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INVESTIGATION OF THE ICE REGIME OF THE EASTERN PART OF THE CASPIAN WITHIN BACKGROUND ECOLOGICAL INVESTIGATION PROGRAM AT YUZHNY JAMBAY- YUZHNY ZABURUNJE

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ABSTRACT

Caspian Sea is featured by a great diversity of ice processes with seasonal ice cover. It is serious natural threat for economic activity of man in the sea (fish and seal production, ship industry and in recent years oil exploration at the Caspian Sea). Ice cover is considerably restricts the man activity and is of real threat to the safety. In this connection the investigation of the ice processes is both of scientific and practical interest. Exploration works recently held in Russia and Kazakhstan in the shallow waters of the northern part of the Caspian Sea (including winter periods) urge scientists to international cooperation in the field of contemporary winter hydrogeological and ice processes in the Northern Caspian Sea. Necessity and timeliness of the ice investigations is also connected with the fact that character and intensivity of the ice processes in the sea considerably changed due to the sea level rising for more that 2 meters during the last 30 years (since 1978). In the present work we applied the investigation data obtained in the period since December 2007 up to March of 2008 within the ice regime investigation of the Caspian sea in the frame of the background ecological investigation at the Yuzhny Jambay – Yuzhny Zaburunje.

GENERAL DATA ON THE ICE REGIME

During the cold seasons of year the eastern part of the Caspian Sea is under the prevalent impact of the spur of the Siberian anticyclone. In this connection the atmosphere pressure is higher here than in the western part which results to the great reoccurrence of the winds of the eastern rhumbs. To the north of the Caspian Sea there are Kazakhstani semi steppes and steppes which get cold rapidly in fall. There are early and severe frosts in winter. That is why the eastern coast of the Caspian is the coldest region of the whole Caspian Sea area. And here the coldest area is the northern part of the eastern coast side of the Emba river.

The first ice appears as ice fat, gruel or rind (primary kinds) and marked at the coastal shallow waters in moderate winters. It takes place in the beginning of November in the are of Zhilaya Kosa and in the area of the Burunchuk Cope in the middle of November during the night frosts. The first appearance of ice is not stable usually – it melts during the daytime. Stable freezing comes in seven days averagely. Fast ice is formed. At the end of November the edge of the fast ice lays along the isobath of 2 meters in 3 – 8 miles from the coast. Almost the whole eastern part of the Northern Caspian Sea is covered by fast ice in December – February.

Ice appears in October in anomalously severe winters. So on the 31st of October in 1960 the edge line of the fast ice was marked at the meters of depths according to the data of the ice air observation. The first ice appears only in December in anomalously mild winters. For example, the first ice was observed on the 11th of December 1939 in the south-eastern part of the coast between Burunchuk Cope and Balashovsky sand islands [1]. It is necessary to note that each second winter in average ice can disappear completely after the first appearance of the ice and even after the ice was completely frozen and then ice can appear again. In some winters such complete ice freezing and complete melting of the ice happens twice and even three times.

Prevailing eastern winds bring great volume of sand and dust from the kazakhstani steppes. It impacts a lot on the ice albedo and facilitates fast spring destruction of coastal fast ice.

The areas of ice pressure and loose appear under the impact of the strong winds. It results in intensive movements, formation of ice clearings, ice holes and ice blocks. The processes are intensive during the spring ice melting. The coastal area of the sea with the depth of up to 40 cm is frozen down to the bottom and ice lies on the ground up to 10 km from the coast. Spring destructions of the fast ice begins with the melting water on the ice and flaw lead then penetrating flow lead or vast coastal ice hole 10-20km of width is formed. In moderate winters spring destruction of the fast ice comes in March and and clearance takes place in the end of March – beginning of April. Complete clearance of the sea from ice take place in the second half of April in anomalously severe winters. The area of the ice cover is inconsiderable by the end of February in mild winters. So, on the 18th of Fubruary 1946 the fast ice was marked only at the north-east in the area of Emba river offing and the edge of the floating ice was spread from Balashovsky sand islands to north-west, the Borozdinny island. There is almost no ice at the eastern part of the Caspian Sea in March during mild winters. Average days with ice is 150 days in the north, 125 in the south. During the mild winters it is 130 and 110 correspondingly and 170 and 140 during the severe winters.

Maximal thickness of the fast ice is in the end of February – beginning of March. It fluctuates from 48 up to 96cm in the area of Zhilaya Kosa and from 24 to 65cm near the Burunchuk Cope.
Maximal thickness of the ice at Zhilkosinsky road was 90cm observed on the 8th of March 1930. it was the maximal thickness of the ice of natural (thermal) building-up registered during observations at the Caspian Sea. Thickness of the ice of 96cm is marked not in the sea but in the former bay separated from the sea.

During the destruction period the fast ice is turned into drifting ice. It may drift westward under the impact of the eastern wind and forming vast areas of clear water at far east of Northern Caspian Sea. There is still a lot of ice at Guryev ice furrow. It covers vast areas and quite solid. The ice starts drifting towards eastern coast, hummock and build-up on shallow waters under the influence of the piled-up western winds. Increase of the level during the piling-up results in ice edges occur on the coast and penetration of the ice into the coast for several kilometers down.

Drift speed of the solid ice reached 0.5m/sec at strong wind (7–8 points). Drift speed of separate ices is 1m/sec at the wind of 4–5 points of strength.

There is no solid snow cover formed on the ice usually. The snow accumulates in the form of snow erosion ridges and spots with the thickness of up to 10cm. There are snow piles with the thickness of 40-50cm are formed at windside toros and rows of toros.

DYNAMIC PROCESSES IN THE ICE COVER

Breaking and clashing of ice is the result of uneven drift of separate ice formations. It comes to the ice cover deformation. Ice deformation is buildups, sublayers and toroses and results in considerable thickening of the ice cover. Visual evaluation of the ice cover torosity level is very complex task considering different age composition of the ice, different time of toros formations and a great diversity of toros forms. Along with it, this element of the observations is one of the most important for evaluation of the fast ice status and solidity of the floating ices. Rows of thick toroses where ice masses forms one solid ice is of draft which exceeds the above water height by 4-7 times and often is an invincible obstacle for both ships and icebreakers. Torossing ice are of great destruction power and is really dangerous for ships, different kinds of hydrotechnical facilities, piers, platforms and etc.

Fast ice especially near the edge is often characterized by a row torosity. Floating ices while drifting are subject to multiple torosity. This torosity of chaos character where separate hummocks and ropacs (standing floes) come with rows of toroses of different directions. In the conditions of shallow waters of the Northern Caspian Sea the drifting toros ices are often cast aground. It is also facilitated by rundown piled up sea levels characteristic for this part of water area. The result is grounded ice - toros ice formations casted aground [2,4].

Increase of the oil exploration activity of Russia and Kazakhstan companies with foreign partners at the Northern Caspian Shelf requires serious scientific, ecological and technical approaches. The results of the cooperated ice investigations were applied to practice. So, reconstruction of typical immersible drilling barge was performed for the needs of OKIOK Kazakh company (Offshore Kazakhstan International Operating Company) in 1999 in Astrakhan. The barge was adopted for unique natural and geological conditions of North-Eastern Caspian Sea. Submersed foundation and barge boards were modified to resist ice loads which had been studied and analyzed for five years. Computer modeling was performed. As the result the area of the barge was increased twice, special ice diverting device from both sides of the barge. Diverting devices were modeled to resist ice pressure. A system of thick metal piles (depth of burial up to 20 meters) are considered from the barge both sides at the place of barge stop in the sea. They are assigned to restrain the pressure of the drifting ice and activisation of toros formation at the far accession to the drilling platform. As the result artificial grounded hummocks are formed which are reliable protection for the platform from floating ice. Forecast of the ice floating direction under the impact of the wind and streams is very important. Lack of consideration of these factors can lead to emergency. So, we can analyze the situation in the area of Kashagan facilities in December 2007. The situation reached the critical point on the 16th of January when the access channel was blocked by an ice 1,5 meters of thickness as the result of storm and intensive ice movements. The ships were paralyzed for several weeks and whole personnel was evacuated.

ICE CONDITIONS IN THE 2007/2008 COLD PERIOD

According to the severity conditions, the 2007-2008 winter (the forecast prepared on October 10, 2007, ice conditions in the Lower Volga and Northern Caspian) was in whole expected to be close to average multiyear values – “moderate winter” (*table 1*).

Table 1.

Classification of winters in the Northern Caspian according to the extent of their severity (accumulated temperature, $\sum$ -t°$_{daily\ mean}$ C in Astrakhan port) [3].

Very severe winter	Severe winter	Moderate winter	Mild winter	Very mild winter
More than 900˚ C	900-700˚ C	700-400˚ C	400-100˚ C	100˚ C and less

The amount of negative daily mean temperatures in Astrakhan port over the winter was -544.9°, which meets the “moderate” winter criterion; in Peshniy and Zhambai (Kazakhstan) -922.1º and -841 accordingly which meets the “very severe” winter criterion (*table 2*).

Table 2.

Accumulated temperature over the 2007-2008 winter in the Northern Caspian settlements.

Settlements	Nov	Dec	Jan	Feb	Mar	The amount of negative daily mean air temperatures (accumulated temperature) over the winter
Astrakhan	since 07.11 -28,7	-100,3	-274,9	-141,0 till 22.02	--	-544,9
Peshnoi	since 07.11 -62,3	-209	-422,2	-228,6 till 23.02	--	-922,1
Zhambai	-51	-190	-400	-200	--	-841

In shallow waters of the northeast part of the Northern Caspian initial ice forms as a nilas (5-10 cm thick) appeared on November 23.

According to satellite data, the ice edge in the east of the sea passed in the 52nd meridian (exploration area) on December 13, then it turned to the west along the northern coast till the 50th meridian; a fast ice belt was formed in depths up to 1-2 m. The ice edge moved to the west, southwest to 5-meter depths by 17.12; the fast ice belt had also formed along the northern coast till the 50th meridian at the depth of 1-2 m.

By 18.12 the ice processes had strengthened and the ice edge moved towards west to the 49th meridian; there was no ice in area 21050. By the end of the month the entire northeast part of the Northern Caspian was fully covered with the fast ice belt (it was in the form of drifting ice packs in area 21050); the ice edge moved from the Mangyshlak gulf along the 45th parallel to the west coast (Sand bank).

In the beginning of January the frost strengthened (in Astrakhan the minimal temperature on 04.01 was up to 23,0°C, in Atyrau from 02.01 till 13.01 minimal night temperatures were below 20,0°, the minimal temperature was marked on 12.01: –27,5°C).

The fast ice belt boundary on January 9 went along a 5-meter isobath; the exploration area was fully covered with stagnant ice. The ice edge was 22 miles to the south from the Astrakhan beacon location along the western seashore and 10-meter isobath to Izberbash port area. The boundary of drifting ice went along a 20-meter isobath.

The ice thickness in the first decade of January 2008 was 45-55 cm in the northeast part and 25-45 cm in the northwest part. The level ice reached maximal thickness over the season in the second decade of January which was 55 cm in the northwest of the sea and 60 cm in the northeast *(table 4).*

During the 2007-2008 winter period the lowest temperatures were marked from 05.01 till 28.01 and from 01.02 till 22.02 along all coasts of the Caspian Sea. Low temperatures along the east coast retained till 28.01 and repeated in February till 21.02

In the northeast of the Northern Caspian and exploration area the fast ice belt broke and drifting grey and white ice was carried away into the deep-water part of the sea on February 1 due to strong northwest winds; cracks appeared in the ice in the exploration area.

Only in the end of February the thermal breakdown of ice started in the Northern Caspian.

On 06.03 the fast ice belt retained at the 1-2 meter depth in the exploration area, there was grey and white drifting ice in the form of pieces of ice fields and small ice fields as well as large and small ice pieces of various concentration; the extent of ice destruction was 1 point.

The boundary of these drifting fields reached the 20-meter isobath. Single drifting fields reached the Medium Pearl bank.

On March 8 the Pearl island was freed of ice, on March 10 марта – Clear Bank and Kulaly islands, on March 12 – Ukatniy island.

By the end of March the exploration area was freed of ice; the drifting ice retained only in the northeast part of the Northern Caspian, concentration of drifting ice (large and small ice pieces) was from 1 to 4 points in Guryev Borozdin and from 4 to 8 points in the east, northeast of area 21120. Also there were grounded ice hummocks among clear water.

The northeast part of the Northern Caspian in 2008 was completely freed of ice on April 1.

Photos received from satellite allowed to generate maps of the actual position of ice edges and properly evaluate characteristics of the ice cover (*figures 1 – 3*).

Figure 1. Ice status as per 29 of December 2007

Figure 2. Ice status as per 30 of January 2008

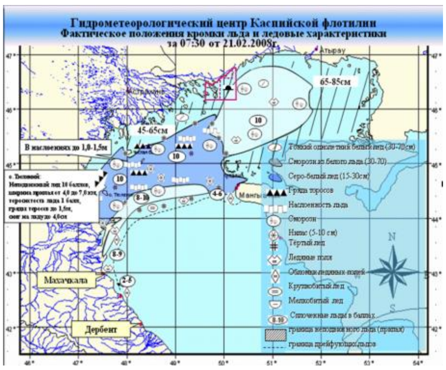

Figure 3. Map of factual ice edge location and ice characteristics as per 21 of February 2008

FIELD INVESTIGATIONS

Ice prospection including observations over the thickness change and thickness of drift and fast ice in winter 2008 (with the help of tool measuring) was carried out according to the Background Ecological Investigation Program at Yuzhny Jambay and Yuzhnoje Zaburunje. Besides, investigation of the ice regime included investigation of the ice morphometry and thickness at the investigation stations; average ice thickness; solidity of ice and ice cover in the whole; relation of ice movement and wind and sea waves direction; study of the toros formation (pressure, movements, lean-on, shift, ice size isolated from edge, velocity of their movement). There were an air investigation of the ice regime of the Caspian by the helicopter (ice observation investigation). There was also application of artificial satellites (space images) and land vehicles (airboats) at the stations which location is given in the *table 3.*

*Table 3.*Location of the ice regime observational points

	Station type	X	Y
1	Investigation of the ice regime	$46^0$20'	$49^0$43’
2	-«-	$46^0$22'30"	$49^0$47’
3	-«-	$46^0$20'30"	$49^0$52’
4	-«-	$46^0$16'45"	$49^0$53’
5	-«-	$46^0$30'	$49^0$56’
6	-«-	$46^0$14'30"	$49^0$52’

Table 4.

Ice thickness at Jambay, cm.

December, 2007			January, 2008			February, 2008			March, 2008	
1^{st} decade	2^{nd} decade	3^{rd} decade	1^{st} decade	2^{nd} decade	3^{rd} decade	1^{st} decade	2^{nd} decade	3^{rd} decade	1^{st} decade	2^{nd} decade
-	-	25	35	45	55	55	60	55	50	40

THE LABORATORY INVESTIGATION RESULTS

Ice kerns were taken for chemical composition investigation during the ice air investigation. Besides, study of the ice solidity was carried out with the help of the ice samples.

Data on the chemical composition of water obtained from the ice kerns are presented in the *table 5*. Chemical analyses were carried out in the laboratory of Monitoring Ltd in Atyrau.

Table 5.

The results of the chemical analysis of water of ice kerns at the investigation stations (Maximal Allowable Concentration for commercial fishing in brackets)

	Substance	Station number and location					
		№1 $46^0$20' $49^0$43’	№2 $46^0$22'30" $49^0$47’	№3 $46^0$20'30" $49^0$52’	№4 $46^0$16'45" $49^0$53’	№5 $46^0$30' $49^0$56’	№6 $46^0$14'30" $49^0$52’
1	Salt ammonium, mg/l (0,5)	0,14	0,12	0,16	0,14	0,15	0,14
2	Nitrites, mg/l (0,08)	0,0148	0,0146	0,0152	0,142	0,144	0,146
3	Nitrates, mg/l (40,0)	0,102	0,108	0,106	0,104	0,104	0,104
4	Chlorides, mg/l	501,5	502,3	503,2	502,4	501,6	501,6
5	Sulphates, mg/l	118,4	120,4	119,6	118,6	118,8	118,6
6	Hydrocarbonates, mg/l	77,5	78,0	76,8	77,6	77,8	77,6
7	Hardness, mg-eqv/l	11,05	11,08	11,06	11,04	11,06	11,04
8	Calcium, mg/l (180)	114,8	115,2	114,6	114,5	114,7	114,6
9	Magnesium, mg/l	64,7	66,8	65,6	64,6	64,8	64,8
10	Dry residue, mg/l	1099,5	1100,0	1098,0	1099,6	1099,8	1099,4
11	∑ Na+K, mg/l (390)	172,2	174,0	173,1	172,6	172,4	172,4

The table shows the content all ingredients is lower the allowed values of MAC. Water is fresh according to the relation of the dry residue from ice kerns.

pH of water in the upper, medium and lower parts of the ice changes from 5,21 to 5,29. According to the accepted classification of pH the water is referred as slightly acidic which is connected with atmospheric precipitation on the ice surface.

ICE SOLIDITY CHARACTERISTICS

Physical status of the ice cover as a rule was determined by slight minus air temperatures and often above zero. Minus temperatures from -1,1…to -4,5ºC were marked only on the ice cover surface. Ice salinity varied from 0,1 to 0,4‰.

Liquid migration from the surface layer considerably impacts on the ice solidity decreasing its value to 830-850kg/m³ in the layer. In the middle and lower layers there is texture stratification strongly marked. It depends on the content of air and the solidity values vary in the limits of 870-900kg/m³ [5].

Conditions of the ice formations with often warming up to the temperature which is close to 0ºC considerably impact on the ice texture features. Increase of liquid content phase up to the maximal values with the following migration during the thaw favors to development of secondary porosity. Stratified ice forms in the conditions of abundance of air pores. Stratified ice consists of semi-clear and not clear layers with not strongly marked whitish shade.

The layer becomes loose and of milky-white color when complete slippage of the liquid phase from the surface layer take place. Analysis of the structure show that ice forms of anisomerous isometric crystals 2-10mm of size which is typical for such ice types as A6 and Б6 (Sea ice…, 1977).

Vertical development of fine-grained crystals along the basic plain occur during the most stable ice formation period. The result is ice layers of A4 and Б4 types formed.

Data on average and extreme values of ice stability of the area under investigation at the bending are given in the *table 6* (upper, medium and lower layers were investigated).

Table 6.

Average and extreme values of ice solidity at bending (σ bending), MPa

Characteristic	Samples				Average for layers			Ice floe
	upper	medium	lower	all layers	upper	medium	lower	
Average value	0,87	0,80	0,68	0,78	0,85	0,79	0,72	0,84
Maximum	2,17	2,16	1,62	2,17	1,93	1,53	1,77	1,77
Minimum	0,01	0,01	0,01	0,01	0,10	0,10	0,09	0,09
Quantity of measuring	191	193	169	553	112	112	110	112

Minimal values of the ice solidity vary from 0,01 to 0,10MPa at the average value of 0,09MPa. Maximal values are from 1,53 to 2,17MPa at the average value of 1,77MPa.

Performed investigations and analysis of the obtained results shows that the most favorable condition for stratified ice formation is prevalence of piled-up south-eastern wind of normal direction for the coastal line.

Formed toroses are referred to blocking and stratified. They form owing to stratification of blocks one on another and their underspaces.

CONCLUSION

Such complex field investigation of the ice cover in the eastern part of the Northern Caspian has not been conducted the last 15-20 years.

On the basis on the submitted data on the ice cover observations in the report one can judge about the complexity, diversity and ambiguity of the ice processes on the investigated area.

Winter ice regime is quite complex and ice processes are of real threat for navigation and all possible hydro technical and other engineering facilities located on shore and especially on the Northern Caspian shelf. Design, construction and emergency free operation of the drilling units in the investigated area depend much on the adequate evaluation of the ice factor and adequate application of the data that we have today on ice regime in the given part of the Northern Caspian in the engineering.

Analysis of the data obtained during the expeditionary investigation of the materials at the contractual territory of Jambay Ltd. (Yuzhny Jambay and Yuzhnoje Zaburunje) in winter 2007/2008 testifies that ice processes in the area of investigation were characteristic for the eastern part of the Northern Caspian.

The total of average minus temperatures in winter in Astrakhan was minus 640ºC (indicator of moderate winter). And in Atyrau the value was more than 900ºC which testifies about severe winter.

Maximal thickness of even ice of thermal building-up in winter was 40-60cm and at the same time the ice thickness in the western part of the Northern Caspian did not exceed 35cm.

Border of the fast ice and edge of the floating ice changed their location under the influence of winds and streams. Ice movement took place at the wind strengthening of any direction including storms (up to 12 and more m/sec). Stratification of ice prevails for thin ice with thickness of less than 35cm. Hummocking prevail in more thick ice (thickness of more than 35cm).

Unfortunately, investigations of the ice regime of the Northern Caspian were closed completely in the recent years due to well known circumstances. At that the reduction of works was carried when Caspian Sea level rose intensively. It also influenced ice processes mobility (drift character, toros, ice thickening, ice surface area, ice appearance terms, sea clearing, etc).

Drift and movements of ice in northern shallow part of Caspian Sea are able to considerably influence on people's economic activity. Moreover it is found that small-scale zones of hypoxia at shallow water areas of intense ridges and hummocks are wide spread at winter season. It leads to sharp decline of species composition and reduction or even total extinction of whole phytoplankton biomass at suffocation areas.

Since more than 50% of Caspian Sea shallow water areas (more than 200 sq km) are subjected to ice exaration (interaction of drifting ice and sea bottom) these processes can be considered as large-scale even being of seasonal character. It plays significant role for this water body environment. Beside pure mechanical movement of enormous subsoil masses the sea bottom, shore and island flora and fauna are depressed. Ice surface can make positive effect at spring period of destruction by cleaning seashore entry of Volga, Ural rivers and shore water shallow areas from faded last previous year vegetation. This reduces possibility of suffocation occurences at warm season.

Caspian ice is a serious danger for oil companies that plan to start oil extraction at explorated parts of northern Caspian sea waters in near future.

Taking into consideration the above mentioned we would like to consider the following:

- the possibility of continuation of regular cooperative visual ice air-monitoring along waters of Northern Caspian Sea (kazakh and russian part) with the following periodicity: each 10 day after established ice surface (Jan-Feb) and each 3-7 days at ice development period (Nov-Dec) and ice destruction period (Mar-Apr);
- feasibility of regular obtaining space (satellite) data of ice surfaces changes and its condition;
- possibility of research of physical, dynamic and other characteristics of ice at areas of planned installation of drilling units using helicopter and vehicles;
- development and implementation of new methods of ice prognosis.

For more detailed evaluation of ice impact on future production activities at Zhambay LLC contract territory the further research on ice processes is required.

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