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Vessel Icing on the Shtokman FPSO

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Abstract

The main objective of the paper is to create and develop a theoretical model of spray icing on sea vessels and floating oil and gas exploration&production structures and facilities. The main goodness of fit is particular match of the model’s results with vessel records and observations data published in special literature. Besides factors affecting the vessel icing are discussed and methodology of their quantitative accounting is proposed. In the paper authors used study materials from different courses, which were taken by them in the University Centre in Svalbard, University in Stavanger and Gubkin Russian State University of Oil and Gas. We would also like to mention that authors prepared the work in close collaboration, overwhelming majority of issues was discussed and the whole paper represents a result of a joint work and therefore most of the arguable points were highlighted and scrutinized. The work presents mostly analytical approaches but for some integrals calculations special numeric simulation software Maple™ was used. This paper is the first part of Cold Climate Operations research and next part will be dedicated to the winterization challenges.

KEY WORDS: icing; vessels; arctic; marine operations; mathematical models; severe environment conditions.

Introduction

Vessel icing is known to be a serious threat for the vessel stability and possibility of carrying out marine operations in cold regions of high latitude (See Fig. 1). Ice accumulation can easily cause vessel destabilization and capsizing – and there are lot of records of such accidents from the very ancient times up to the last year. On of possible reasons the Kolskaya jack-up capsized as it is discussed now was icing on the platform together with harsh environment conditions.

With regard to the latest news from Gazprom and Shtokman Development A.G. there is a need to reconsider the development concept for the Shtokman field to improve insufficient economy of the project. This anticipates possibility of full subsea production with no floating facilities which has shown good performance on the Ormen Lange, Norway.For the effect of different concept estimations winterization concerns are also important and may put certain limitations on the possible technical solutions.

Despite of the fact that the phenomenon of vessel icing has a long record history it is not well studied and even discussed. The answer to this is the fact that first knowledge of vessel icing was presented by fishermen and marine explorers. And it is quite obvious that they didn’t stay in the area where the vessel was subjected to icing – on the contrary the only rational action to escape was to leave to another location. Nowadays when world-growing demand of hydrocarbons calls for exploration and production in severe Arctic region, the problem of vessel icing has gotten new light. Point here is that during exploration and all the more so production operations we merely can’t leave the location for a very long time (depends on type of activity, for some of them time of planned work is up to 50 years). It means that new methods of icing prevention and de-icing should be invented which is completely impossible without clear understanding of mechanisms of the process.

It should be said up front that some technologies and techniques of ice prevention and de-icing are widely used mostly in aerospace and automobile industries. But vessel icing is yet another phenomenon to study.

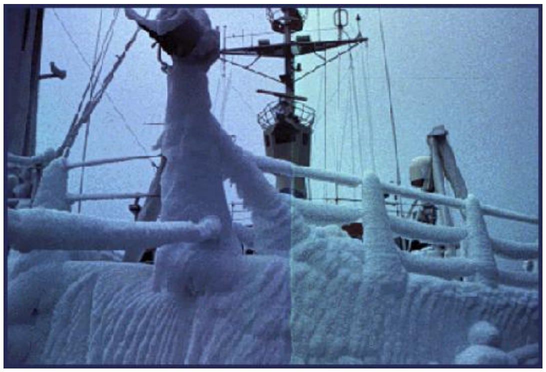


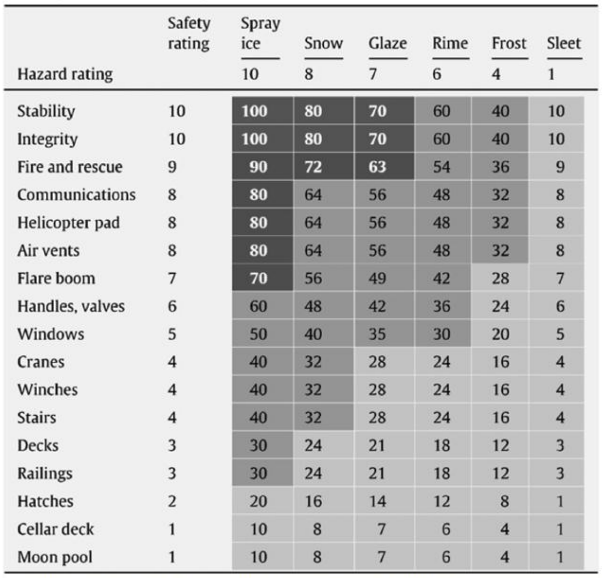
Fig. 1 Vessel icing (Peter Guest, 2008)

Generally icing can be divided into two types: atmospheric and “sea” icing. Spray icing is the greatest hazard for the vessel stability and is discussed in the work.

An overview of ice types (Charles C. Ryerson, 2011):

1. Sea spray (superstructure) ice;
2. Snow can add considerable weight to a platform and contribute to instability of floating platforms;
3. Glaze is a precipitation deposit from freezing rain or freezing drizzle, and primarily affects horizontal surfaces;
4. Rime ice results from super-cooled fog or cloud drops carried by the wind;
5. Frost deposits directly from water vapor onto surfaces;
6. Sleet forms when falling raindrops freeze before hitting surfaces.

In order to give a qualitative estimation of icing hazard on a platform a special cross-tabular methodology was developed by to assess the impact of ice by type (See Table 1).



	Safety rating	Spray ice	Snow	Glaze	Rime	Frost	Sleet
Hazard rating		10	8	7	6	4	1
Stability	10	100	80	70	60	40	10
Integrity	10	100	80	70	60	40	10
Fire and rescue	9	90	72	63	54	36	9
Communications	8	80	64	56	48	32	8
Helicopter pad	8	80	64	56	48	32	8
Air vents	8	80	64	56	48	32	8
Flare boom	7	70	56	49	42	28	7
Handles, valves	6	60	48	42	36	24	6
Windows	5	50	40	35	30	20	5
Cranes	4	40	32	28	24	16	4
Winches	4	40	32	28	24	16	4
Stairs	4	40	32	28	24	16	4
Decks	3	30	24	21	18	12	3
Railings	3	30	24	21	18	12	3
Hatches	2	20	16	14	12	8	1
Cellar deck	1	10	8	7	6	4	1
Moon pool	1	10	8	7	6	4	1

Classification: 70–100 dark grey, 30–69 medium grey, 0–29 light grey.

Table 1. Joint safety impacts by ice type and platform component or function, with large numbers denoting a more serious safety hazard (Charles C. Ryerson, 2011)

The most serious form of icing affecting marine operations is so called spray icing that is created due to seawater droplets accumulating and freezing on the surfaces of structures. Generally there are to main factors to be considered (Charles C. Ryerson, 2011): environmental factors and vessel characteristics.

Environmental factors affecting sea spray icing are (Peter Guest, 2008):

- Wind Speed
- Air Temperature
- Water Temperature
- Freezing Temperature of Water
- Wind Direction, Relative to the Ship
- Swell and Wave Characteristics: wave size, wave length and wave propagation direction.

Vessel characteristics are as following (Peter Guest, 2008):

- Ship Speed
- Ship Heading (with respect to wind, waves and swell)
- Ship Length
- Ship Freeboard
- Ship Handling
- Ship Cold Soaking

Ice protection and de-icing are not discussed in the paper but we would like to give a short overview of some of these techniques with reference to.

A wide variety of technologies are available for deicing, anti-icing, and detecting ice on offshore structures (Charles C. Ryerson, 2011):

1. Chemicals and chemical application;
2. Coatings;
3. Design of the structure exposed to icing;
4. Expulsive systems;
5. Heating measures;
6. Infrared energy is a remote method of delivering heat to an object from an electrically or gas-fired emitter;
7. Manual deicing;
8. Piezoelectric actuators deice by distorting and/or accelerating surfaces sufficiently that the adhesion strength of ice is overcome;
9. Pneumatic boots;
10. Special covers;
11. Windows are a special deicing challenge because of their optical and mechanical requirements;
12. Heating cables.

This paper presents an assessment of spray icing on the vessel through mathematical modeling of the icing process. In the work we tried to describe the processes of icing in different regimes and on different structures. Besides vessel stability reduction in case of icing is studied.

New Mathematical Model of vessel icing

Model assumptions:

- all water droplets are of the same size, but the gap between them in the spray or splash can be different;
- the droplet's movement is described as steady motion and there is no acceleration;
- there is no slipping between water droplets and air;
- the frame of water droplets is fixed, i.e. the relative speed of droplets is equal to relative speed of the wind and therefore to absolute speed of wind;
- the pack of droplets is cubic hexagonal;
- wind profile can be described with power equation;
- vessels can be approximated with rectangles.

In reality water droplets are of different sizes (radius, see Fig. 2) and have random volume distribution. But in order to simplify the calculations in our model we will discuss the water droplets as uniform-sized droplets that form a cubic lattice. Let's assume that the cube's edge length (an element of the lattice, see Fig. 3) is equal to **a**, and that **a** varies with the height.

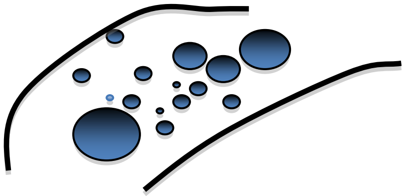


Fig. 2 Real droplet flow

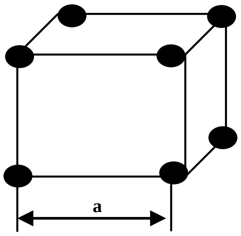


Fig. 3 Pattern element of cubic lattice

Let's introduce $\mathbf{m_1}$ and **r** as the mass and radius of one water droplet. Also we introduce the lattice parameter $\mathbf{\Delta x}$, which is equal to the length of our cube’s face (See Fig. 4).

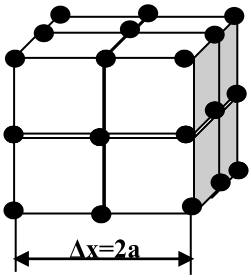


Fig. 4 3-D cubic lattice

Thus the mass of this cube without the mass of the air will be equal to:

$$\Delta m = \left(\frac{\Delta x}{a} + 1\right)^3 m_1 \tag{1}$$

Let's move from microscopic description of the droplet structure to macroscopic introducing **dx**, **dy** and **dz**. We assume that **dx, dy, dz** >> **Δx**. Then the mass of an elementary volume contained in a 3D parallelepiped **dxdydz** is defined as:

$$dm = (\frac{\Delta x}{a} + 1)^3 m_1 \frac{dx}{\Delta x} \frac{dy}{\Delta x} \frac{dz}{\Delta x} \tag{2}$$

Introducing the wind speed **u** and assuming that water droplets move with the wind speed we have:

$$dx = udt \tag{3}$$

Let’s introduce the mass gain for a unit area in the unit time **q**.

$$q = \frac{dm}{dt(dydz)} = (\frac{\Delta x}{a} + 1)^3 m_1 \frac{u}{(\Delta x)^3} \tag{4}$$

After simplification we get:

$$q = (\frac{1}{a} + \frac{1}{\Delta x})^3 m_1 u \tag{5}$$

Using:

$$\frac{1}{a} \gg \frac{1}{\Delta x} \tag{6}$$

and introducing coefficient **n**

$$a = nr \tag{7}$$

we get

$$q = \frac{1}{a^3} u m_1 \tag{8}$$

Presenting droplet mass through the radius and density we get:

$$q = \frac{1}{a^3} u \frac{4}{3} \pi r^3 \rho_w \tag{9}$$

Finally we have:

$$q = \frac{1}{n^3} u \frac{4}{3} \pi \rho_w = \frac{4}{3} \frac{\pi \rho_w u}{n^3} \tag{10}$$

Let's write down the expression for the force acting on the droplet:

$$F = \Delta p S \tag{11}$$

Where S – plane area of a water droplet, $S=Pi*R^2$.

Assuming the droplet frame fixed and using the Bernoulli (See Fig. 5) equation [1] we have:

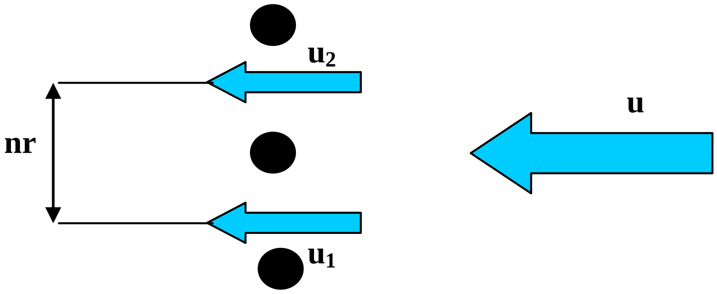


Fig. 5 Air flow through the cubic lattice

$$\Delta p = \frac{\rho_{air}}{2}\left(u_2^2 - u_1^2\right) = \frac{\rho_{air}}{2}\left(u_2 + u_1\right)\left(u_2 - u_1\right) = \frac{\rho_{air}}{2} 2u\Delta u \qquad (12)$$

Using square difference formula we have:

$$\Delta p = \rho_{air} u\Delta u \approx \rho_{air} udu = \rho_{air} uu' dz \qquad (13)$$

Writing **dz** we get:

$$dz = a = nr \qquad (14)$$

$$F = \rho_{air} uu' dz \pi r^2 = \rho_{air} uu' n\pi r^3 \qquad (15)$$

Setting the gravity force acting on the droplet and the pressure difference force equal:

$$\frac{4}{3}\pi r^3 \rho_w g = \rho_{air} uu' \pi n r^3 \qquad (16)$$

Evaluating **n** we get:

$$n = \frac{4}{3}\frac{\rho_w g}{\rho_{air} uu'(z)} \qquad (17)$$

Combining the geometric equation and the forces equation we get the main equation for mass gain for a unit area in a unit time:

$$q = (\frac{3}{4})^2 (\frac{\rho_{air}}{\rho_w})^3 (\frac{uu'}{g})^3 (\pi u \rho_w) \qquad (18)$$

$$q = \frac{9}{16}(\frac{\rho_{air}}{\rho_w})^3 \frac{u^4 (u')^3}{g^3} (\pi \rho_w) \qquad (19)$$

It should be said that for the derivation of this equation a lot of assumptions with different extents of confidence were made. That’s why it is rational to introduce dimensionless deflection coefficient k.

$$q = k \frac{9}{16}(\frac{\rho_{air}}{\rho_w})^3 \frac{u^4 (u')^3}{g^3} (\pi \rho_w) \qquad (20)$$

Taking into account that wind speed changes with height we will follow the power function (from Marine Technology Course by Ove Tobias Gudmestad held at University of Stavanger in Spring 2011 [4])

$$u(z) = u_{hub} (\frac{z}{z_{hub}})^{0.11} \qquad (21)$$

Coefficients are determined for the height of 10 m.
Taking the first derivative with respect to height we get:

$$u(z) = u_{10} (\frac{z}{10})^{0.11} \qquad (22)$$

$$u'(z) = \frac{u_{10}}{10^{0.11}} 0.11 z^{-0.89} \qquad (23)$$

Rewriting:

$$u_{10} = \bar{u} \qquad (24)$$

and substituting in the equation (19) we have:

$$q = k 0.11^3 (\frac{3}{4})^2 (\frac{\rho_{air}}{\rho_w})^3 \frac{\bar{u}^3}{10^{0.33}} z^{0.33} \frac{\bar{u}^3}{10^{0.33}} z^{-2.66} \frac{1}{g^3} \pi \rho_w \frac{\bar{u}}{10^{0.11}} z^{0.11} \qquad (25)$$

After simplification we finally get (See Fig. 6 and Fig. 7):

$$q \approx k 10^{-12} u^{-7} z^{-2.25} \qquad (26)$$

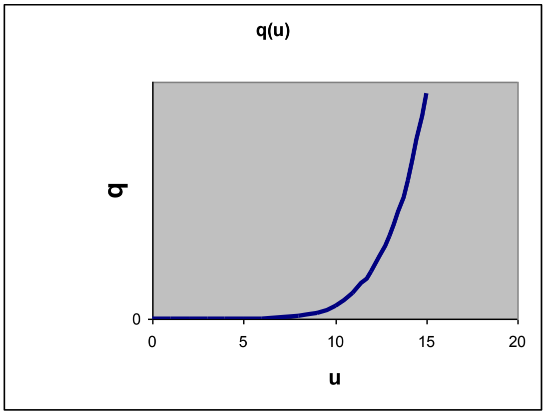


Fig. 6 Dependence of droplets mass flow* on wind speed u (m/s) at constant z (*mass gain for a unit area in unit time)

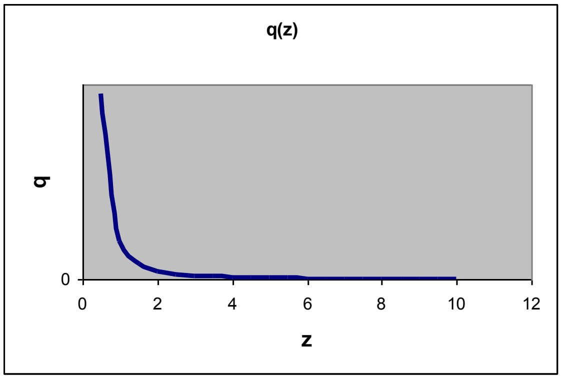


Fig. 7. Dependence of mass flow on height for a constant wind speed

Icing on fixed plate perpendicular to flow

For the geometry of the problem (See Fig. 8) the mass of water droplets hitting the plate can be determined as an integral When t is equal to the time of icing period:

$$m = \int_{0.5}^{h} k10^{-12} u^7 z^{-2.25} btdz \tag{27}$$

$$m = k10^{-12} u^7 bt \frac{z^{-1.25}}{1.25} \Big|_h^{0.5} \tag{28}$$

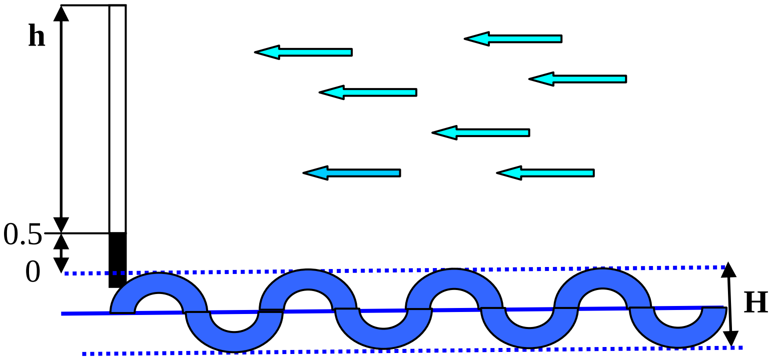


Fig. 8 Droplet flow perpendicular to a fixed plate

It’s important to note here that the integration begins from 0.5 m – this gap above wave crest is selected to avoid influence of splashes and whitecaps in the proximity of the plate. b – width of the plate.

Using experimental data from [6,7] for icing we determine that our deflection coefficient k varies in the limits:

$$k:2-5 \tag{29}$$

Icing on a plate oscillating harmonically in the horizontal plane

This type of motion can represent the heave motion of a vessel in waves.

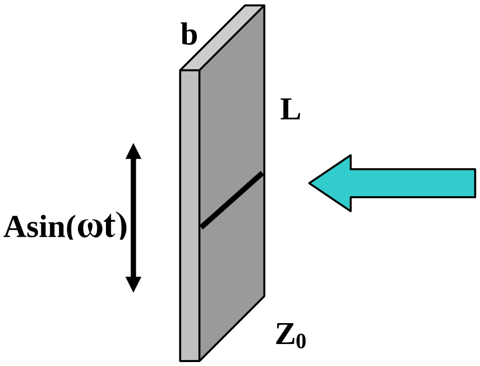


Fig. 9 Droplet flow perpendicular to the a oscillating in the vertical plane

For the geometry of this problem (See Fig. 9) the mass of water droplets hitting the plate can be determined as a double integral:

$$m=\int_0^T dt \int_{Z_0+A\sin\omega t-L/2}^{Z_0+A\sin\omega t+L/2} k10^{-12}u^7bz^{-2.25}dz \tag{30}$$

Evaluating the inner integral we get:

$$m=\int_0^T kb10^{-12}u^7\frac{1}{1.25}((Z_0+A\sin\omega t-\frac{L}{2})^{-1.25}-(Z_0+A\sin\omega t+\frac{L}{2})^{-1.25})dt \tag{31}$$

Such type of integrals can be evaluated numerically. Using the Maple™ software we can get the following plot of the mass’ dependence of the frequency.

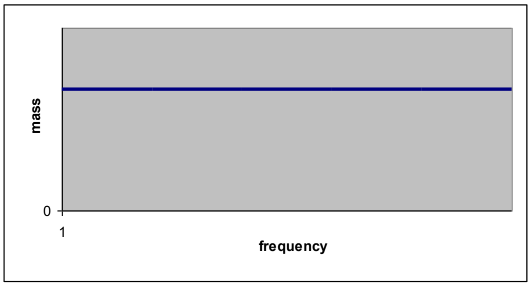


Fig 10. Releationship between wigling frequency and accumulated mass

This result gives the conclusion that the iced mass does not depend (See Fig. 10) on the frequency of the vertical motions of the plate.

Icing on the plate oscillating harmonically with changing angle between the vertical plane and the plate

This type of motion represents (See Fig. 11) the roll and pitch motion of the vessel in the waves.

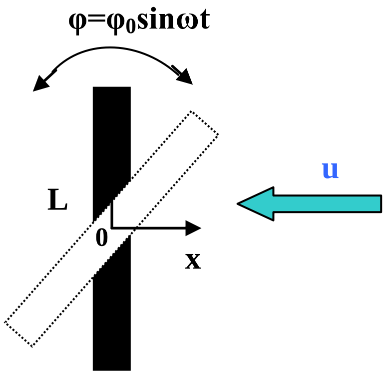


Fig. 11 Plate with harmonically changing angle

Introducing standard geometric nomenclature we get:

$$\phi = \phi_0 \sin \omega t$$

$$x = x_0 \sin \omega t \qquad (32)$$

$$x_0 = y \sin \phi_0$$

Let's determine horizontal speed of the plate points as function **y**:

$$x = y\phi_0 \sin \omega t \qquad (33)$$

$$V_x = y\phi_0 \omega \cos \omega t \qquad (34)$$

It is considered that whilst hitting the plate the total energy of the water droplet transfers in hit energy:

$$e = \frac{m_1 (u + y\phi_0 \omega \cos \omega t)^2}{2} \qquad (35)$$

In the expression the drop's relative speed in the hit moment is taken into account.

Droplets hit energy plays a significant role in the icing process.

Introducing a dimensionless parameter **c** which determines the difference in density of water and water-air-ice mixture we evaluate the energy of hits on a unit area of the plate in a unit time as:

$$dE = edxdydz \qquad (36)$$

$$\frac{dE}{dtdzdy}=\frac{c\rho_w}{2}\left(u+y\varphi_0 cos\omega t\right)^2 \tag{37}$$

Thus the total hit energy in unit time for a plate with width **b** and length **L** can be determined as:

$$\frac{dE}{bdt}=\int_{-L/2}^{L/2}\frac{c\rho_w u}{2}\left(u+y\varphi_0 cos\omega t\right)^2 dy \tag{38}$$

After taking the integral we have:

$$\frac{dE}{bdt}=\frac{c\rho_w u}{6\phi_0\omega\cos\omega t}\left(\left(u+\frac{L}{2}\phi_0\omega\cos\omega t)^3-(u-\frac{L}{2}\phi_0\omega\cos\omega t\right)^3\right) \tag{39}$$

Simplifying the obtained expression the get:

$$\frac{dE}{dt}=bc\rho_w u\left(u^2\frac{L}{2}+\frac{L^3}{4}\left(\phi_0\omega\cos\omega t\right)^2\right) \tag{40}$$

In the case of a fixed plate the total energy of hits in unit time can be determined as:

$$\frac{dE^*}{dt}=\frac{bc\rho_w u^3 L}{2} \tag{41}$$

Then during one wiggling period T the hit energy will be:

$$T=\frac{2\pi}{\omega} \tag{42}$$

$$E_T=bc\rho_w u\int_0^T\left(\frac{L^3}{4}(\phi_0\omega cos\omega t)^2+u^2\frac{L}{2}\right)dt \tag{43}$$

Taking the integral we get:

$$\frac{1}{4}\frac{bc\rho_w u\pi\left(4u^2+L^2\phi_0^2\omega^2\right)L}{\omega} \tag{44}$$

This expression has the minimum corresponding to the minimum hit energy.

$$\omega^* = \frac{2u}{L\phi_0} \tag{45}$$

Moving from the periods towards the total time t (for times significantly exceeding the plate wiggling period) we obtain:

$$E(t) = \frac{L}{8} bc\rho_w u\left(4u^2 + L^2\phi^2\omega^2\right)t \tag{46}$$

Motions of the FPSO and condensate tankers

This chapter discusses the FPSO and tankers that might be used in the Shtokman Project from the point of possible icing issues.

FPSO

Dimensions:

- Length 340 m.
- Width 63 m.
- Draft 18 m.

Heave period – 9.5 sec
Roll period – 10.74 sec
Pitch period – 8.8 sec

The dependence of the heave period of the FPSO on the relative mass (See Fig. 12) of the condensate filling.

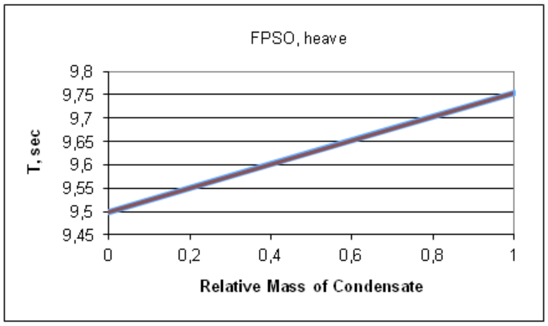


Fig. 12 Dependence of heave period on relative mass

Analyzing the graph we can say that filling up the FPSO with condensate affects the icing just in a small extent. In fact the only thing here that matters is the draft that leads to slight increase of icing.

Two typical charter tankers that might be used in the Shtokman project (Yaroslav Efimov, 2011 [2]):

Tanker PERSEVERANCE

Dimensions

- Length: 228 m;
- Width: 32 m;
- Draft: 8.5 m;
- Board height: 18 m.

Heave period – 6.53 sec
Roll period – 8.35 sec
Pitch period – 6 sec

Tanker Vladimir Tikhonov

Dimensions
- Length: 281 m;
- Width: 50 m;
- Draft: 8.5 m;
- Board height: 18 m

Heave period – 6.53 sec
Roll period – 6.75 sec
Pitch period – 6.06 sec

Analyzing the data we can say that icing on the Vladimir Tikhonov tanker is much more than on the PERSEVERANCE tanker. This is due to the fact that 1) the roll frequency for Vladimir Tikhonov is bigger and 2) the board (front) area is also bigger.

Icing evaluation in case of stepped construction

This case represents icing, for example, on topsides of the vessel when we have several blocks with different height above each other.

Let's assume that ice is accumulated only on horizontal pads and slips off from vertical walls (See Fig. 13).

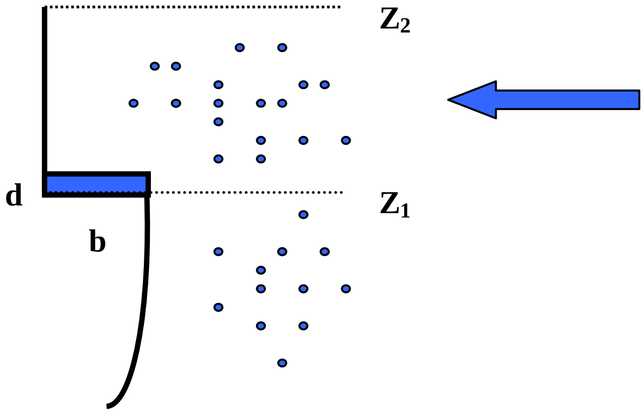


Fig. 13 Sketch of spray icing on the stepped construction (vessel type)

Let's determine the mass of ice accumulated on the horizontal pad in time **t**:

$$m = \frac{k10^{-12}u^7 lt}{1.25}\left(\frac{1}{z_1^{1.25}} - \frac{1}{z_2^{1.25}}\right) \tag{47}$$

The width of accumulated ice can be evaluated as:

$$d = \frac{m}{\rho_{ice} lb} \tag{48}$$

$$d = \frac{k10^{-12}u^7 t}{1.25\rho_{ice} b}\left(\frac{1}{z_1^{1.25}} - \frac{1}{z_2^{1.25}}\right) \tag{49}$$

Methodological instructions of stability estimation in case of severe icing on a vessel and the FPSO icing calculation

Main formulas [4] used for simplified stability estimation for a barge type vessel (See Fig. 14).

$$GM = \frac{d}{2} + \frac{b^2}{12d} - KG' \tag{50}$$

$$d = \frac{M_{vessel} + \sum_{i=1}^{n} M_{ice\ i}}{\rho_w Lb} \tag{51}$$

$$KG' = \frac{M_{vessel} KG + \sum_{i=1}^{n} M_{ice\ i} z_i}{M_{vessel} + \sum_{i=1}^{n} M_{ice\ i}} \tag{52}$$

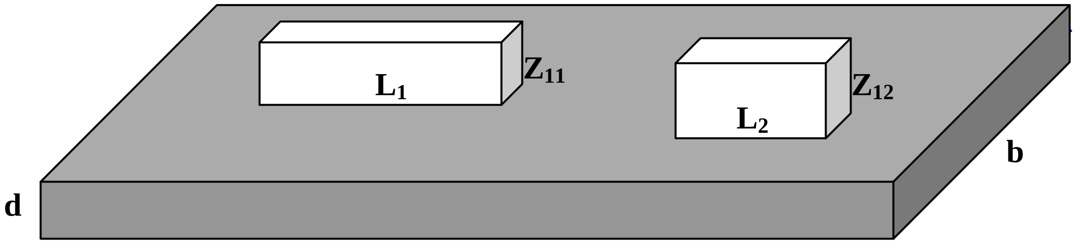


Fig. 14 Sketch of the vessel and deck constructions

Let's re-arrange formulas taking into account that **d** – vessel's draft and Z1i – vertical distance from the keel to the ice accumulation level. Then we have:

$$GM = \frac{d}{2} + \frac{b^2}{12d} - \frac{M_{vessel} KG}{M_{vessel} + \sum_{i=1}^{n} M_{ice\ i}} - \frac{\sum_{i=1}^{n} M_{ice\ i} z_i}{\sum_{i=1}^{n} M_{ice\ i}} \tag{53}$$

Let's examine the numerator of the last term in the expression because it has the biggest influence on the stability.

$$\sum_{i=1}^{n} M_{ice\ i} z_i \tag{54}$$

Introducing coefficient **C**:

$$C = \frac{k 10^{-12} u^7}{1.25} \tag{55}$$

We determine the mass of ice accumulated in time **t**

$$M_{ice\,i} = Cl_i \left(\frac{1}{(z_{1i} - d)^{1.25}} - \frac{1}{(z_{2i} - d)^{1.25}} \right) t \tag{56}$$

Taking into account and summarizing all the places of ice accumulation we get:

$$\sum_{i=1}^{n} M_{ice\ i} z_i = \sum_{i=1}^{n} Ctl_i \left(\frac{1}{(z_{1i} - d)^{1.25}} - \frac{1}{(z_{2i} - d)^{1.25}} \right) z_{1i} \tag{57}$$

By neglecting the term

$$\frac{z_{1i}}{\left(z_{2i} - d\right)^{1.25}} \tag{58}$$

we get that reduction of GM is proportional to:

$$Ct \sum_{i=1}^{n} \frac{l_i}{(z_{1i} - d)^{1.25}} z_{1i} \tag{59}$$

Analyzing the last expression we can distinguish three factors affecting GM reduction and thus the vessel stability:
1 – **time of icing**

$$t$$

2 – **meteorological factor**

$$\frac{k 10^{-12} u^7}{1.25} = const * u^7 \tag{60}$$

3 – **vessel construction factor**

$$\sum_{i=1}^{n} \frac{l_i}{(z_{1i} - d)^{1.25}} z_{1i} \tag{61}$$

More often than not, the blowing and thus the icing of the vessel happens to be from different sides. **The construction factor** can be presented as the perimeter of topsides and equipment: bridge, deck office, towers, etc.:

$$\sum_{i=1}^{n} \frac{P_i}{(z_{1i}-d)^{1.25}} z_{1i} \tag{62}$$

FPSO Icing calculations

Based on proposed model a rough estimation of ice build-up on the FPSO is carried out. So as we have found it out earlier in case of icing od stepped construction:

$$m = k10^{-12} u^7 bt \frac{z^{-1,25}}{1,25}\Big|_{+\infty}^{20} \tag{63}$$

Assuming mean wind speed as 25 m/s and effective FPSO's length as 300 m, we have:

$$m = k10^{-12} 25^7 300t \frac{1}{1,25}\left(\frac{1}{20^{1,25}} - 0\right)t \tag{64}$$

$$m = k0,035t \tag{65}$$

For mean period of possible icing at the site of 100 days we have:

$$m = k0,035 \cdot 3600 \cdot 24 \cdot 100 = k302\, t \tag{66}$$

Taking k – factor as 5 we have that total ice mass that can accumulate at the vessel is about 1500 tonnes.

It should be said that this work is only the first volume of the research authors are intented and eager to continue on vessel icing as a part of Cold Climate Operations for oil and gas E&P activities in Arctic. Next paper will hopefully scrutinize and estimate all known vessel icing models and standards.

Conclusions

The article presents a new quantitative model of vessel icing. In the course of it the following results were drawn based on the work presented in this paper:

1. A theoretical model based on a geometric and force analysis of water droplets in the air is proposed;
2. A problem of icing on a fixed plate is solved;
3. A problem of icing on a plate wiggling harmonically in vertical plane is solved. Independence of iced mass on the frequency of vertical motions is proved;
4. A problem of icing on a plate wiggling harmonically in horizontal plane is solved. A quadratic dependency of water droplets' hit energy on the frequency of motions;
5. A correction coefficient for model and observed data is proposed. As it is in a range from 2 to 5 we can say that the model is adequate;
6. Motions of floating production storage and offloading structures of the Shtokman field on waves are discussed, their frequencies and affects on the icing processes are analyzed;
7. Evaluation of icing process on stepped constructions is carried out. Stepped constructions approximate real vessels with deck housings and structures, bridges and equipment;
8. Vessel stability evaluation in case of icing is carried out, changes of vessel's GM in case of icing is discussed;

9. The factors affecting on the vessel stability in case of potential icing are proposed – time factor, meteorological and construction factors.

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