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Designing for performability: An icing risk index for Arctic offshore

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ABSTRACT

Ice accretion affects the performability of offshore production facilities in various ways, including repair time and failure rate. It can increase power losses, life cycle costs, and safety hazards. There are few studies and limited systematically collected information about the impact of ice accretion on performability and its attributes (reliability, maintainability, quality, safety, and sustainability) for Arctic offshore production facilities. This paper will discuss the effects of different types of ice accretion on the performability of Arctic offshore production facilities. Then, to quantify their effect on the performability of offshore production facilities, an icing risk index is developed; its application is then shown by means of a case study.

1. Introduction

Over 25% of the world's undiscovered oil and gas petroleum reserves are expected to lie in the Arctic region, where approximately 84% of these reserves will be offshore (Gudmestad et al., 2007). The Arctic is known to be a harsh, sensitive, and remote area. Taking into consideration the unique and challenging Arctic operational conditions, the designed systems and selected technologies must be dependable and safe as well as economically viable (Gudmestad et al., 2007; Barabadi et al., 2015). Considering the high sensitivity of the area and its remoteness, which make any simple logistics a challenging task, the selected technology must be able to minimize environmental pollution and the need for spare parts and to require the minimum quantity of raw materials and energy.

Designing for production performance comprises appropriate approaches that can enable designers to meet these important goals. Production performance is described as the capacity of a system to meet the demand for delivery or performance. During recent years, production performance management programs have experienced faster development, and they increasingly play an important role in supporting the decision-making process (Gao et al., 2010). Moreover, some standards such as ISO20815 (2008) and NORSOK Z-016 (N. Z-016, 1998) have been developed to provide processes and activities, requirements and guidelines for systematic production performance management. The focus of these standards is on the reliability, availability, and maintainability of equipment. In most studies related to production performance, the main objective is to optimize reliability, availability, and maintainability to achieve the production assurance goals (Barabadi, 2011; Barabadi, 2012). Fig. 1 shows the performability concept of a system. As illustrated, an effective design should consist of all the attributes of performability simultaneously. A product or a system having these attributes is usually expected to perform well over its lifetime, incurring minimum life cycle costs.

Designing for performability in the harsh, sensitive, and remote Arctic area is a challenging task. It requires a range of tools to be employed and is dependent on a large amount of data and information. However, taking into consideration the unique Arctic operational conditions, most of the available tools need to be modified, and in some cases, new tools should be developed. At this point of development, there is not enough of the data and information (such as reliability or maintainability data and information) which is required for an accurate performability analysis.

One of the most challenging parts of performability analysis is quantifying the effect of operational conditions on performability (Barabadi, 2012; Kayrbekova et al., 2011). More specifically, ice accretion is one of the most hazardous operational conditions in cold regions; it can significantly affect the performability of equipment (Gudmestad et al., 2007; Ryerson, 2011). In a place like the North Sea, icing is considered more as a nuisance, but in the harsh Arctic climate condition, it can present many more operation, maintenance and safety problems (Gao et al., 2010; Ryerson, 2011). Furthermore, in the Arctic, icing can be very frequent, and, hence, according to the accident pyramid concept, it can lead to fewer but more serious accidents, such as those involving

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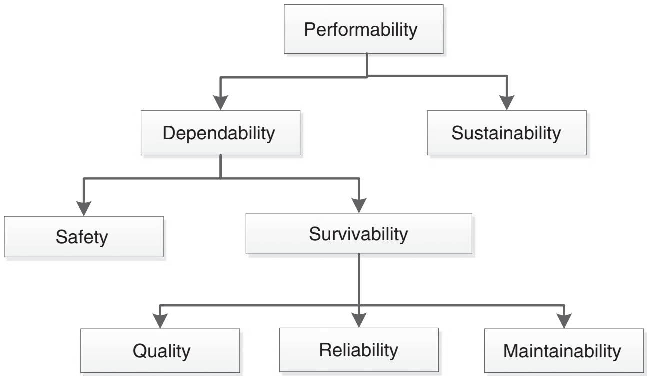

Fig. 1. Performability concept (Misra, 2008).

fatalities (Ryerson, 2011; Heinrich, 1941). Ice may build up in different forms (such as sea spray icing, frost, sleet, and glaze) based on the equipment shape, meteorological parameters (such as air temperature, wind speed, cloud liquid water content, cloud droplet spectra), and the elevation of equipment from sea level. Offshore platforms are complex systems with many items of equipment in various shapes, which makes them susceptible to different types of icing and icing problems (Ryerson, 2011).

Different types of icing may have different effects on performability attributes (sustainability, safety, quality, reliability, maintainability). Hence, to develop an effective practical solution and increase the performability of production facilities, one must have comprehensive knowledge of the different types of ice, how they form, and where they appear on offshore production facilities (Barabadi, 2012; Kayrbekova et al., 2011). In addition, it is very important to know how and how much they can affect the different concepts of performability. Considering the complexity of the icing effect on performability and its attributes, it is necessary to develop a standard factor for the identification, assessment, and prioritization of their risks. However, there are few studies and limited systematically collected information about the impact of ice on the performability of offshore production facilities. Recently, some researchers have focused on quantifying the effect of icing on offshore production facilities' performance in the Arctic (Ryerson, 2011). However, reliability and safety is their main focus, and these studies are not well detailed regarding the other concepts of performability. In this paper, the different types of ice accretion and their effect on the performability of offshore production facilities will be discussed. Then, in order to quantify the effect of different types of ice on performability, the concept of an icing effect index (IEI) on performability is developed. An IEI on performability can represent the consequences of icing on equipment. Thereafter, considering the probability of ice accretion and IEI on performability, the icing risk index for performability can be quantified. The rest of this paper is organized as follows: in Section 2, different types of ice accretion on offshore production facilities will be discussed; Section 3 will review the effect of icing on the different concepts of performability. Section 4 introduces the concept of an icing risk index for performability. The application of the method is illustrated by a case study in Section 5. Finally, Section 6 provides conclusions.

2. Physics of icing on Arctic offshore production facilities

Ice accretion is defined as the process of ice build-up on the surface of an object. Ice accretion on offshore production facilities can be categorized in two main groups: *i*) atmospheric icing and *ii*) sea spray icing or superstructure icing. Atmospheric icing is defined as the processes where falling or drifting raindrops, refrozen wet snow, or drizzle form accretions on an object that is exposed to the atmosphere (Ryerson, 2011; Farzaneh et al., 2008). Based on the procedure, feature and physical appearance, atmospheric icing can be categorized as (Ryerson, 2011; SAE, 2002):

- Glaze: This results from precipitating cold-water droplets that hit a surface and freeze upon impact. Up to 270 Metric Tons of glaze ice has been reported on a Canadian platform (Ryerson, 2011; Liljestrom and Lindgren, 1983), with thicknesses of up to 3 cm (Ryerson, 2011; Brown and Mitten, 1988).
- Snow: Snow accumulation up to 136 metric tons has been reported at a depth of 0.3 m on decks (Ryerson, 2011; Liljestrom and Lindgren, 1983).
- Rime: This results from droplets in fog, sea smoke, or cloud drops that hit a surface below 0 °C and freeze (Ryerson, 2011). Fett et al. (Fett et al., 1993) reported an accumulation of up to 10 cm on decks and 30 cm on railings in 12 h.
- Frost: This is the result of direct transformation of water vapor to ice and wet snow. Frost forms on windless clear nights on surfaces facing the sky (Ryerson, 2011).
- Sleet or ice pellets: Formed from raindrops that have been frozen before hitting surfaces, sleet accumulates loosely on horizontal surfaces such as decks, stairs, hatches, and helicopter landing pads (Ryerson, 2011).

In the case of sea spray icing, the sea spray droplets are carried by the wind and hit objects in their way. When the air temperature is colder than the freezing temperature of seawater, approximately around −2 °C, freezing spray occurs (Jones and Andreas, 2012). Waves, volume of spray flux, and salinity of seawater are important factors that affect rate of sea spray. Sea spray accumulation occurrence is very rapid when there are high winds, low air temperature, and low sea temperature.

Sea spray icing on stationary offshore structures differs significantly from sea spray icing on ships. Spray is generated on ships by heaving and pitching as the ship interacts with the waves it is moving through. Platform legs, bracing, blowout-preventer guidelines, mooring chains, marine risers, and flexible kill and choke lines in the splash zone 5–7 m above the sea are some potential areas for sea spray icing accumulation (Ryerson, 2011; Baller, 1983). Jones and Andreas (2009, 2012) developed a model to calculate the icing rate on cylinders with axes perpendicular to the wind direction. For more information, see also Horjen (2015). Fig. 2 shows the potential ice accretion areas on a drilling rig. For detailed information about different types of icing on a rig, see Ryerson (2009).

3. Icing effect on performability concepts

Different types of ice may have different effects on the performability attributes. For example, glaze is not an effective factor for the reliability or sustainability of a staircase in an offshore production facility, but it is a major hazard for safety and maintainability. Here, the effect of icing on performability attributes will be discussed briefly.

Fig. 2. Potential ice accretion areas on a rig (Ryerson, 2011).