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ARCTIC COASTAL CLIMATIC IMPACT ON DESIGN CONSTRUCTION AND OPERATION OF THE HAMMERFEST LNG PLANT

M. A. Drage [1] and Truls Mølmann [2]
[1]University of Bergen, Bergen, Norway
[2]Barlindhaug Consult AS, Tromsø, Norway

ABSTRACT

Linde AG, Germany, is constructing a Liquid Natural Gas (LNG) plant for Statoil on the island Melkøya outside Hammerfest, Norway. A study of the climatic factors has been carried out to give input to design, construction and operational aspects of the Hammerfest LNG Plant. Theoretical modelling, on site measurements and observations of icing and snow conditions during the 1997 – 1998 and 2001 - 2002 winter seasons have been performed. Sea spray icing must be considered for a 25 m zone from the shoreline, including jetties. Maximum sea spray ice thickness has been estimated to 75 cm. Eccentric loading situations have to be taken into account. Atmospheric icing caused by rain or wet snow causes eccentric loads, and the maximum build-up has been estimated to 12 cm of ice. A sudden increase in the mean wind to more than 25 m/s due to polar lows passing Melkøya, with a frequency of approximately one polar low about each 2 years has been expected.

INTRODUCTION

The Hammerfest LNG plant is situated on the island of Melkøya (70° 38' North, 23° 33' East, area 3 km^2, highest point 70 m a.s.l). This paper results from studies and evaluations of climatic data obtained from the Norwegian Meteorological Institutes synoptic weather stations at Fruholmen Lighthouse, and Hammerfest Radio (1957-1998), and to some extent meteorological measurements and observations on the site during the 1997 – 1998 and 2001 – 2002 winter seasons. This icing and snow drift study defines the expected frequency and severity of specific winter climate events, such as extreme wind, icing and snow drift, which should be considered in design, construction and operation of the Hammerfest LNG Plant.

CLIMATIC FACTORS

Icing types and properties

Icing is classified according to the different formation processes:

1. sea spray icing
2. atmospheric icing (precipitation icing, in-cloud icing, negative sublimation).

According to NORSOK N-003, the density of sea spray ice is defined in the order of 850 – 900 kg/m^3. Typical properties of accreted atmospheric ice are glaze (900 kg/m^3), wet snow (300-600 kg/m^3), hard rime (600-900 kg/m^3) and soft rime (200-600 kg/m^3) (ISO 12949).

Ice loads

Ice loads on structures at Melkøya are a function of parameters such as:

- the icing process (sea spray, wet snow, freezing rain etc)
- surface temperature of the construction/ structure
- the slope and direction of the surface
- distance from shoreline, etc.

Uneven distributions of ice must be considered. Ice caused by sea spray, wet snow and rain will cover all surfaces facing the wind. It may be assumed that the ice will cover half the circumference of tubular structures.

Design ice loads are based on operational requirements for the removal of ice accumulated during an icing period. Icing values are then to be considered as maximum design values for one single icing incident and can in this context be considered as a 100- year return period load.

Weather data

All analyses are primarily based on weather data from the synoptic weather stations Fruholmen Lighthouse (1957 – 1998) and Hammerfest Radio (1957 – 1987). The Hammerfest Radio meteorological station is located approximately 3 km South East of Melkøya, 70 m above sea level. The Fruholmen Lighthouse is located 45 km in northerly direction. Weather statistics from neither of these locations fully represent the conditions at Melkøya. Evaluations based on local knowledge, Finite Element Model (FEM) simulations and to some extent measurements have therefore been made to describe the meteorological conditions of significance to the construction and operation of an LNG plant. Table 1 gives an overview of the annual and seasonal weather conditions at Fruholmen Lighthouse.

Snow statistics

Precipitation has never been recorded at Melkøya, and the 2001-2002 winter measurements gave only limited snow data. The nearest locations with long time records of snow precipitation are Hammerfest Radio and Fruholmen Lighthouse. The Fruholmen Lighthouse data are assumed to be more representative for the Melkøya conditions than Hammerfest Radio because of less local topography effects. Figure 1a shows that the main wind direction for snow events is in the 340-10 sector. The events with freezing rain or wet snow come from the 250-10 sector. For these wind directions the air temperatures at Fruholmen can be regarded as representative for Melkøya.

Table 1: Overview of the annual and seasonal weather conditions at Fruholmen Lighthouse. The analysis is based on data from 1957 – 1987 for air temperature and wind conditions, and on data from 1957 – 2001 for precipitation.

	annual	winter	spring	summer	autumn
Mean wind speed [m/s]	9,0	10,5	8,9	7,3	9,2
Standard deviation [m/s]	4,8	5,3	4,6	3,9	4,9
Median [m/s]	8,2	10,3	8,2	7,2	8,2
Over 10 m/s [%]	37,9	50,1	37,5	23,9	40,2
Maximum wind speed [m/s]	35,0	35,0	31,9	25,7	34,0
Mean air temperature [ºC]	2,8	-2,1	0,8	8,7	3,8
Min air temperature [ºC]	-17,4	-17,4	-14,3	-1,9	-9,1
Max air temperature [ºC]	26,1	11,0	21,7	26,1	16,6
Mean precipitation [mm]	1098,5	315,3	196,5	217,3	356,4
Min precipitation [mm]	673,4	136,9	82,4	87,7	117,6
Max precipitation [mm]	1630,4	571,5	350,8	426,9	618,1

Snow drift

The shortest distance between the island Melkøya and the main island Kvaløya is about 100 m. This fetch is too long for any transport of drifting snow onto Melkøya. Our measurements during the winter season 2001-02 indicate that about 50 % of the snow precipitation will be transported away from the island. Hence, Melkøya is probably the best location in the region for the LNG plant as regards the potential problems of snow and drifting snow.

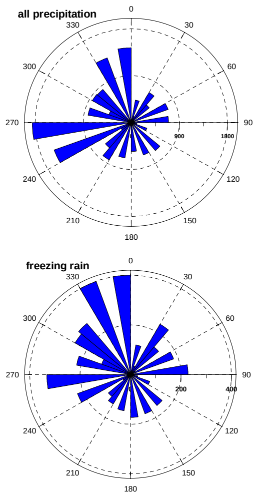

Figure 1a. Wind direction during precipitation events at Fruholmen Lighthouse (1957 – 1987). Rain T > 2°C, freezing rain and wet snow 2°C < T < -2°C, and snow T < -2°C.

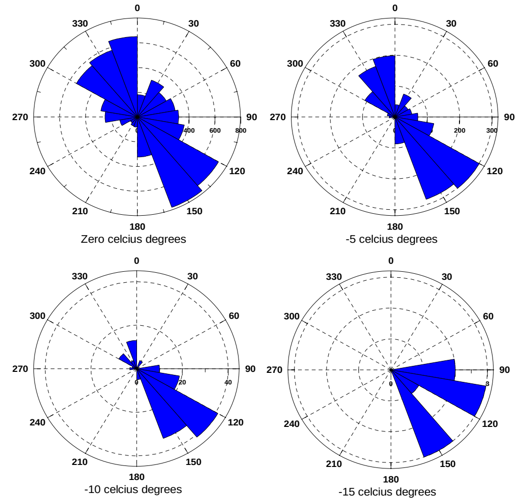

Figure 1b. Frequency of winds stronger than 10 m/s for different air temperatures at Fruholmen Lighthouse (1957 - 1987).

The snow standard used in the Hammerfest area can consequently also be used at Melkøya.

The most frequent wind directions for snow precipitation are in the NW – N sector and consequently it can be concluded that wind from this sector will lead to most of the snow depositions.

In situations with snow precipitation and strong winds, the snow crystals will accumulate in slow velocity areas near obstacles and create snow depositions. These depositions will again influence the velocity field around the obstacle, and the snow drift formation process is therefore often self-intensifying. Snow deposition could in some cases be a highly non-linear process which is at present not possible to fully solve by available numerical tools.

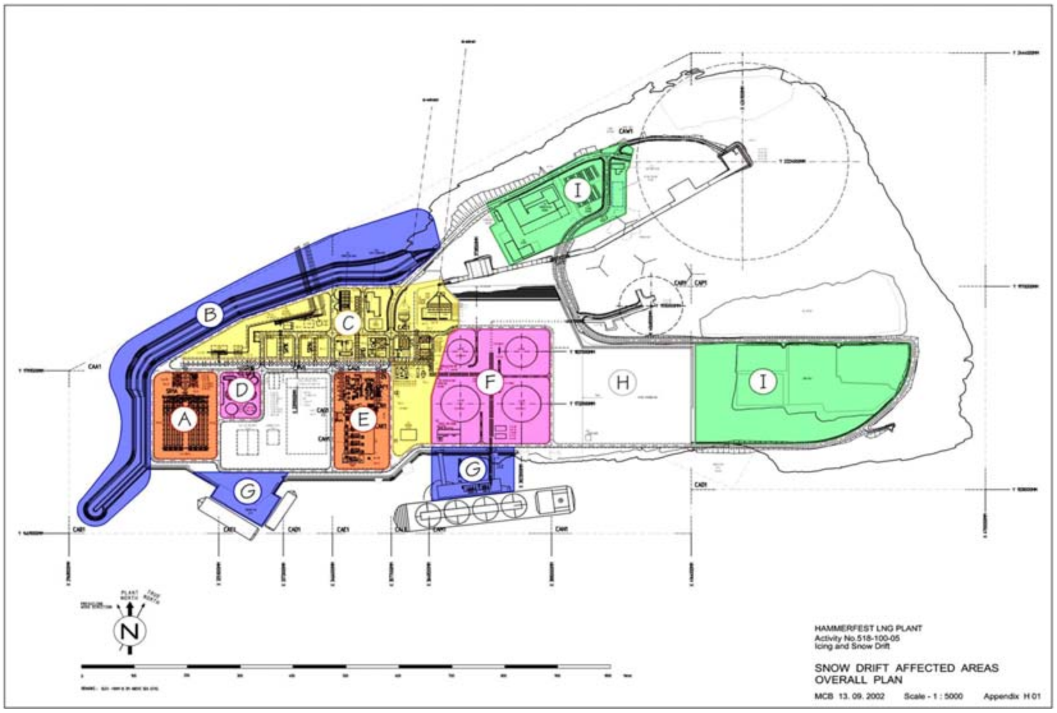

Fig. 2. Overall plan of snow drift areas on the Hammerfest LNG-plant.

Elevated structures with ground clearance (constructions on poles) are recommended because they create higher wind speeds close to the ground which cause the erosion of deposited snow. The following comments with respect to estimated snow drift formations are related to the defined zones on the Hammerfest LNG plant site plan.

- *A: Slug catcher area.* The pipeline system will in principle collect drifting snow, but the rate of deposition will be strongly reduced due to the horizontal orientation of the pipes and ground clearance. The ground surface underneath the pipeline "roof" should be as smooth as possible.
- *B: Breakwater.* The breakwater will collect snow on the lee (South) side. Side slopes less than 1:4 will reduce or remove the problems along the toe of the fill.
- *C: Piperacks/ Air separation unit/ Sea water outlet.* The area consists of a variety of installations, structures and buildings. Snow drifts will form over the whole area. Bigger installations like buildings will generally have snow deposition on the lee side (South). Small depositions may also be expected 2-3 m from walls parallel to the N-S direction.

- *D: Smaller tanks.* Snow drifts will form between the tanks in the E - W direction while erosion will take place in the N - S direction.
- *E: Process barge.* Heat loss from the process equipment will reduce the problems of snow drift because of melting and run off. Heavy snow storms, however, may fill voids and openings in exposed areas (predominantly facing North).
- *F: LNG/ LPG/ condensate storage tanks.* Snow drifts will form between the tanks in the E – W direction while erosion will take place between the tanks in the N – S direction. Constructions on the top of the tanks may initiate formation of snow drifts as described in section 4.4.
- *G: Jetties.* Installations on the jetties may collect snow on lee (South) side.
- *H: Future expansion area.* The high South facing rock faces will have large depositions of snow at plant level. At the base of the rock face the thickness of the snow deposition may be of several meters. Overhanging snow drifts will also form on the top.
- *I: Admin building/ Camp area.* The parking area will give limited snow drift problems if cars are aligned as indicated and no permanent obstacles are placed on the open square. Buildings will experience snow drift formations on the lee side and doors and openings should generally be placed on East or West facing walls. The administration building will collect snow on the SE side with a snow drift starting on the NW corner.
- *J: Roads.* Road constructions should be elevated from adjacent terrain. This will reduce deposition of snow on the road itself. The road along the bog deposition and breakwater will experience frequent snow drift formations. The problem is reduced if side slopes of adjacent terrain are less than 1:6. There should also be an open space between road embankments and adjacent fill or cut sections to provide for snow deposition when snow clearing is necessary.

Polar lows

Low-pressure systems of different scales and of different intensities appear frequently in the Northern oceans. The definition of a polar low is that it forms in cold maritime air, has diameter of between 200 and 500 km and wind speeds in excess of 15m/s. Polar lows only form and develop over sea in arctic regions in the winter season. As soon as they make landfall they die out rapidly. A polar low is rather short-lived, typically from less than a day up to 2 days, and it is difficult to predict its path, intensity and duration. However, one way of discovering a polar low even at its early stage is by inspection of satellite images.

The passage of a polar low at a specific location can take several hours. As the low approaches a location, there is a sudden increase in the mean wind to more than 25 m/s, with gusts of hurricane force. During the passage of the low, the wind direction changes by about 180º. The very sudden wind increase and change in wind direction within just a few hours are characteristic for polar lows. Also characteristic is that the wind is strongest near the surface, and decreases gradually upwards. When a polar low approaches there is a rather strong temperature increase. Within a few hours, the temperature will typically increase from around -10 ºC up to a few degrees above freezing. After the passage, the temperature will gradually fall again. The frequency of polar lows passing Melkøya during the last 20 years is approximately one polar low every second years.

MODEL STUDY OF WIND CONDITIONS AROUND MELKØYA

Meteorological data has been collected at Melkøya for 2 years, which should provide an indication of the typical conditions. The data have been collected using standard weather stations, in addition to specialized equipment to access icing. The main purpose of the model study was to complement the observations by providing more detailed information about the three-dimensional structure of meteorological fields, for example: wind profiles, horizontal distribution of the wind field around Melkøya, vertical velocities, turbulent kinetic energy and turbulent length scale, and stability of the atmosphere close to the surface.

A secondary objective was to evaluate the reproducibility of the SYNOP station at Fruholmen Lighthouse as compared to those at Melkøya. The analysis consists of 3 nested models, HIRLAM 10, MC2 and SAFRA. An example from SAFRA is given in Fig. 3.

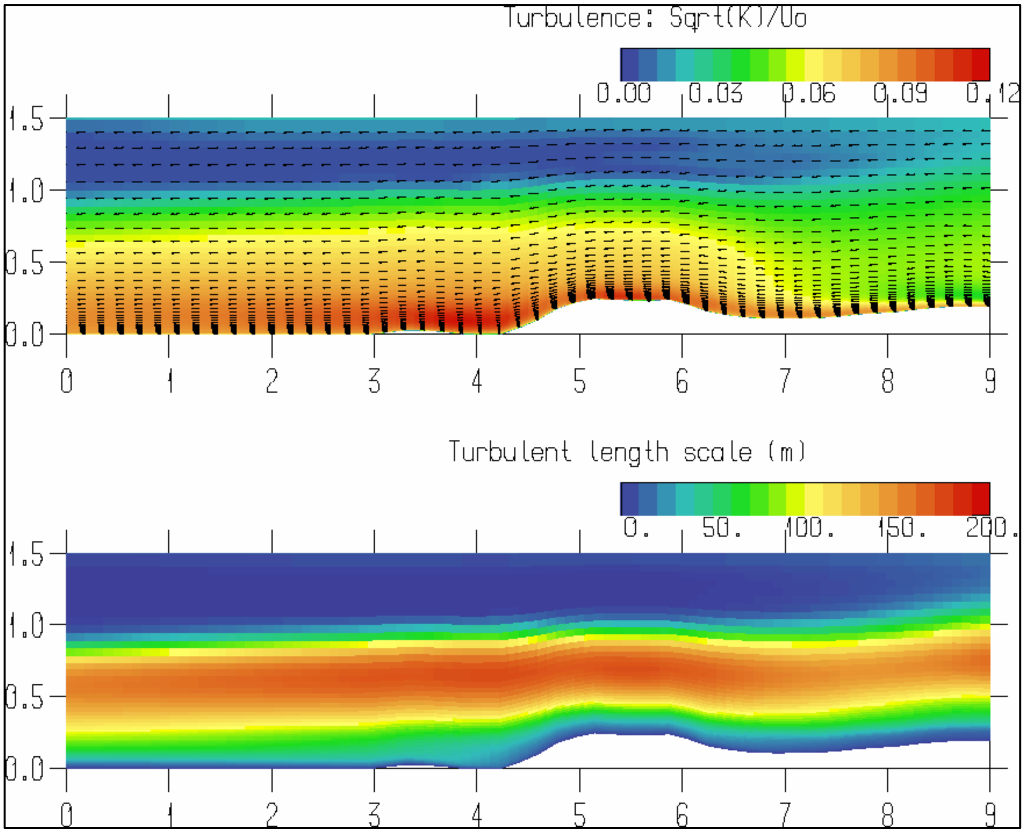

Fig. 3. The east case 3.3.2000, SAFRA: East-west profile over Melkøya for Turbulent Kinetic Energy (TKE) and turbulent lenght scale (TLS). The horizontal and vertical scales are in km. Melkøya is situated between 3 and 4 in the figure.

SEA SPRAY ICING ON MELKØYA

Sea spray icing on Melkøya normally occurs when a high pressure system is transporting cold air from inland out to the coastal area. Weather data from Fruholmen Lighthouse shows that during the last 40 years there has been only one event lasting as long as 36 hours with air temperatures less than –10°C and strong southerly winds. It should be noted that the air temperature at Melkøya is expected to be in the order of 2°C lower than at Fruholmen during weather situations like this. Nevertheless, it is a fact that the combination of low air temperatures and strong winds is rather rare in the region. Normally all cold air which is stored inland will be transported away during a period of 12 – 24 hours giving weather situations with surface winds stronger than 10 m/s.

Observation in 1998

During the winter of 1998 a major sea spray icing build up was recorded at Melkøya. Sea spray icing as severe as documented in Figure 4a has never been observed before. Since this may be considered as a worst case sea spray icing scenario, it has been important to be able to model the situation using the available long term meteorological data (primarily from Fruholmen Lighthouse). Then, all other sea spray icing situations can be predicted within acceptable tolerances both with respect to severity and frequency. The photograph was developed in March 1998, but no written documentation exists as to exactly when it was taken.

Observation in 2002

Due to the 1998 documented near shore sea spray ice build up, it was stated as important in Multiconsult/Barlindhaug's work scope to try to document similar incidents and three video cameras where mounted to observe sea spray icing during the 2001 – 2002 winter. Figure 4 b) shows sea spray icing on January 26, 2002 on the same spot as shown in the 1998 photograph. During the period from January 23 to 27, 2002, there were two days with temperatures in the range of – 9°C to – 11°C and wind from south with wind speeds up to 18 m/s. This weather situation lead to an ice growth rate in the order of 30 cm in a zone 25 m from the shoreline during 48 hours, and maximum ice thickness was measured to approximately 30 cm on January 27.

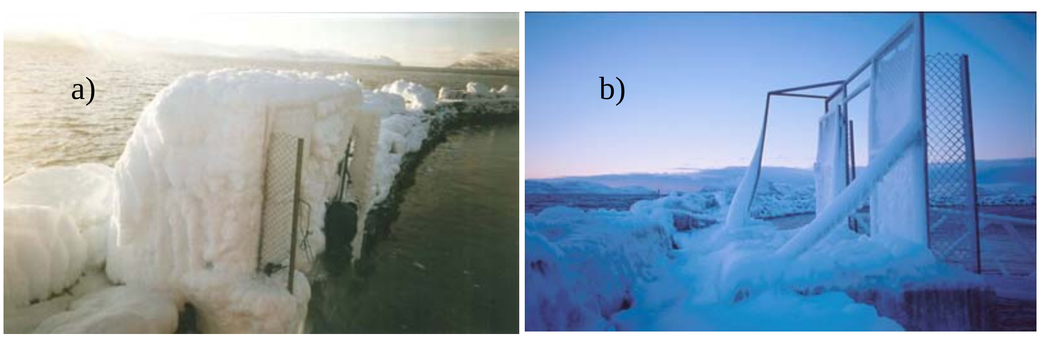

Fig. 4. Icing caused by sea spray on the existing breakwater on Melkøya in:
a) 1998 (left) and b) 2002 (right). The same gate structure is observed on both photos. (Photo: a) Ragnhild Normann – Spring 1998 and b) Ola Brandt – January 26, 2002).

Modelling sea spray using Mertin's diagram

Mertin's diagram for icing has been used for a rough estimate of ice growth rates on Melkøya (Mertins, 1968). The estimates are based on the following input from Fruholmen Lighthouse: wind (1957-1987), air temperatures (1957–2000), and sea surface temperatures (1968-2000). The Mertin's diagram categorizes icing as:

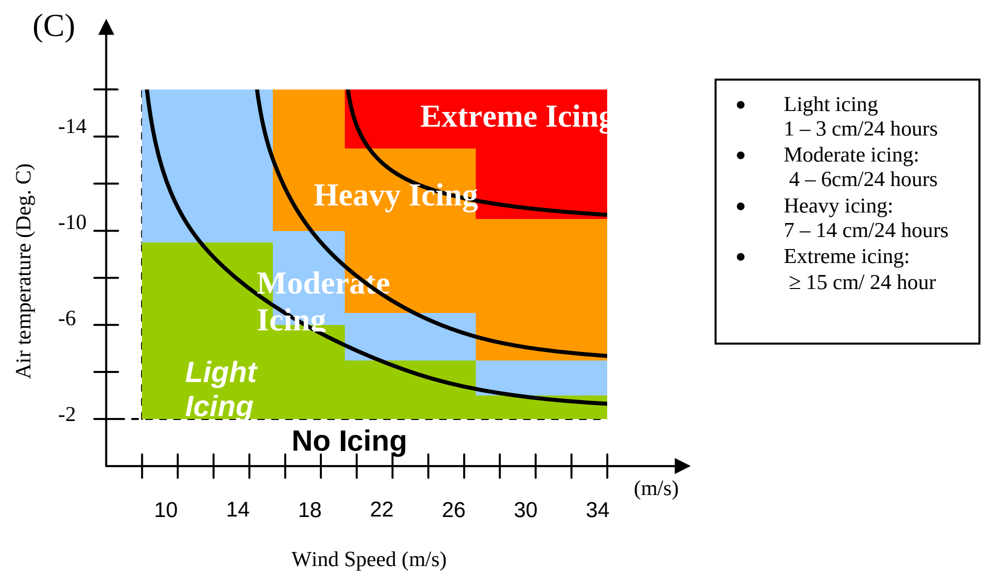

Fig. 5. Diagram used for icing calculations due to sea spray (based on Mertin's diagram, 1968).

Frequency analysis

A frequency analysis of the Fruholmen data showed a main trend of sea spray icing from southerly directions (Fig. 1b). It should be noted that simultaneous wind measurements at Fruholmen Lighthouse and Melkøya showed that wind from the South East sector may be stronger at Melkøya than at Fruholmen Lighthouse. This means a slight underestimate of the frequency of incidents at Melkøya. The frequency of wind speed stronger than 15 m/s and air temperatures lower than -8 ºC at Fruholmen Lighthouse during the period, has been estimated to 2.45 per year (1957-1987).

The frequency analysis gave incidents of heavy icing (7-14 cm/24 h) in 13 winters of the 43 years of data record from 1957 to 2000. Only in 1966 and 1998 were there as many as three days during the year with heavy icing, while January 1999 showed the longest continuous period with heavy icing; 24 - 30 hours. For 1998 the analysis shows heavy icing on February 9 (7 PM), February 14 (1 PM and 7 PM) and February 15 (1 AM). The 2002 icing incident was estimated using Mertin's diagram. The results showed an icing rate of "extreme icing" (> 15 cm/ 24h). The ice accumulation estimated with Mertin's diagram fit well with observed icing as documented in the photos from the 2002 incident. This leads to the conclusion that estimates of icing based on Mertin's diagrams conform well with the icing conditions on the breakwater of Melkøya. Mertin's diagram was therefore applied in this study.

ATMOSPHERIC ICING

Both theoretical calculations and on-site measurements of atmospheric icing at Melkøya have been carried out. In the initiating phase of the icing study it was assumed that surface temperatures of the structures will be higher than -15°C. Three cooled cylinders with different surface temperatures where mounted (Fig. 6). The general conclusion is that atmospheric icing will create less significant ice accumulation with a frequency of incidents less than that of sea spray icing. There will be negligible atmospheric icing defined as deposition (negative sublimation) or accretion (freezing of super cooled cloud drops) on surfaces with temperatures equal to ambient air temperatures.

Icing on structures caused by freezing rain or wet snow accretion will occur on surfaces predominantly facing South West to North. Even though no ice of this type was measured on the cylinder with surface temperature equal to ambient air temperature, statistical evaluation of climatic data supports the conclusion of maximum ice build up to 12 cm.

Fig. 6. Riming measurement cylinders at Melkøya, with surface temperatures -15°C (left cylinder), 5°C lower than ambient air temp. (middle cylinder), and -5°C (right cylinder).

CONCLUSIONS

A study of icing and snow drift conditions at Melkøya has been carried out in order to review and supplement the Statoil Metocean Design Criteria. The study consists of theoretical modelling and to some extent on-site measurements and observations of icing and snow conditions during the 2001 – 2002 winter.

Observations during the 1998 winter show an excessive sea spray ice build up on the old Melkøya breakwater, which indicates that icing problems can be far more severe than normally expected on near shore installations in Northern Norway. The study focused on describing the weather situation leading to the documented ice build up, and based on this, preparing predictions as to the frequency and severity of the icing.

Melkøya is very exposed to wind which reduces potential snow and snow drift problems at the LNG plant. Wind conditions has also been modelled and measured. Results were used as input for the estimates of icing and snow conditions. In addtion, they were used as a basis for a general review of the defined wind profile for wind load predictions.

The major conclusions of the study are as follows:

- potential icing problems must be addressed in the plant operational procedures
- all calculation are based on the assumption that all weather exposed plant equipment, components, structures or buildings will have surface temperatures equal to ambient air temperature
- sea spray ice has to be considered for a 25 m zone from the shoreline (including jetties). No sea spray ice build-up will be considered more than 25 m from shoreline. Maximum sea spray ice thickness is estimated to 75 cm. Eccentric loading situations have to be taken into account
- atmospheric icing caused by rain or wet snow will cause eccentric loads, and the maximum build-up will be 12 cm of ice
- due to the compact and complicated geometry of the process area, falling ice will form only limited design input
- maximum design icing values are estimated
- all structures are in general to be designed according to the Norwegian Standard series NS 3491 – Basis of design and actions on structures; part 3: Snow Loads
- overhanging snow drifts may form on top of tall rising structures like columns or storage tanks. Traffic zones or installations should be avoided or sheltered beneath exposed areas
- blowing snow will tend to fill voids in open structures and installations
- polar lows passing approximately every 2 year will give a sudden increase in the mean wind speed to more than 25 m/s.

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