not considered a serious deviation from the research design, though any array of cylindrical detectors constructed in the future should be of the 1-in. diameter.) There were seven cylinders mounted in each array by a nut welded inside the piece of pipe and a bolt welded on the support as a threaded stud. Two cylinders were mounted vertically at the ends of stand-off arms, two more cylinders and on the ends of stand-off arms, and the remaining three cylinders were positioned in the horizontal plane 120° apart, but not in line with the plane of the other four cylinders (and also on stand-off arms) (Fig. 4). This arrangement was intended to determine the effects of orientation on ice accretion.

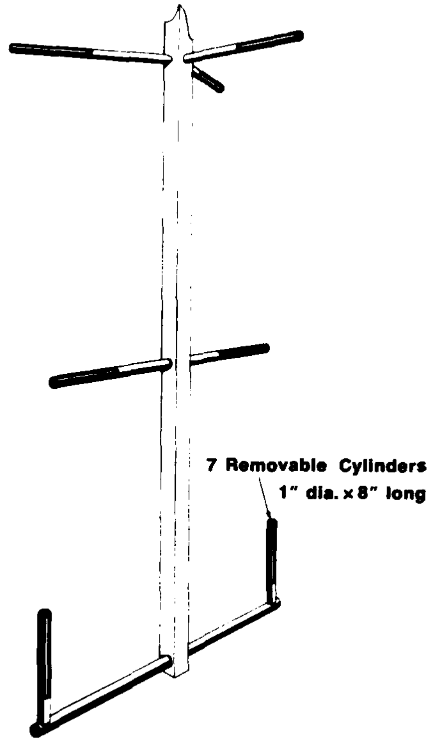

Figure 4. Array of ice accretion measurement cylinders.

The open end of each cylinder was welded closed and ground to a smooth cap, then all outer surfaces were buffed and sprayed with cold galvanizing compound. Cylinder weights ranged from 1.13-1.19 lb (512-540 g). WD-40 lubricant was applied to all threads prior to installation. The arrays were bolted on railings or ladder cages below the main deck where locations were chosen based primarily on accessibility and secondarily on exposure.

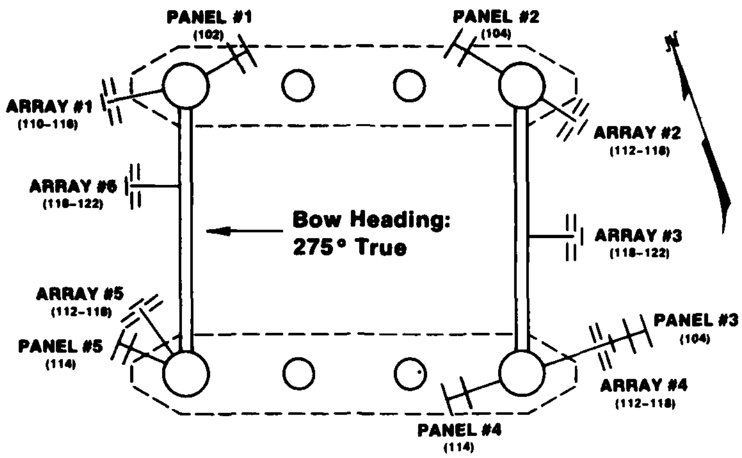

Figure 5. Plan view of the SEDCO 708 showing locations of cylinder arrays and icephobic coating test panels.

Figure 5 shows locations of the arrays and lists their heights above elevation 0 (bottom of pontoon; normal drilling draft is 85 ft).

Icephobic coatings

Past work at CRREL has involved the search for a low-energy coating which would effectively reduce the strength of adhesion of ice on helicopter rotor blades and which would survive the severe flight environment of rain for an hour or more. A test procedure was developed and more than 100 commercial low-energy coatings were tested (Minsk 1980). Another CRREL project resulted in the development of an icephobic coating for application to navigation lock walls to reduce the effort needed to remove ice to enable ship passage (Jellinek et al. 1978). However, no coatings have been evaluated for effectiveness and longevity in the marine environment.

Four of the more promising coatings identified in the prior work were selected for application on 1-ft-square steel plate panels. Five sets of these panels were positioned around the rig as shown in Figure 5. An additional panel was mounted above each of these arrays and coated with Carbomastic no. 14, a marine coating made with 2-component coal tar epoxy, manufactured by Carboline Co., St. Louis, Missouri, for comparison of ice accretion on a typical hull coating.

The four coatings were:

1. General Electric LR5630 (65% polysiloxane, 35% polycarbonate), a copolymer, mixed with toluene and dimethyl silicone oil.

2. General Electric 117-8441B, a developmental coating consisting of cyanoethanol silicone and dimethyl silicone.

3. General Electric 117-8643-10, another developmental coating similar to 117-8441B, but with a water repellent fluid added.

4. General Electric RTV 157, a room-temperature vulcanizing silicone rubber that cures to a tough film with high tear and peel strength and a hardness of 26 Shore A.

OBSERVATIONS

There were only two significant storms while SEDCO 708 was on station: in early December, and 3-8 January 1983. The author was on board during the January storm to observe and photograph any icing. Figure 6 is provided to plot the relationship among meteorological and oceanographic vari-

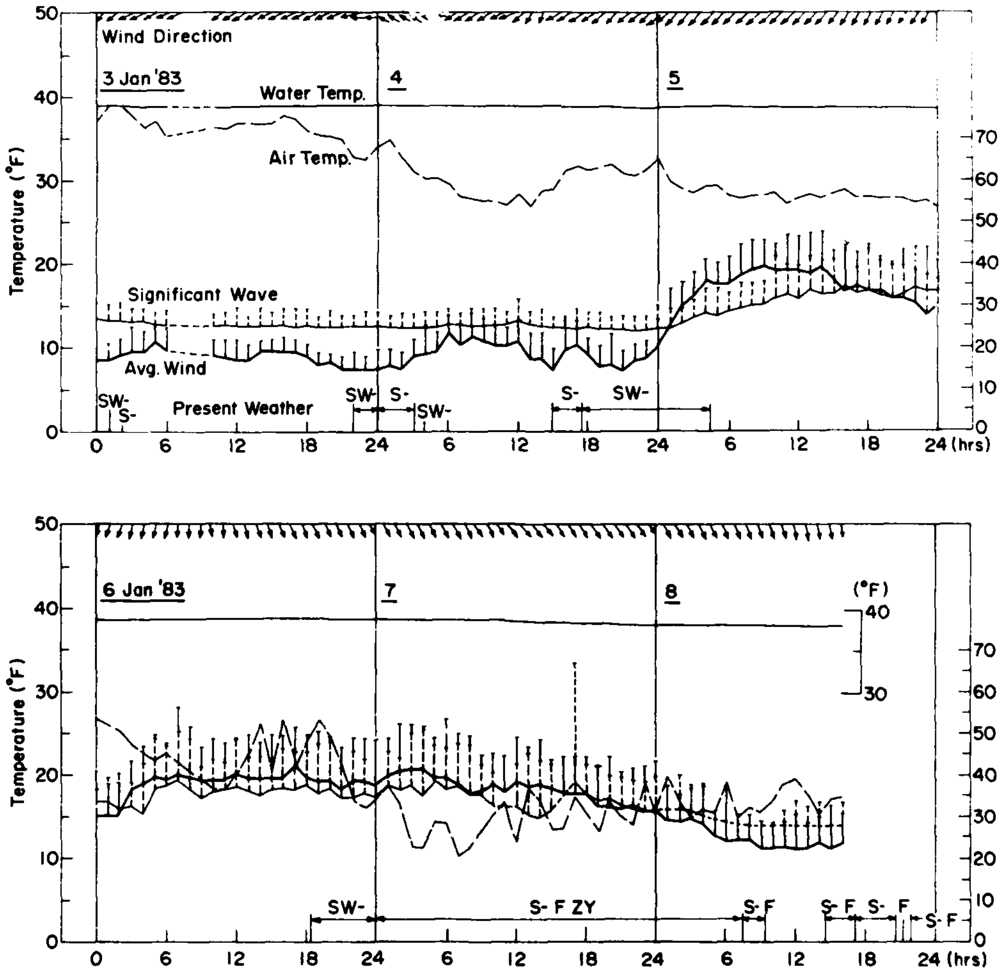

Figure 6. Meteorological and oceanographic conditions during the 3-8 January 1983 storm (SW-, light snow showers; S-, light snow; F, fog; ZY, freezing spray).

ables for the six days of the January storm. These variables and their ranges over that period are:

average wind speed	13.7-42.2 kn
peak wind speed	53.6 kn
water temperature	37.8-39.0°F
air temperature	9.6-38.9°F
significant wave height	4.1-18.5 ft
peak wave height	47.0 ft

The data are taken from the data acquisition system installed by EG&G Inc. Though readings were printed every 20 minutes, only the hourly values are plotted in Figure 6. The extremes, however, were taken from the entire data set. Wind direction was also plotted from the EG&G data system. Only present weather was taken from the Nortec weather observer reports.

ICE ACCUMULATION

There was no atmospheric icing heavy enough to trigger the Rosemount ice detectors at any time during the period when the detectors were installed, functioning and energized -- from 18 October 1982 to 8 January 1983. Some wet blowing snow adhered to vertical surfaces during the early stages of the storm on 2-3 January but there was no buildup. Spray ice did accumulate below the main deck, on the columns and diagonal trusses.

Contrary to what one might expect, the windward columns (those facing north) accreted very little ice even though the timber bumpers on the central two columns should have because they offered increased area above the wave zone (Fig. 7 and 8). Accumulation was heaviest on the diagonal cylindrical trusses in the central part of the structure, where ice thickness up to approximately 5 in. was estimated by scaling photographs (Fig. 9 and 10). The lower third of the exposed stiffeners was scoured by wave action and was completely ice-free, and accumulation tapered off with height, that is, as the underside of the deck was approached. No ice accreted on the underside of the deck (Fig. 11); as waves broke or crashed against the structure, the droplets that were generated were carried in clouds that diminished in height as they passed under the deck, and no droplets appeared to reach the underside of the deck. Only a rough estimate of the total mass of ice that was accreted can be made by scaling photographs; the

Figure 7. Minor ice accumulation on north-facing columns (starboard, windward side). View approximately west (6 January 1983).

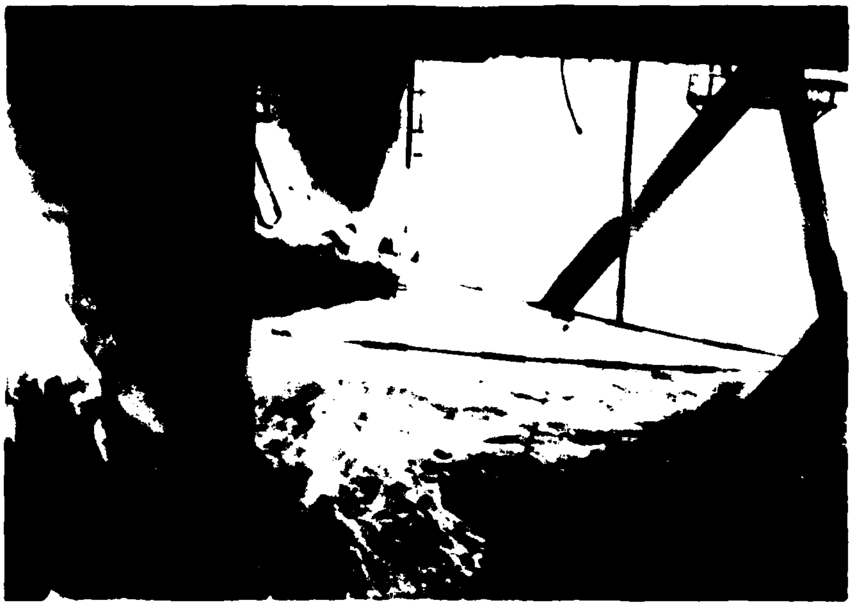

Figure 8. View east from below-deck porthole of starboard aft columns (lee to right). Only slight icing occurred (6 January 1983).

Figure 9. Ice accumulation on diagonal cylindrical trusses under rig (immediately aft of below-deck porthole), which reached a thickness of about 5 in. at bottom, tapering to near zero at underside of main deck. View southwest from below-deck porthole of aft port area (6 January 1983).

Figure 10. Aft of rig looking approximately south toward aft port column, showing ice accumulation on diagonal trusses (6 January 1983).

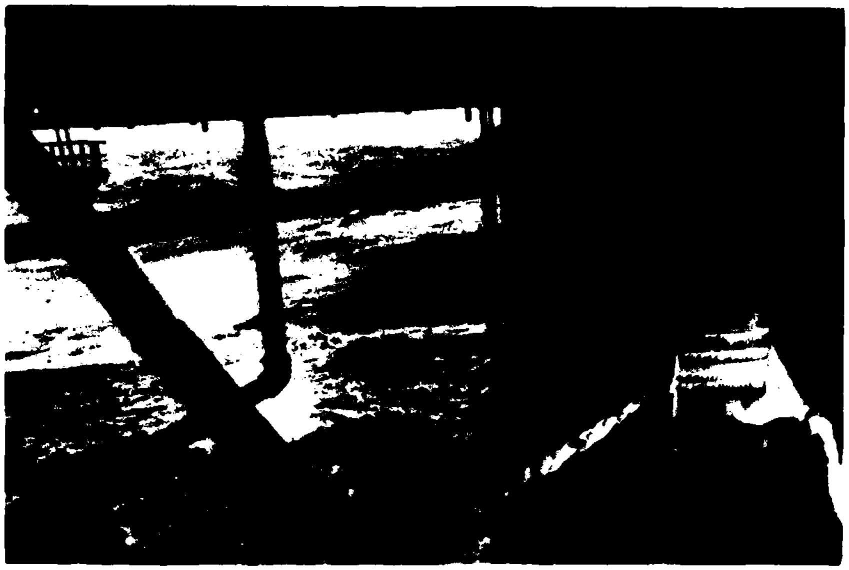

Figure 11. View southwest from below-deck porthole of forward port column; note that underside of deck has no ice accumulation (6 January 1983).

figure of 30 tons agrees with the barge engineer's statement that approximately this amount of ballast had to be pumped to maintain trim, but part of that might have been necessary to offset the drilling mud consumed.

A brief comment concerning ship icing is in order, since it emphasizes the importance of freeboard. One of the workboats operated by Biehl standing off SEDCO 708 during the January icing event reportedly became severely iced, but no details are known.

Though the original plan for measuring the amount of ice accreted on the cylinders involved removing each cylinder from its support arm and bringing it on deck where either its weight could be determined or the ice profiled, or both, it was impossible to reach the cylinders during the January storm because of the hazard involved. Thus accretion rate could not be determined directly. Photographs were made of the arrays during the icing event, but only estimates of ice deposited can be made (the maximum [on array 4] was approximately 1 in.). The coated test panels were also photographed during the 3-8 January storm, though it was possible to reach only two of the installations during the storm.

Icephobic coatings were applied to the steel test panels on 17 October 1982 and installed at the test locations a few days later. Inspection in mid-November indicated that all the coatings were intact. However, at the time of the return visit to the rig on 28 December, only two coatings remained: Carbomastic and the RTV 157 silicone rubber. The other three silicone-based coatings had been removed completely, and the underlying steel was rusty. Observation of the panels during the spray icing event of 3-8 January showed significantly less ice accreted on both the Carbomastic and silicone rubber surfaces than on the bare steel. Narrow rivulets of water froze on the two coated panels; the ice was difficult to break off the Carbomastic surface but was easily removed from the RTV 157 by light finger pressure. Subsequent lab testing of a coal tar epoxy similar to the Carbomastic, Sherwin-Williams SHER-TAR, in CRREL's linear shear apparatus showed a high strength of adhesion of ice: 54 $lb/in.^2$ -- this contrasts with 15 $lb/in.^2$ for the silicone rubber.

DISCUSSION

What were the differences between the conditions at the time the Ocean Bounty accumulated about 400 tons of ice and those during the SEDCO 708 icing (the latter conditions are given for the major icing period from 0000 hours 7 January to 0700 hours on 8 January)?

	Ocean Bounty	SEDCO 708
Maximum wave height (ft)	32	47
Significant wave height (ft)	9-16	8.6-18.5
Air temperature (°F)	3-9	9.6-18.9
Water temperature (°F)	42	38.2-38.6
Wind direction (deg)	290-300	314-335
Average wind speed (kn)	88	34.0-41.6
Peak wind speed (kn)	117	53.6

All but one of the variables are very similar. The exception is wind speed; the Ocean Bounty experienced average and peak winds roughly double those that were measured on the SEDCO 708. The slightly lower air temperature during the Ocean Bounty event is not likely a significant influence. However, the effect of the wind is to increase the droplet flux with height so that a larger quantity can reach the main deck level to form ice. The photographs made of the Ocean Bounty icing show the vessel to be lower in the water than was the SEDCO 708; however, there may have been a change in draft after the storm, when the photograph was made. That this is the case is suggested by the short height of the scour zone; the significant wave height of 9-16 ft recorded by the Ocean Bounty would have scoured much more of the visible columns.

The conditions during the SEDCO 708 icing were compared with the predictions based on ship-icing nomograms devised by Wise and Comiskey (1980) and by Mertins (1968). The former is a modification of the latter to account for the lower temperatures and lower humidity of Alaskan waters compared with the North Atlantic. The meteorological parameters (air temperature 15°F, water temperature 38°F, wind speed 35 kn) predict heavy icing, defined as 4 in. of ice in 24 hours. It may be only coincidental that the maximum ice thickness on trusses below the semisubmersible deck approached this magnitude.

CONCLUSIONS

Atmospheric icing is not highly probable on the North Aleutian Shelf during the fall and early winter, but since it is possible, methods of detecting, eliminating or preventing it should be pursued. Spray ice accretion, however, is a potential hazard. The most important variable affecting this source of ice appears to be wind speed; the greater the wind the greater the droplet flux and the higher the droplets will be carried. Height of deck above the wave zone during a storm is an unknown influence, since it will affect both the wind speed below the deck and the sail area in the droplet cloud. In the absence of information regarding the height of the Ocean Bounty's deck above waterline, no conclusion can be drawn with regard to height of droplet cloud. Only one conclusion can be stated with certainty -- minor spray icing occurs at a wind speed averaging 40 kn with peak gusts of 54 kn and an air temperature of around 10°F, but heavy icing will occur at the same temperature with winds averaging 88 kn and gusting to 117 kn. Water temperature is not a significant factor. A factor that can not be assigned any degree of importance is the geometry of the structure, though the well established decrease of ice accretion with increasing cylinder diameter demonstrated for small cylinders (on the order of fractions of an inch to several inches) in both field and laboratory tests appears to be duplicated with the large columns of a semisubmersible.

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