EVALUATION OF ICE CONDITIONS OF THE NORTHERN OB BAY ASSOCIATED WITH CONSTRUCTION OF THE PORT OF SABETTA

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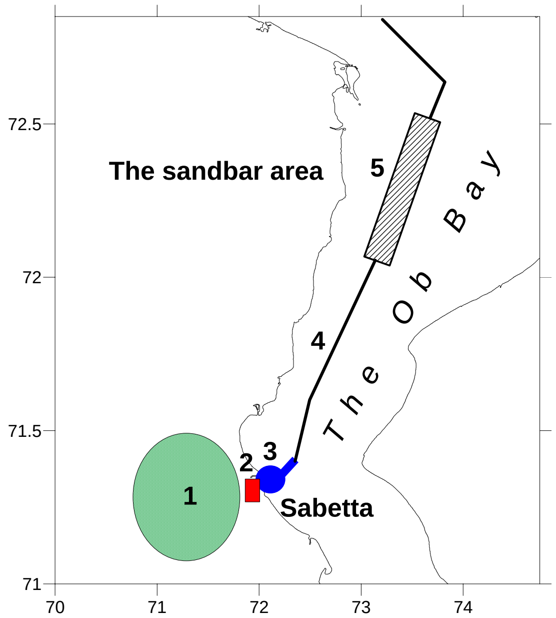
ABSTRACT
To export the liquefied natural gas (LNG) from the region of the South Tambey Deposit, the construction of port was initiated nearby the Sabetta settlement (NE coast of the Yamal peninsula, Russia). The designed port (the largest and the only one at the moment in the northern part of the Ob Bay) will allow all-the-year-round export of LNG by the Northern Sea Route to the west and to the east. Operational regime of port supposes LNG carriers will come there to get loaded with regularity of 1-2 days. AARI has been involved into the Yamal projects since mid- 2000s and during this period a series of winter and summer expeditions having their aim to study a wide range of ice and hydrometeorological processes and phenomena were carried out. Along with that the works on analysis of archive data and simulation of natural processes were carried out. AARI's comprehensive surveys on ice conditions in the northern Ob Bay are of high importance for practical needs that are focused on development of the port infrastructure, maintenance of all-the-year-round navigation and designing of ice-class vessels. Special attention is paid to protection of the port water area from possible negative effects of the ice cover, wind waves and lithodynamical processes.

INTRODUCTION
The present paper is based on results of multi-year (2005, 2010-2012) field studies and analytical investigations of Ob-Taz region where there are tens of oil and gas fields including South Tambey deposit. The strategy of its development implies use of the port of Sabetta and continuous outflow of liquefied gas to national and foreign customers. Prospects of transportation volumes for the port of Sabetta have been estimated up to 2025-30 and shown in table 1. The general layout of the fields and adjacent areas of the Ob Bay is presented in fig. 1. The core tactical issue is to support design and construction of the port of Sabetta by input data on natural conditions. Tactical problems are solved by means of field studies and analytical investigations using mathematical and physical simulation.

Table 1. Prospective transportation volumes for the port of Sabetta

Product	2016	2017	2018	by 2025-30
Liquefied natural gas (LNG), mln ton /year	5	10.5	16	Up to 25
Condensed gas, thousand ton /year	450	950	1350	Up to 2200



1 – South Tambey Deposit
2 – the LNG plant
3 – the port of Sabetta with the access channel
4 – the navigation channel
5 – the sea channel in the sandbar of the Ob Bay

Figure 1. The layout of the basic fields and structures in the Northern Ob Bay.

The paper shows some investigation results of the Northern Ob Bay obtained by AARI under the commission of JSC "NOVATEK" affiliate companies (JSC "Yamal LNG", "NOVATEK – Yurkharovneftegas" Ltd. etc.) in 2005-2012. Detailed and complete data were provided in the presentation [Zubakin et al., 2012].

Objectives of work:

- Evaluation of ice conditions for design of Sabetta port and transport infrastructure in the Northern Ob Bay based on historical archives and data of the field studies,
- Simulation of ice conditions and means of their surmounting.

In order to fulfill the objectives the following issues are to be considered and implemented:

1. Brief natural-climatic characteristics of the Northern Ob Bay
2. Ice conditions of the studied area based on archive sources and data of the field studies
3. Simulation and calculation of ice channels in the Northern Ob Bay and evolution of ice cover in the port of Sabetta
4. Simulation of heating processes for the port water area.

BRIEF NATURAL-CLIMATIC CHARACTERISTICS OF THE NORTHERN OB BAY

The studied area of the Northern Ob Bay is located within 71º00'N and 72º54'N and between the 71º23'E and 76º00'E. There are the following particularities of the region:

- Quite a small width (60-75 km) and shallow depths (10-20 m),
- Polar night and polar day,
- Irregular amount of incoming solar radiation during the year,
- Considerable duration of the ice period (on the average 290 days).

Total amount of negative temperatures (i.e. accumulated degree days) in a certain region is the basic indicator of severity of natural conditions. In Sabetta port area this value comprises about 4100-4200 degree days of freezing on the average and up to 5770 during a cold winter (according to the data of Tambey hydrometeorological station). For comparison one could provide values of this parameter for the areas subjected to theoretical and/or practical research on protection of water areas against freezing [Hüffmeier et al., 2008; Makitalo, Sandkvist, 1985; Pan, Eranti, 2009 etc.] as well as similar Russian seas:

- Norwegian fiords, the Gulf of Finland – 500÷1000 degree days of freezing;
- Southern coast of Greenland, Murmansk – about 1000 degree days of freezing;
- The Northern Gulf of Bothnia (the port of Piteo, Sweden), Great Lakes, the river of St. Lawrence (USA, Canada), North-Eastern coast of Kola Peninsula (the port of Teriberka), the White Sea - 1000÷1500 degree days of freezing;
- Melville Island (the Canadian Arctic) - 6400÷6500 degree days of freezing.

A period of negative air temperatures represents a significant parameter. For Sabetta it amounts to about 240-270 days. One should mention that Melville Island is characterized by the analogous parameters; as regards the other regions (locations) periods of negative air temperatures are shorter.

The other important meteorological conditions of the ice period which influence a degree of ice cover development include air temperature (from October to June the range of average temperatures is [-6 ÷ -26ºC], predominance of winds of southern directions including rather strong ones (Vav=5÷7 m/s, Vmax=35÷40 m/S), cloudiness, snow cover etc. Table 2 provides average monthly values of the basic meteorological parameters for the area of Tambey hydrometeorological station (which is located 30 km to the north of Sabetta settlement).

Table 2. Average monthly values of the basic meteorological parameters based on multi-year observations, Tambey hydrometeorological station

Parameter	Months									
	IX	X	XI	XII	I	II	III	IV	V	VI
Air temperature, ºC	2.5	-0.1	-15.5	-20.7	-24.6	-26.2	-24.2	-16.0	-7.3	0.7
Wind speed, m/s	6.4	7.0	6.9	6.9	6.8	6.3	6.3	6.6	6.8	6.3
Relative humidity, %	89	89	86	85	83	82	83	85	87	90
Snow height, cm	-	8	14	20	24	28	31	34	34	5

High importance is attached to a direction of wind flows during freezing and breaking up of ice when there is drift ice. If in autumn period ice thicknesses are small during break-up (June-July) the sizes and

and thickness of rather strong ice floes constitute a basis for protection of the port waters. In June-July 40-60 % of winds have a northern component. Taking into account the direction of reverse-oriented tidal ice drift a situation occurs which require efficient design solution. It was a substantiation of ice-breaking dams from the north and south of the port water area.
According to average multi-year data in winter period in the area of Sabetta port the temperature and salinity of water in the surface layer amounts to about -0.4ºC and 6-8 ‰, in the bottom layer -0.8ºC and ~19 ‰, respectively. In summer period everything is different. In the port area there is fresh water throughout the flow bulk, the above mentioned thermocline and halocline tend to shift to the north, to the area of Drovyanoy Island, i.e. almost a sandbar zone of the Ob Bay. The existence of a hydrofront in the Northern Ob Bay and its seasonal changes are understudied. One should highlight its fundamental property – the hydrofront is the main marginal filter component of the estuary area of the Ob Bay. Substances deposited after filtering form bottom and costal relief shapes under the influence of waves, tidal and wind currents.
Considerable tidal and wind currents are observed in the port area, however taking into account the construction of the prospective dams (according to the project) their values in the port are should plummet. Moreover, one should mention the influence of the fresh water discharge of the Sabetta-Yakha River leading to earlier periods of autumn and spring ice phases in the estuary area compared to adjacent waters. In particular, it is the river estuary which is the earliest water area to free from ice cover. The river discharge also causes intensified water dynamics in the near-estuary part during the spring flood time (on the average – in June-July).

ICE CONDITIONS OF THE STUDIED AREA

Table 3 shows for comparison phases of autumn and spring ice phenomenas for a number of hydrometeorological stations of the Ob Bay. Geographical locations of the stations are given in fig. 2. Tambey hydrometeorological station located 30 km to the north is the closest station to the port of Sabetta.

Table 3. Average characteristics of ice phenomenas in the Northern Ob Bay based on hydrometeorological stations data

Ice Phase	Drovyanoy	Tambey	Seyakha
Stable state of floating ice	4.X	9.X	10.X
Formation of fast ice as far as the horizon	15.XI	30.X	30.X
Autumn ice drift period, days	41	21	20
Duration of ice period, days	294 ± 31	291 ± 31	286 ± 28
The date of the first ice break-up	6.VII	6.VII	7.VII
The date of final freeing from ice	25.VII	27.VII	21.VII
Spring ice drift period, days	19	21	14

There is no need to explain the data given in table 3 but it is noteworthy that ice period duration in the area of Sabetta port (Tambey hydrometeorological station) comprises 291 days. Complete freezing is observed in almost all stations by November. The first ice break-up in Tambey region was observed in the first 10 days of July, the complete water opening (ice-free) – in the third 10 days of July. The most difficult and dangerous period for hydrotechnical structures - spring ice drift period – lasts for 2-3 weeks. Drift ice consists of bits of broken fast ice of northern and partly middle parts of the Ob Bay, ice floes of various sizes and small floes. The southern Ob Bay opens 20-30 days earlier than the northern part and ice melts in place.
Ice thickness, mainly of fast ice, belongs to other important elements of ice regime. The presence of the ice cover for the perod of 290 days is a reason to consider the ice as a “navigational environment”. Based on understanding of this environment and awareness of its parameters the task of continuous shipping for outflow of LNG with shipment discreteness of 40 hours was set during Sabetta port design and construction of facilities for LNG loading.
Fig. 2 shows distribution of ice thicknesses in the period of its maximum development (late April). Local peculiarity of ice thickness distribution is associated with the middle part of the Ob Bay from the cape Kamenny to the cape Poruy. The area is characterized by the thickest ice within 800-km of Ob Bay, from the cape Drovyanoy to the cape Yam-sale. It seems to be ice response to the closed area of low temperatures. Is it true? Climatic reference books containing data from the hydrometeorological stations

in this and near-by regions do not show such an extremum. Explanation is the following. The effect is a subsequent implication of the hydrofront shift in autumn-winter period and blocking of heat flows from the bottom to the surface.

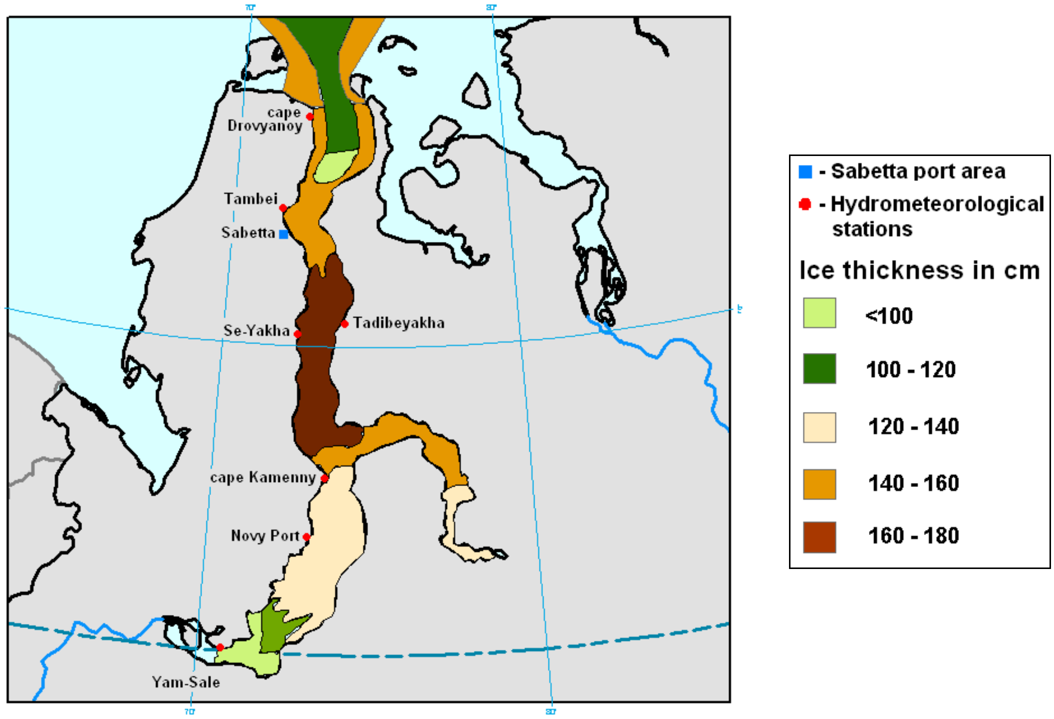


Figure 2. The scheme of characteristic ice thickness distribution in late April in the Ob Bay.

The third important consequence of sea water presence and "pumping" of the hydrofront is the presence of a polynya at the entrance to the Ob Bay (fig. 3). Depending of meteorological conditions, direction of winds, heat content of sea waters at the bay-sea boundary location of the southern border of the polynya is very variable [Nalimov et al., 2008].

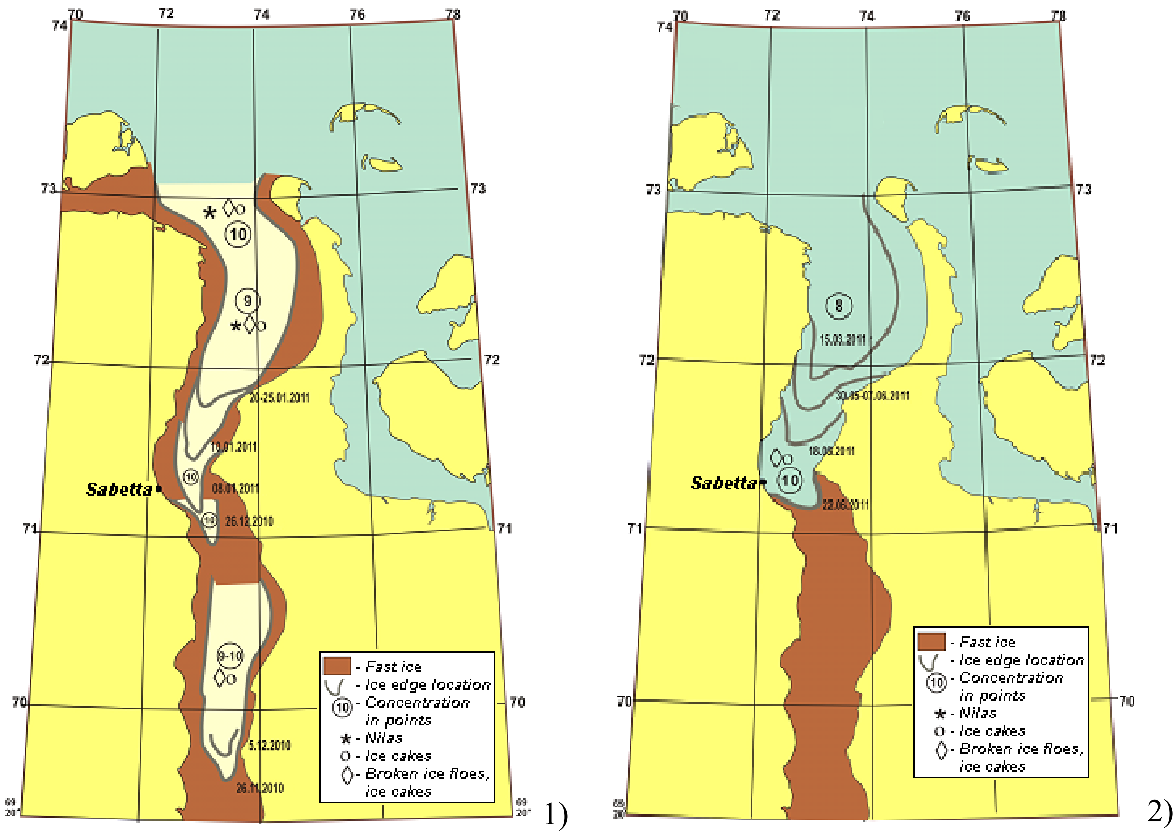


Figure 3. Changes of polynya border during formation (1) and break-up (2) of fast ice in the Northern Ob Bay in 2010–2011.

Fig. 3 shows an example of formation of the polynya and breaking-up of fast ice in 2010-2011 winter period. One should mention that the given year was quite warm and close to average values according to its climatic parameters. The processes of changes of the polynya border, forming and breaking-up of fast ice are shown in detail. The information given in fig. 3 is applicable for empirical problem solutions as well as for mathematical simulation.
In order to evaluate shapes and sizes of ice floes in spring break-up period in the area of Sabetta port satellite image data with sufficient discreteness of satellite passing the studied area have been sorted out. The period 18.06.2006 - 20.07.2006 was analyzed, with the ice area of 880 km^2 (40x22 km) being covered where ice cover (area covered with ice of different concentration) was fixed. Then changes of ice shapes (sizes of ice floes) were recorded. According to those investigations by 11.07.2006 final transformation of ice floes occurred, by 20.07 the breaking-up process produced drift ice, ice cakes and small ice cakes which do not pose threat to navigation and various hydrotechnical facilities. The obtained data was used to carry out project solutions for substantiation of the northern and southern dams protecting the port of Sabetta.

BASIC RESULTS OF FIELD WORKS AND SCIENTIFIC INVESTIGATIONS IN THE AREA OF SABETTA PORT

Basic results of field works and scientific investigations given in the paper were obtained in 2011/12 after definition of the certain location of the port, LNG plant and other important facilities construction.

Field works and data

In 2011 field winter and summer works in the area of Sabetta port lasted in total for 230 days, in 2012 – more than 140 days. Ice investigation included research on morphometry of ice cover, its physical-mechanical properties, ice drift, dynamics of tide cracks, observations of fast ice break-up, aerial survey of ice, satellite surveys. Hydrological, meteorological, hydrochemical, hydrographical observations, a set of lithodynamic investigations and hydrological observations at the Sabetta-Yakha river were conducted at the same time. Annual monitoring of meteorological, synoptic and ice conditions of the area was performed.
Primary processing of field data and comparison of data according to structural, morphometrical and physical-mechanical ice properties allows to unite data on ice cover in 2011 and 2012 in the water area of Sabetta port, the access channel, the sandbar region is a single group to obtain statistically verified assessments of various parameters. Therefore, the amount of hummocks studied in the whole area comprises 12 and 28 grounded hummocks, 23 of them were investigated by means of aerial photo survey. There are characteristic data on some parameters of hummocks: average sail height – 1.55m, maximum – 3.27 m; average keel draught – 6.11m, maximum – 8.83 m; relative length of a consolidated layer of 2.5 m is 0.47 m. Some average data on physical-mechanical properties of level and hummocked ice (small samples and discs tests) are given below:

- thickness-averaged bending strength limit of level ice, MPa -2.11
- thickness-averaged bending strength limit of hummocked ice, MPa -3.57
- thickness-averaged level ice strength limit at uniaxial compression perpendicular to the surface of ice cover, MPa –2.80
- thickness-averaged level ice strength limit at uniaxial compression parallel to the surface of ice cover, MPa -1.40
- thickness-averaged hummocked ice strength limit at uniaxial compression parallel to the surface of ice cover, MPa -4.5 (an expert evaluation which requires further research)

The obtained data on morphometry and physical-mechanical properties have been used in analytical works (tasks 3, 4 of the section “Introduction”).
The main particularities of ice drift in the Northern Ob Bay include its periodicity in terms of tidal nature as well as seasonal occurrence (autumn and spring periods - before formation of fast ice or from breaking-up to the ice-free perod). If in autumn period movement of newly formed drift ice of primary forms (which is observed during 2-3 weeks) does not pose threat to hydrotechnical facilities, during breaking-up of fast ice, ice floe sizes reach tens of square km and thickness amounts from 1.5 m to 2.5 m. According to ARGOS buoys data (fig. 4) ice drift can be observed in the Northern Ob Bay during 3-4 weeks and poses danger to designed structures of the Sabetta port. Table 4 shows distribution of total drift speeds based on data of June-July 2011. Reverse-oriented tidal flows which affect the port water area with

southern and northern components make considerable contribution to total drift. Moreover, as it has been mentioned, during break-up (June-July) repeatability of northern winds comprises 40 - 60% that results in additional difficulty of opening of the water area and ice discharge into the Kara Sea.

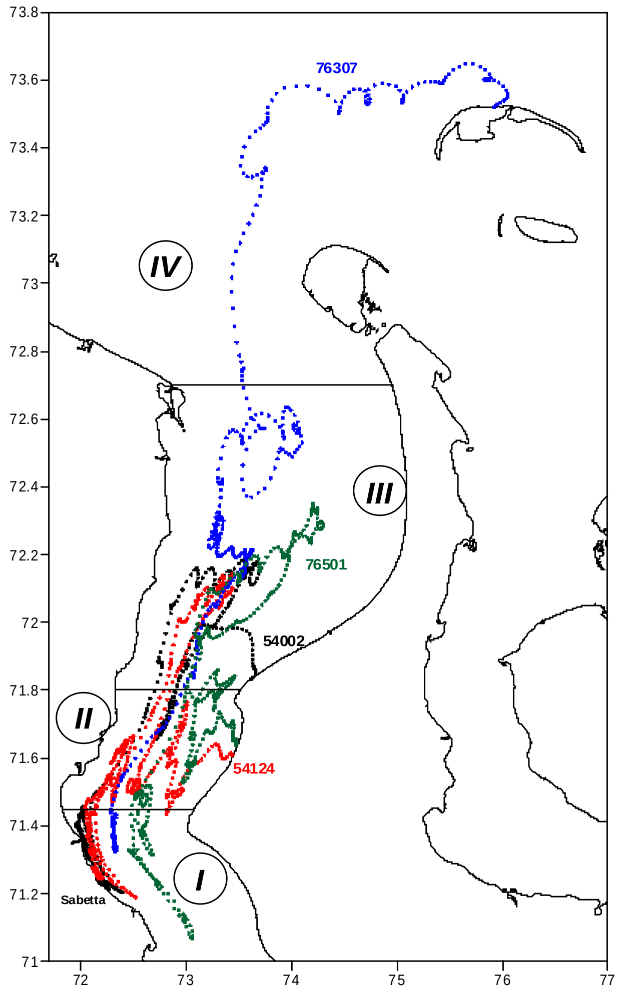


Figure 4. Drift paths of ice floes instrumented with ARGOS buoys, 2011.

Table 4. Characteristics of ice drift in the area of Sabetta port in the period 19.06-04.07.2011

Direction	P, %	Speed (m/s)	
		Average	Maximum
N	11.1	0.22	0.75
NE	5.0	0.07	0.28
B	8.3	0.11	0.56
SE	25.9	0.13	0.55
S	11.1	0.12	0.57
SW	4.7	0.06	0.5
W	4.9	0.04	0.13
NW	29.0	0.17	0.74
Total	100	0.14	0.75

One should mention high importance of data on ice drift which provided analytical substantiation of the necessity of design and construction of the northern ice-breaking dam.

Ice exaration studies have shown the presence of single gouges at the depth of more than 5 m. Ice gouge depths amount to 1.0 – 1.5 m, width exceeds 150 m, length is more than 2 km. Gouge direction coincides with directions of prevailing total currents (south-north).

Therefore, field data both have independent value (for direct calculations and evaluations) and are used to solve a whole number of analytical tasks. Some of them are given below.

Analytical works, simulation

Simulation and calculation of ice channels in the Northern Ob Bay and evolution of ice cover in the port of Sabetta.

Navigation in winter period in the Ob Bay is associated with navigation in a permanent channel lined in fast ice. The practice witnesses that intensive navigation in the channel leads to accumulation of large amounts of brash ice which gradually creates difficulties for navigation. This phenomenon is observed during use of ports in winter – active maneuvering of vessels in a small water area leads to very intensive accumulation of ice cakes and small ice cakes which can consolidate and create serious obstacles for the port operations. The thickness of brash ice layer can reach several meters; intensiveness of its accumulation depends on navigation intensiveness.

The abovementioned phenomena in navigation channels can have considerable influence of LNG transportation schedule and complicate the port operation. To minimize these negative effects new navigation channels should be lined in the sea-port section area and an efficient system of ice breaking in the port water area should be created. In order to define a moment when a new channel is advised to be lined one should know the volume of brash ice in the channel in each instant of time beginning from the moment of a channel lining as well as a speed of vessel's movement in the existing channel in undisturbed fast ice during the channel lining and an expected speed of movement in a new channel (made by an icebreaker).

Calculation of accumulation of brash ice in the channel in terms of regular navigation has been carried out for the Northern Ob Bay. Calculations have been implemented using a mathematical model based of the equation of thermal balance of water-ice bulk filling the channel. The intensiveness of navigation, i.e. the frequency of vessel runs in a channel or a time period between vessel runs, has been regarded as the most important fact largely defining brash ice accumulation in the channel (Klyachkin et al., 1999). Calculation of vessel movement in the channel and in unbroken fast ice has been performed by an empirical-statistical model evaluation navigation difficulty and taking into account the main parameters of ice cover (ice concentration, thickness, hummocking, fracturing, strength, ice floe sizes) and the basic vessel parameters (length, width, power, ice class). A detailed description of the model of navigation difficulty is given in the papers (Buzuev, Fedyakov, 1981; Buzuev et al., 1981; Buzuev, 1982; Adamovich et al., 1995). The model is largely applied in operative practice of FSBE "AARI" for support of sea operations in the Arctic and the Far East. It allows calculating a speed of movement of a given type of vessel (as well as a convoy of a given composition) in any ice conditions. Numerous comparisons of calculated and actual speeds of vessels and different convoys' movement have shown that average speed calculation error does not exceed ±10%.

Model calculations implemented with account of specifics of the future sea operations in the Ob Bay and particularities of its ice regime have shown the following:

1. In cold winters at the access to the port of Sabetta (the "access" implies a part of navigation channel from the axis of Ob Bay where natural depths are sufficient and dragging is not required (i.e. from the point of –16 m to the entrance to the port of Sabetta)) 4 parallel channels may be required. The first channel is lined during formation of stable fast ice – approximately in mid-October, the second – in the second part of January, the third – in late March, the fourth – in mid-May. Every successive channel is used during a smaller period of time compared to a previous one; the speed of movement in every successive channel is lower than in a previous one.
2. In intermediate and warm winters lining of two channels is required at the access to the port of Sabetta. The first channel is lined during formation of stable fast ice in the second part of October, the second – in the second part of February (intermediate winter) or in the first part of March (warm winter). However in intermediate winters the speed of movement in the second channel by mid-May approaches the critical value of 5 knots, i.e. in certain circumstances (slightly more severe natural conditions or some additional vessel runs in the channel) the third channel could be required.
3. In cold winters two channels need to be lined in the sandbar area of the Ob Bay. The first channel is lined during formation of stable fast ice in mid-March (it has been accepted that in cold winters formation of fast ice in the sandbar area occurs from drift ice due to consolidation of separate ice floes in a single mass when ice reaches the thickness of 1.60-1.65 m), the second – in early May.
4. In intermediate winters one channel in the sandbar area is enough. It should be lined during formation of stable fast ice in mid-April when ice reaches the thickness of 1.60-1.65 m. Within the whole exploitation period the speed of vessel movement would considerably exceed the critical value.

Therefore, the recommended amount of ice channels at the access to the port of Sabetta is 4+1 (4 at ice-breaking capacity of 2.2 m plus 1 channel in case of decreasing ice-breaking capacity of an actual vessel); 2 channels are recommended to be lined in the sandbar area at the exit of the Ob Bay into the Kara Sea. Total width of 5 parallel ice channels comprises 420 m with minimum inter-spacing caused by the width of riding-up of ice on edges of each channel. The width of 2 channels is 150 m.

Calculation of brash ice growth in the area of the designed Sabetta port with the planned schedule of 18-19 vessel callings per months (the inter-calling period is about 40 hours) showed that in natural conditions, i.e. without artificial heat inflow, very large volumes of brash ice will accumulate by the end of winter season. At the port entrance, accesses to the main quays and in the turning circle zone the brash ice layer thickness can reach almost 7 m in cold winters, and 8 m directly near quays. At accesses to quays of the port service fleet the brash ice layer thickness comprises about 7.5 m, and 10.5 m directly near quays. In intermediate winters the brash ice layer thickness will be some 1-1.5 smaller. Such volumes of ice will certainly create serious difficulties for the port operations, especially for mooring. Artificial decrease of intensiveness of the process of ice formation by discharge of warm water and it distribution in the water area is one of possible ways to solve the problem or at least to alleviate it.

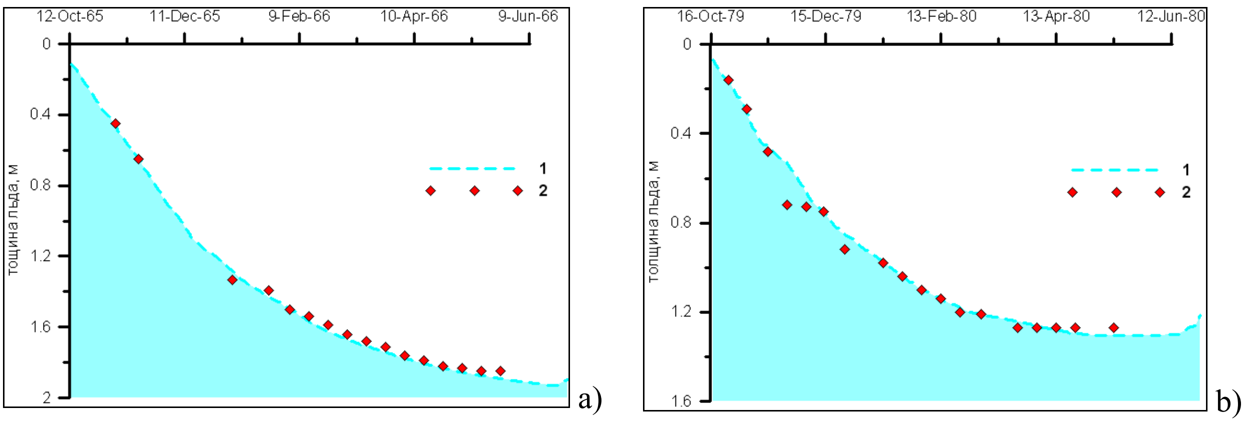
Simulation of the port water area warming processes

Theoretical and practical studies of this problem were implemented in different countries in 1970-80s, modern operative experience of Sweden and Finland shows that in the shallow depths with the almost fresh waters and a small heat content a combination of air-bubbling and thermal discharge from industrial facilities (heat stations, pulp and paper plants etc.) is the most effective for preventing the freezing of the port area. [Nyman, 2000; Huffmeier, Sandkvist, 2008; Hüffmeier et al., 2008]. Application of this approach for weakening of ice cover and support of navigation in the area of designed Sabetta port faces the following basic difficulties:

1) Severe climatic conditions compared with the Canadian Arctic according to the main parameter (accumulated degree days of freezing) and not having analogues among the implemented projects;
2) Shallow water area which lacks heat reserves in the bottom layer or it is even characterized by decline of temperatures with depth;
3) Strict environmental regulations which impose considerable limitations on intake and discharge of water according to volumes and temperatures.

Several methods have been considered to solve the set task with account of the local conditions. The following mathematical models have been used: 1) 1D thermodynamic model of sea snow-ice cover evolution [Andreev, Ivanov, 2001] and 2) models of forced convection (a single vertical stream flowing at a final depth [Madni, Pletcher, 1977] and a thermal torch above a linear heat source [Gebkhart et al., 1991]).

The performed testing of the sea snow-ice cover evolution model has shown that the model is efficient and adequately reproduces the growth of sea ice thickness in the Ob Bay regardless of severity of weather conditions that is convincingly shown in fig. 5. It allows to draw the conclusion that the model is quite applicable for calculations associated with definition of heat amount necessary for maintenance of a fixed sea ice thicknesses in the given water area. The data shown in table 5 have been obtained in the course of further calculations; it represents seasonal heat spending for keeping ice thickness at the level of 0.3-0.5 m in different parts of the water area of Sabetta port depending on severity of winter conditions. In table 5 the main port water area includes quay lines and the turning circle, total operative area additionally includes the area of auxiliary quay lines with adjacent water area used for maneuvering.



1 – simulation results, 2 – observation results. X axis – Time, Y axis – thickness of ice (m)
a) 1965-66 winter (severe); b) 1979-80 winter (warm)

Figure 5. Calculated and observed values of sea ice thickness in the Ob Bay

Table 5. Average seasonal heat spending (MW) for maintaining the ice thickness of 0.3-0.5 m in different parts of Sabetta port water area depending of severity of conditions

A part of the port water area	Degree of severity of winter conditions		
	severe	intermediate	mild
The main (tanker) quay line (0.3 km^2)	27-45	26-39	23-33
The main area of the port waters (1.5 km^2)	135-225	128-195	113-165
Total operation area of the port waters (2.2 km^2)	198-330	187-286	165-242

According to technical parameters the given amount of heat can be partly or completely compensated by the plant lines of cooling during production of LNG at any degree of winter severity. Table 5 shows the simplest solution is possible at heating the main tanker quay line.

A shortcoming of a single vertical stream [Madni, Pletcher, 1977] implies quite a large amount of coefficients which can be defined only by means of technically sophisticated experiments. Comparison of the considered options of heat supply – a single vertical stream and a thermal torch from a linear heat source [Gebkhart et al., 1991] – has shown that in the second case heat would spread more evenly, thus, the option is preferable. During adjustment of the model of a thermal torch from a linear heat source calculations have been performed which results have shown that in general the model provides rather realistic estimates of heat flows. The result of simulation of heat distribution from a linear source at "maximum" initial parameters is given in fig. 6 as the most apparent example.

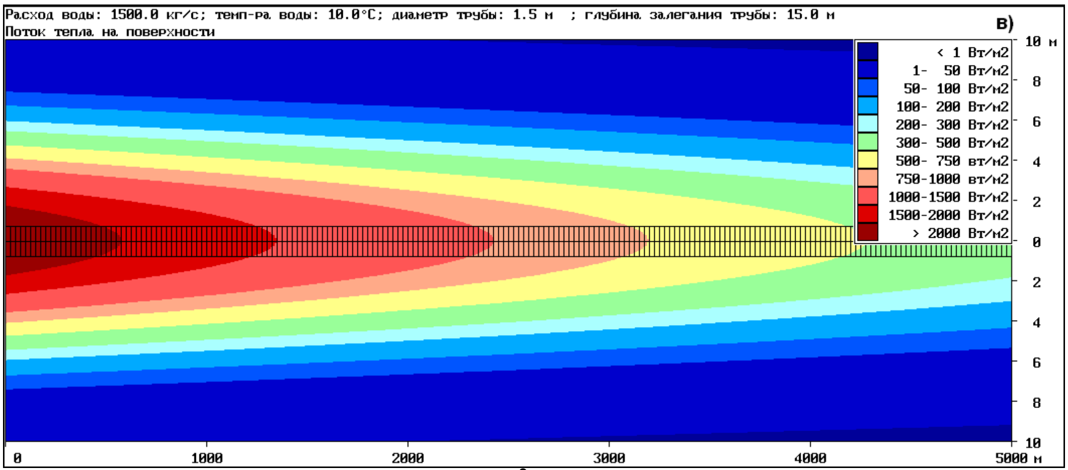


Figure 6. The schematic plan of heat flows (W/m^2) which reach the sea surface at "maximum" initial parameters (the tube diameter is 1.5 m, water flow - 1500 kg/s, water temperature - 10°C).

According to the natural conditions of the area of Sabetta port the most rational methods of struggle against the port area freezing are represented by heating of bottom water in a closed cycle (i.e. without discharge of heated water into the port) independently or together with air-bubbling. Use of water discharge and air-bubbling (together or independently) is not effective or is absolutely inacceptable according to the natural conditions and the environmental requirements. It is planned to continue both theoretical calculations and physical modeling of the considered processes in the AARI's ice tank.

CONCLUSIONS

The results of the abovementioned works can be briefly summarized as follows:

1) Ice regime of the Northern Ob Bay has been studied based on archive sources and field work data, statistical estimates of some parameters necessary for design of the port of Sabetta and transportation infrastructure in general have been obtained.
2) Based on initial data and simulation results recommendations on rational location of some facilities of the port of Sabetta (in particular, ice-breaking dams) have been given.
3) 2011-12 field and analytical work results of AARI have been taken into account by design enterprises at initial stages of development of the transportation system for LNG shipment.

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