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WATER CIRCULATION TO IMPROVE THE QUALITY OF PORT ICE MANAGEMENT

Abstract: *Nowadays a lot of projects take place in cold arctic environment. Ice floe is significant obstacle for ports, docks and other coastal constructions in the arctic areas and areas with seasonal ice cover. To ensure continues operations of such ports and constructions heating is suggested by some scientists. Heating is a highly energy consumable process. To decrease the energy waste and therefore costs of the construction operations the heating can be performed by mixing of the water in the target water basin water with warmer water from the sea. The difference in the water temperatures can be only a few Celsius degrees; however, it can be enough to prevent ice formation at the considered water basin. In this case the energy is required only for the water transportation and therefore is more economically reasonable than direct heating. The amount of the water to be transported is estimated accordingly to the amount of thermal energy losses from the target basin. The key energy losses occur through the open water surface, and submerged constructions/vessels. If the water basin is relatively big then a big inflow of the energy with water is required and therefore significant currents can occur. Maximum allowable current at the considered basin establishes the limitation of the method. Water circulation at the closed basin can improve quality of ice management.*

Keywords: *Arctic construction, arctic engineering, ice cover, port heating, ice melting, water circulation.*

1. Introduction

Ocean and maritime waterways take an important role in the modern world. Huge part of the world cargo traffic is transported by vessels. Some island countries are fully dependent on their transport fleet. The demand for new ports is constantly increasing all over the world. To establish new transport route or/and develop mineral deposits in the arctic areas engineers construct new facilities (ports, docs, etc.) to resist severe cold environmental conditions. Ice is possibly most important factor for such constructions. Ice covers the water basin and prevents normal operations such as cargo loading/unloading and vessel maneuvering (S Loset & Marchenko, 2009). Moreover, ice loads are relatively big comparing to other loadings and therefore special design to resist ice loads is required for arctic constructions. Some constructions use sloped design to reduce ice loads, however it is not suitable for port moorage walls. Action from the ice is also one of the most uninvestigated actions (Frederking, 2012), (Timco & Croasdale, 2006). Costs of the special design and final construction can be significantly

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high comparing to constructions in warm waters (S. Loset, Shkhinek, Gudmestad, & Hoyland, 2006), (Gudmestad et al., 2007). However, the building of such constructions can be economically reasonable depending on the amount of commodity circulation.

The same problem exists for the seasonal ice-covered water basins. Commodity circulation through facilities located in such water basins during cold season can secure cost-effectiveness of the ice preventive measures at the water basin. For some areas the possible trade and transport way can be constructed only in region with ice cover regardless of being economically feasible.

One of the solutions for the ports in cold environment is to develop a number of measures to avoid ice accumulation (Sharapov, Shkhinek, & DelValls, 2016) near the important facilities such as moorage walls, insight dock space, water gates, etc. The variety of the measures is available. They include special covers, heating, mechanical removal of ice (Tsinker, 1995), (ISO-19906, 2010), (SNiP-2.06.04-82, 1989), (SP38.13330.2012, 2012), (RMRS, 2008). The article describes the idea of using the water from the basin to heat and remove the floated and accumulated ice from the target areas. Such approach can improve the quality of ice management at the port water basin if the temperature gradient in water is high.

2. Task statement

2.1. Heat carrier

Currently one of the most popular ways to remove ice is to use mechanical methods for demolition and replacing of the ice fragments. However, the obstacles occur when continuous operation of the moorage wall is required (constant flow of vessels) or when the ice removal is not possible (closed dock). Ice removal is also complicated for the area between vessel and moorage wall during groundage. To facilitate ice removal from the moorage wall some researchers suggest using heating coils (Sharapov, Shkhinek, & DelValls, 2015). The method provides required effect but is very energy consumable. Certain measures to save the demanded power will allow using heating widely.

Using natural temperature difference at the considered area is a solution which will allow heating the moorage wall by minimum energy spending. By using this approach the energy is required not for the heating but for the transportation of the heat carrier to the target object. The final task is to provide a method to estimate the possibility of the bottom water use for the heating of the target object (e.g. dock).

2.2. Principal scheme

Ice starts to grow from the water surface during cold air temperatures (McGuinness, 2009). Thermal isolation of the water below ice is increased with ice thickness and therefore the speed of the ice formation is decreasing (Meirmanov, 1992). The water under the level ice has temperature above freezing point. The water temperature profile is changing with depth and local features of the particular site. The principal scheme is presented in the Fig.1.

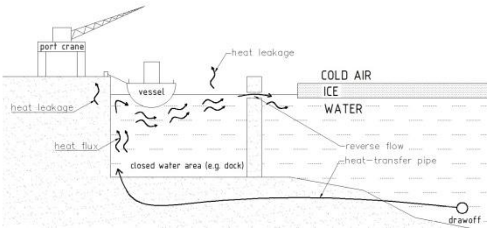

Figure 1. The principal scheme of the heat stream

The principal scheme includes the water drawoff, pump station and pipeline to the considered closed water basin. The drawoff for the water intake should be located at the appropriate depth to secure positive water temperature. Water is transported by pipeline to the basin. As temperature of the transported water is above freezing point it prevents wide ice formation at the basin. Constant and sufficient water flow should supply enough thermal energy to replace the energy leakage into the air and surroundings.

3. Heat flow calculation

Calculation of the water flow is based on the thermo-balance equation. To fix the temperature in the water basin above freezing point (avoid ice formation) the amount of the incoming energy (with water flow) should be equal or above the loss of energy into the air and surrounding structures. Consideration of the one linear meter of the construction/moorage wall simplifies equations for the calculations.

3.1. Surface energy losses

The loss of the energy in the air from the water basin is key factor for the calculation. The loss of the energy from the water surface can be estimated by Eq.1.

$$Q_{air,outflow} = a \cdot S \cdot (t_{surface} - t) \quad (1)$$

where

a – surface heat emission factor to air;

S – emission surface area;

t – air temperature;

$t_{surface}$ – water surface temperature;

Surface heat emission factor depends on the air circulation near the water surface and can be estimated with Eq.2.

$$a = (4.9 + 3.5 \cdot v) \cdot 4.2 \, \frac{kJ}{h \cdot m^2 \cdot ℃} \quad (2)$$

where

v – velocity of the air near the water surface.

For the calculation it is possible to substitute the wind speed, however velocity profile should be taken into account. The representation of the considered parameters for the estimation of the energy loss through the water surface is presented in the Fig.2.

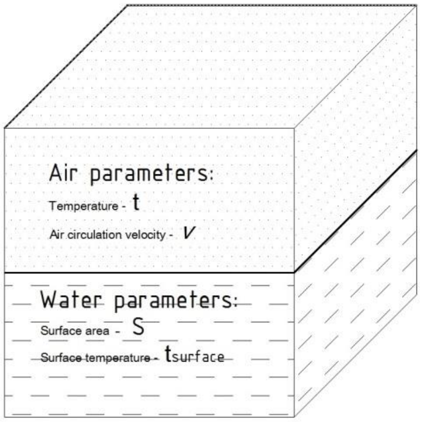

Figure 2. Parameters for the estimation of the energy loss through water surface

The ratio of the energy loss through water surface to other energy loss in the model is increasing with surface area. For the big water basins the losses through surrounding structures can be neglected, however big water areas require for big energy inflow and therefore significant water currents can occur. Therefore the water basin volume limitation exists.

3.2. Bottom and side energy losses

Normally temperature of the water basin bottom at the significant depth is steady-state value due to constant heat flux from the Earth interior and permanent contact with the water layer. This temperature can be measured. Bottom temperature in cold seas usually is a few Celsius degrees warmer than water surface due to water density dependence on the temperature. The example of water density profile is presented in the Fig.3.

As it is seen from the figure, the water density profile has extremum above freezing point. Temperature of maximal density of sea water is calculated with Eq.3, where salinity is measured in ppt (Dietrich, Kalle, Krauss, & Siedler, 1980). Dense water flow down and as a result the bottom layer has temperature corresponding to the maximum on the water density profile.

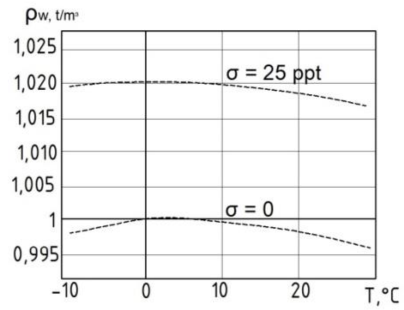

Figure 3. Sea water density depending on the temperature

$$T_{\max density} = 3.98 - 0.229 \cdot \sigma \ (℃) \quad (3)$$

Considering constant heat influx from the Earth interior and the fact that cold water from beneath the level ice does not go down to the bottom layer (as water at the bottom has bigger density) it is possible to assume that heat energy outflow through bottom is neglectful for defined water basin.

Lateral heat outflow is absent in the ideal model. Continues temperature isolines go through the soil and water layers along the Earth surface (Fig.4.). Therefore any vertical section will cut the matter into two parts and each point at the first part will correspond to the equal point with the same temperature at the second part. Therefore no temperature gradient exists and no heat flux occurs.

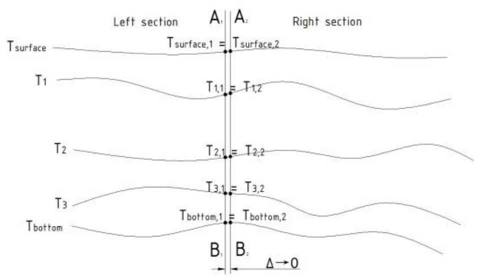

Figure 4. Temperature isolines in the earth and water layers

3.3. Heat fluxes

Heat fluxes can be divided into two groups: inflow and outflow (Fig.5).

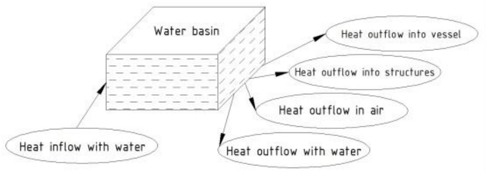

Figure 5. Principal Scheme of the heat transport in the water basin

Heat inflow is organized by continues water income with temperature above temperature in the target water basin. Main heat outflow is heat outflow to the cold air. The value of this outflow can be changed by ice/snow cover or vessel. Ice and snow is not considered in the project, as the goal of the project is to prevent ice formation. However, vessel influence on the heat flow should be considered. In one hand vessel decreases the surface area and therefore the heat outflow is decreasing. In the other hand vessel walls provide a “bridge” for the energy to escape from the basin into the air. Similar “bridges” occur when any steel/concrete cover or structure submerged in the water. The energy balance equation is presented below (Eq.4).

$$Q_{water,inflow} = Q_{air,outflow} + Q_{vessel,outflow} + Q_{structure,outflow} + Q_{water,outflow} \quad (4)$$

where

$Q_{water,inflow}$ – energy transported by water inflow into the heated water basin;

$Q_{air,outflow}$ – energy loss through the open water surface from the heated water basin;

$Q_{vessel,outflow}$ – energy loss from the water basin through the vessel;

$Q_{structure,outflow}$ – energy loss from the basin through the submerged into the water basin structures;

$Q_{water,outflow}$ – energy outflow with excess water. $Q_{water,outflow} = 0$ for the ideal scenario. This mean that transferred energy was unleashed in the water basin and water escapes the basin with the temperature equal to freezing point. However in real process

$Q_{water,outflow}$ should be above zero to avoid possible ice formation.

$Q_{vessel,outflow}$ and $Q_{structure,outflow}$ occur due to the similar phenomena and therefore the value estimation is similar. For the vessel the key factor is the thickness of the steel wall. Thicker steel can transport more thermal energy from under the water into the air and therefore cool down the water basin. For the structure the important is to estimate the amount of heat transfer through the steel and concrete constructions. Numerical modelling should be used for the precise estimation. However, rough estimation can be done based on the general parameters such as thickness of steel cover.

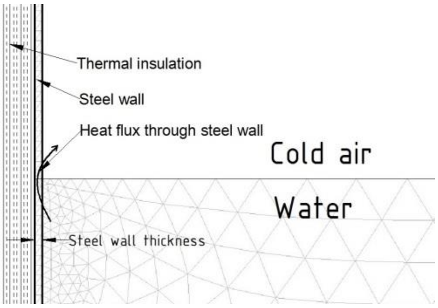

Figure 6. Scheme of heat transfer through submerged steel wall

The heat flux is estimated at the horizontal section through steel wall at the water surface level. As the thickness of the horizontal section vanish, therefore at the initial moment of time the heat through steel pass zero distance from the water into the air. Consequently, calculated heat flux is high. However, after ice on the water surface is formed, the heat energy starts to go through nonzero distances in the steel and real values obtained. The heat transfer value decreasing with time as ice grows and therefore the distance of the heat transfer is increasing (Asaithambi, 2007), (Salva & Tarzia, 2011), (McGuinness, 2009).

For the current project the ice should not be considered as the goal is to prevent it formation. However, for the accurate calculation of the heat energy flux through steel it should be introduced to obtain correct values. The calculations are conducted depending on the time (Fig.7). Heat flux decreased during calculation. For the further estimation probable value should be chosen. For the steel of 2 cm thick the heat flux can be approximately three watts for linear meter.

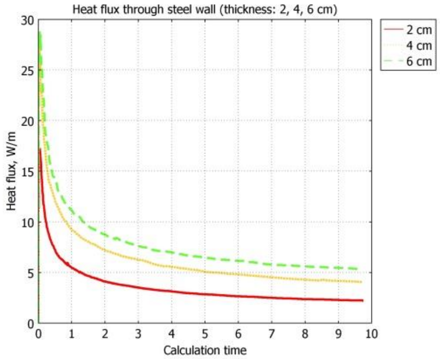

Figure 7. Heat flux values through submerged into water steel wall

4. Water flow

Estimation of the required water flow to supply energy influx depends on the number of parameters. They are surrounding structure properties, vessel and environmental conditions. Vessel absence can be assumed for the general calculations. In this case no energy loss through vessel exists and the water surface area occupied by vessel is zero. For the rough estimation the necessary energy influx into water basin assumed equal to losses in the air. The water flow volume can be estimated by Eq.5.

$$V = \frac{Q_{water,inflow}}{\rho_{water} \cdot \Delta t_{water} \cdot C_{water}} m^3 \qquad (5)$$

where

$Q_{water,inflow}$ – required energy influx into the water basin;

ρ_{water} – water density, $\rho_{water} = 1020 \frac{kg}{m^3}$;

C_{water} – water thermal capacity, $C_{water} = 4132{,}5\, J/kg°C$;

Δt_{water} – temperature difference between water freezing point and the temperature of the inflow water, $\Delta t_{water} \approx 2°C$ for rough estimation.

Fig.8 presents simplified 2D solution for the water volume influx (m^3/h) for one linear meter of the construction depending on the water basin width for different air circulation velocities.

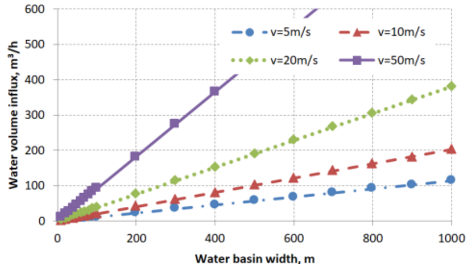

Figure 8. Water volume influx depending on the water basin width for different air circulation velocities (air temperature *t = -10°C)*

As it is seen from the Fig.8, the maximum water flow limitation should exist and therefore the maximum width of the water basin to be heated by water circulation can be defined. This limitation is provided by significant currents in the water basin when the required heat influx is big and therefore the inflow water volume is big.

Water volume inflow depending on the air temperature is presented in the Fig.9. Water inflow dependences on the water basin width and air temperature are linear as it is seen from the Fig. 8, 9. Lower air temperatures correspond to higher water volume influx.

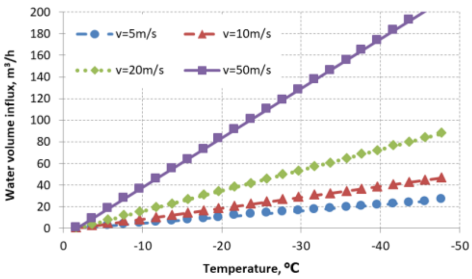

Figure 9. Water volume influx depending on the air temperature for different air circulation velocities (basin width 50 m)

5. Conclusion

Coastal constructions in the areas with cold arctic climate require for special design. To avoid ice grow and accumulation on the structure and water surfaces number of measures can be implemented. Heating of the limited water area can solve the ice accumulation problem. Heating requires for a significant energy spending. Other possibility is to heat the limited water basin by using warmer water from the neighboring sea. In this case the energy spends on the water pumping from the sea and the total energy spending is less.

The method to estimate the required water flow is based on the energy balance equation. The amount of energy losses should not exceed the amount of the energy income. Energy losses occur due to number of parameters. The rough estimation of the energy loss can be based on the assumption that energy loss occurs only from the open water surface.

Significant water surface area leads to the big energy loss through it. Therefore, significant warm water inflow will be required to replace the energy loss through water surface. Big water inflow can create significant water current at the water basin. Therefore, the limitation of the heating method applicability exists.

Precise estimation of the required water inflow required for the all energy losses to be included into the calculations. Except energy loss through the water surface those are losses through submerged constructions, vessels, water outflow. Losses through vessel are significant for the consideration but should be calculated for prescribed vessel type. Vessel presence decreases open water surface and should be included into the calculations.

To save the thermal energy the isolation of the warm water supply pipe should be performed. The efficient of the method depends on the difference between water freezing point temperature and "warm" water from the sea. Possible temperature difference is about 2°C. Different water layers at the sea can have different salinity. This should be taken into account as it is influence on the freezing point and density of the water.

Artificial water current at the limited water area can be used for the ice floe and floated ice blocks removal. Special design of the extra water discharge holes should be done to remove ice blocks by water current. However, the ice located between vessel and moorage wall is hard to remove.

To ensure the quality and effectiveness of the method, it must have a significant margin of power.

6. Acknowledgment

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Appendix

Data for calculation of water volume influx depending on the water basin width for different air circulation velocities

t = -11.7 ℃ – air temperature;
$t_{surface}$ = -1.7 ℃ – water surface temperature;
ρ_{water} – water density, $\rho_{water} = 1020\frac{kg}{m^3}$;
C_{water} – water thermal capacity, $C_{water} = 4132{,}5\, J/kg$℃;

air circulation velocities, m/s	surface heat emission factor	water basin width, m	loss of the energy from the water surface, J	water flow volume, m^3/h
5	94,08	10	9408	1,138294
5	94,08	20	18816	2,276588
5	94,08	30	28224	3,414882
5	94,08	40	37632	4,553176
5	94,08	50	47040	5,69147
5	94,08	60	56448	6,829764
5	94,08	70	65856	7,968058
5	94,08	80	75264	9,106352
5	94,08	90	84672	10,24465
5	94,08	100	94080	11,38294
5	94,08	200	188160	22,76588
5	94,08	300	282240	34,14882
5	94,08	400	376320	45,53176
5	94,08	500	470400	56,9147
5	94,08	600	564480	68,29764
5	94,08	700	658560	79,68058

5	94,08	800	752640	91,06352
5	94,08	900	846720	102,4465
5	94,08	1000	940800	113,8294
5	94,08	2000	1881600	227,6588
5	94,08	3000	2822400	341,4882
5	94,08	4000	3763200	455,3176
5	94,08	5000	4704000	569,147
5	94,08	10000	9408000	1138,294
10	167,58	10	16758	2,027586
10	167,58	20	33516	4,055172
10	167,58	30	50274	6,082759
10	167,58	40	67032	8,110345
10	167,58	50	83790	10,13793
10	167,58	60	100548	12,16552
10	167,58	70	117306	14,1931
10	167,58	80	134064	16,22069
10	167,58	90	150822	18,24828
10	167,58	100	167580	20,27586
10	167,58	200	335160	40,55172
10	167,58	300	502740	60,82759
10	167,58	400	670320	81,10345
10	167,58	500	837900	101,3793
10	167,58	600	1005480	121,6552
10	167,58	700	1173060	141,931
10	167,58	800	1340640	162,2069
10	167,58	900	1508220	182,4828
10	167,58	1000	1675800	202,7586
10	167,58	2000	3351600	405,5172
10	167,58	3000	5027400	608,2759
10	167,58	4000	6703200	811,0345
10	167,58	5000	8379000	1013,793
10	167,58	10000	16758000	2027,586
20	314,58	10	31458	3,806171
20	314,58	20	62916	7,612341
20	314,58	30	94374	11,41851
20	314,58	40	125832	15,22468
20	314,58	50	157290	19,03085
20	314,58	60	188748	22,83702
20	314,58	70	220206	26,64319
20	314,58	80	251664	30,44936
20	314,58	90	283122	34,25554
20	314,58	100	314580	38,06171
20	314,58	200	629160	76,12341
20	314,58	300	943740	114,1851
20	314,58	400	1258320	152,2468
20	314,58	500	1572900	190,3085

20	314,58	600	1887480	228,3702
20	314,58	700	2202060	266,4319
20	314,58	800	2516640	304,4936
20	314,58	900	2831220	342,5554
20	314,58	1000	3145800	380,6171
20	314,58	2000	6291600	761,2341
20	314,58	3000	9437400	1141,851
20	314,58	4000	12583200	1522,468
20	314,58	5000	15729000	1903,085
20	314,58	10000	31458000	3806,171
50	755,58	10	75558	9,141924
50	755,58	20	151116	18,28385
50	755,58	30	226674	27,42577
50	755,58	40	302232	36,5677
50	755,58	50	377790	45,70962
50	755,58	60	453348	54,85154
50	755,58	70	528906	63,99347
50	755,58	80	604464	73,13539
50	755,58	90	680022	82,27731
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50	755,58	600	4533480	548,5154
50	755,58	700	5289060	639,9347
50	755,58	800	6044640	731,3539
50	755,58	900	6800220	822,7731
50	755,58	1000	7555800	914,1924
50	755,58	2000	15111600	1828,385
50	755,58	3000	22667400	2742,577
50	755,58	4000	30223200	3656,77
50	755,58	5000	37779000	4570,962
50	755,58	10000	75558000	9141,924