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Winterization Design based on Weather Occurrence Probability for Arctic Ship and Offshore Plant

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ABSTRACT

The ship or offshore plant operating in the Arctic region needs the proper winterization to secure the safe working environment and normal operation of the topside facilities in harsh weather condition. In this paper, winterization design methodology for a drilling platform is established based on the weather occurrence probability in the operation site eventually inducing the local flow and temperature around the topside equipment. Each heat loss from the topside equipment is calculated by this probability basis synchronizing the weather database with the local flow database corresponding to various wind speeds and directions. Heat loss from the pipelines, deck plates and other equipment according to weather conditions is estimated and then the total required heat and electric load can be added up to the considered facility availability, which is applicable to the design of the electric power system. This methodology can be utilized for the energy saving design of the Arctic ship and offshore plant.

KEY WORDS : Winterization; Weather database; CFD; Heat loss; Heat tracing.

INTRODUCTION

The ship or offshore plant operating in the cold environment needs proper winterization provisions to secure the safe working environment and normal operation of the topside facilities. Electrical heat tracing (EHT) as a heat source has been widely used to prevent freezing or icing of the topside facilities. Heating capacity of the EHT has to be designed under the considerations of wind chill effects and its heat loss for each component in the exposed space. DNV-GL (2016) shows the winterization class notation prescribing how much air temperature has to be reflected to the heat loss calculation and it is rated by the ranges of air temperature. However, the heat loss is not calculated by the air temperature only. An additional engineering procedure is therefore necessary to get an exact value of the heat loss by combining air temperature with the effects of external wind chill around the heated parts. Overestimation of the heat loss causes overheating of the parts and the energy loss. Recently, a ship builder has been requested to design heating systems with efficient and economic perspectives. Risk-based winterization (Yang, et al., 2013) has been proposed for determination of winterization levels or requirements on a case-by-case basis. In here, estimation of probability of the failure was calculated by using the limit state function based on the temperature. Risk assessments of the designed winterization systems were performed. However, fixed wind speed condition without the consideration of flow distribution on the topside was used and it was limited to an evaluation method in order to check whether heating systems meet the need and what condition they may fail.

In this paper, winterization design methodology has established based on the weather occurrence probability analyzed from the past data over 20 years in the operation site eventually inducing the air flow and temperature around the topside equipment. The occurrence probability of the heat loss from the topside equipment is calculated by synchronizing weather occurrence database with local flow database corresponding to various wind speeds and directions. Maximum heat loss for the each topside equipment can be defined by just selecting the satisfaction criterion in the respect of the safety and availability. The proper heating capacity of the EHT is automatically applied to the design procedure and total electrical loads for the winterization are also provided. For a demonstration of the methodology, a case study applying to a semi-submersible drilling platform.is described.

WINTERIZATION METHODOLOGY

The heat loss of topside equipment due to wind chill effects, which are governed by weather conditions such as air flow and temperature, is the key value to design winterization system and its heating capacity. Weather characteristics at the operation site or local position along the ship route can be quantified with analysis of past weather data. Local flow features around the topside equipment induced by external wind are varied with the position of target equipment and external wind conditions like wind speed and wind direction. Flow analysis based on CFD techniques can be useful to define local flow characteristics with consideration of complex topside structure. Each quantitative heat loss by wind chill effects is calculated by using empirical equations expressed with Nusselts number for the forced convection heat transfer. Consequently, occurrence rate of the certain heat loss is defined by probability calculation synchronized weather database with local flow database. Details are as bellows.

Weather Analysis

Weather data like air temperature, wind speed and wind direction for the operation site have been openly supplied on the website of NOAA (National Oceanic and Atmosphere Administration). Past weather data collected 4 times a day for 20 years are used. Within each 6 hours, mean values for wind speed and wind direction and minimum value for air temperature are taken for this work. For example, occurrence distribution diagrams for wind speed and air temperature and wind roses are shown in Figure 1. Data of air temperature and wind speed are divided with intervals of 1˚C and 1 m/s, respectively. Wind directions are separated with the angle of 45˚ and thus 8 intervals in the wind rose are applied.

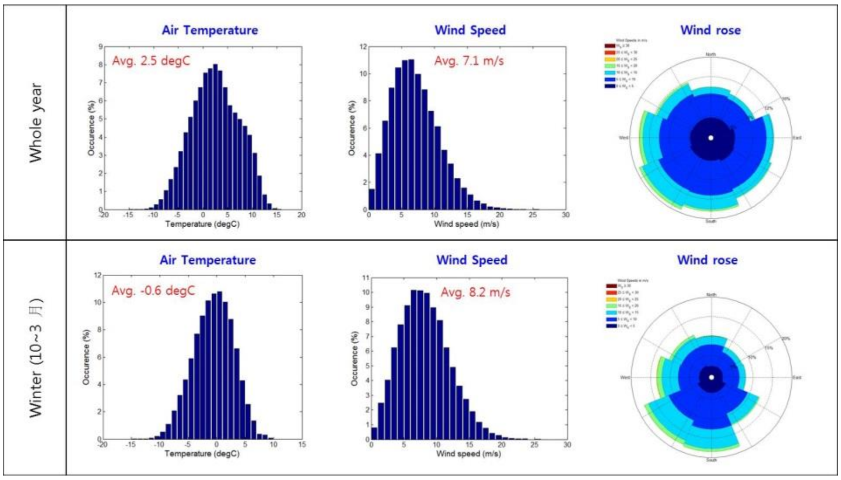
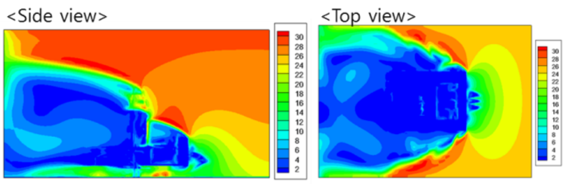


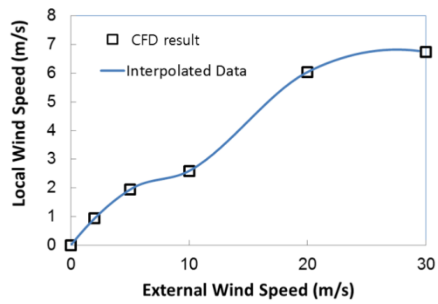
Figure 1. Example of diagnosis of weather probability

Flow Analysis

Local air flows in the exposed space of the ship or offshore plant are analyzed with a conventional CFD package. External wind conditions varied with several combinations of wind speed and direction, 5 external wind speeds (2, 5, 10, 20, 30 m/s) and 8 wind directions (N ~ NW), are used for input boundary conditions of the CFD simulation. 40 cases are calculated, and from the results local flow speed under the certain external speed is defined with spline interpolation method. Topside structure of the ship or the offshore plant disturbs external wind flow and induced local flow speed around the topside facilities can be down to about 1/10 of the external wind speed as the flow contours are shown in Figure 2(a). Moreover, Figure 2(b) shows that local flow speed is not linearly proportional to the external wind speed due to the turbulence flow phenomenon.



(a)



(b)

Figure 2. (a) Wind speed contour for external wind of 20 m/s and (b) local flow speed distribution under various external wind speeds

Occurrence Probability of Heat Loss from Topside Equipment

Empirical equations (Bergman, et al., 2011) for the forced convection heat transfer are used to get how much heat loss occurs on the plate or cylinder, representing the deck surfaces, passage ways and pipes on the topside. The equations and heat flux are as follows,

Plate: $\overline{Nu_L} = \left(0.037Re_L^{4/5} - A\right)Pr^{1/3}$ (1)

Cylinder: $\overline{Nu_D} = 0.3 + \frac{0.62Re_D^{1/2}Pr^{1/3}}{\left[1+(0.4/Pr)^{2/3}\right]^{1/4}}\left[1 + \left(\frac{Re_D}{28200}\right)^{5/8}\right]^{4/5}$ (2)

$h = \overline{Nu_L} \times \frac{k}{L} \;\; or \;\; \overline{Nu_D} \times \frac{k}{D}$ (3)

$q'' = h(T_s - T_\infty)$ (4)

where q'' is the heat flux of wind chill, T_s is surface temperature, T_∞ is air temperature, L is the length of plate, D is the diameter of pipe, Re_L and Re_D are Reynolds number, Pr is Prandtl number and k is the thermal conductivity.

By using interpolated CFD results, an external weather combination, i.e. wind speed (V) and wind direction (θ), specifies the local flow speed (V_{local}) at the point of a target topside facility and thus the probability of the local flow speed (P_{local}) can be obtained by using a summation of the probabilities corresponding to the weather combination like Eq.(5~8). Finally, the local flow speed and air temperature can be translated to the specific heat loss and its probability [Eq.(9)].

$P_{ws}(V),\; P_{wd}(\theta),\; P_{temp}(T) \leftarrow Weather\ DB$ (5)

$V_{local}(V, \theta) \leftarrow Local\ Flow\ DB$ (6)

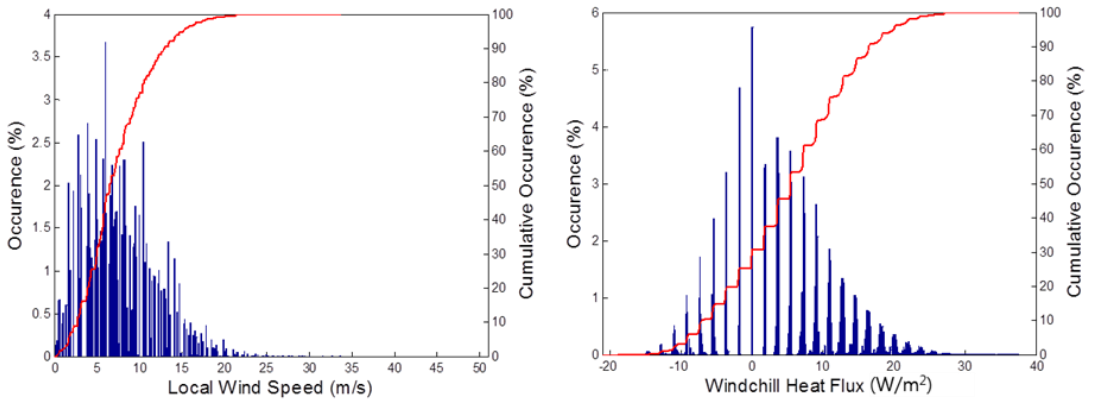
$q''(V_{local}, T) \leftarrow \text{Eq.}\,(1\text{~}4)$ (7)

$P_{local}(V_{local}) = \sum P_{ws} \times P_{wd}$ (8)

$P_{heat\ loss}(q'') = \sum P_{local} \times P_{temp}$ (9)

Winterization of a Drilling Platform

For an example of winterization methodology, a case study is prepared by applying to a semi-submersible drilling platform operated at the Barents Sea. From the weather analysis of the operation site and local flow database, probability distribution of the local flow speed (P_{local}) at the certain location of the topside is calculated as illustrated in Figure 3(a). Probability distribution of the heat loss from the 100A pipe with thermal insulation is shown in Figure 3(b). Below 12.4 m/s of local flow speed satisfies 90% of a year. For satisfying 99.999% of a year, 30.4 m/s of local flow speed should be considered to calculate the maximum heat loss. 16.3 W/m^2 of heat loss for the 90% basis and 35.9 W/m^2 for 99.999% are provided at the final. 0.001% of the time is about 5 minutes a year and it could be negligible compared to icing and freezing phenomena. If the satisfaction criteria are defined for each of the topside facilities, the proper heating capacity of EHT are automatically selected with consideration of their heat loss, and moreover total electric loads for the winterization can be summarized. It is helpful to design the electric power system. The winterization system can be optimized by utilizing an adjustable satisfaction criterion for each of topside facilities reflecting its safety aspects and operation availability.



(a) Local flow speed (b) Heat flux

Figure 3. Occurrence distributions of (a) local flow speed and (b) heat flux due to wind chill effects

CONCLUSIONS

Winterization design methodology has been established based on the weather occurrence probability in the operation site eventually inducing the external air flow and temperature around the topside equipment. For the winterization system, the proper heating capacity is designed on the basis of occurrence probability of the heat loss. It is applicable for optimized heating system and saving energy of ship or offshore plant operating in the Arctic region.

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