upgraded during the term of the project. In order to develop the field, the first semi-submersible drilling rigs, Polar Star and Northern Lights, have been constructed and delivered to the customer - Gazflot LLC. These sixth generation platforms are able to work in brash, first-year ice up to 0.7 m thick.

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ASSESSMENT OF RESERVOIR TEMPERATURES OF TARYS AND CHOYGAN GEOTHERMAL SYSTEMS (EASTERN TUVA)

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The territory of the eastern Tuva refers to the continuation of the Baikal seismogenic Rift Zone and has significant reserves of geothermal resources. These hydrotherms formed due to the numerous deep faults and the presence of faults in rocks. The thermal and sub-thermal springs manifest by the high temperatures and active depth heat and mass transfer in the bowels of the Eastern Tuva [3].

One of the interesting aspects of the geothermal system study is to determine the subsurface reservoir temperatures, as one of the factors in the groundwater formation. Geothermometers are the most important and universal geochemical tool for the evaluation of reservoir temperatures. The first geothermometers developed by Bodvarsson and Palmason in 1961 were exclusively empirical and based on the link between the silicon content and the contents of some the cations with the reservoir temperature [2]. Using geothermometers involves the establishment of the chemical equilibrium in the geothermal system between a mineral and fluid

In this regard, the aim is to study the thermal conditions of the geothermal system in the Eastern Tuva.

The study of thermal waters in the Baikal Rift Zone was conducted by Lomonosov I.S. (1974), Lisak S.V. (1976), Polyak B.G. (1992), Zaman L.V. (2000), Plyusnin A.M. (2000), Golubev V.A. (2007), Shvartsev S.L. (2015) et al. Badminov P.S., Orgilyanov A.I., Ganchimeg D. (2011) studied subsurface temperature in this territory. Rychkova K.M., Duchkov A.D., Lebedev V.I. and Kamensky I.L. etc. (2007, 2010) carried out the assessment of the heat flow in the Tyva region. In Polyak’s works (1994) isotopic composition, heat, and mass transfer of fluids for the Baikal Rift Zone were recorded.

The thermal springs of natural spa complexes Choygan and Tarys were selected for the geothermometric evaluation of the Eastern Tuva geothermal system. Choygan is located in the East Sayan in the north-east of the Republic of Tyva on the border with Buryatia. This is a reservoir of carbonic cold and thermal waters. Groundwater is discharged in the form of springs with the temperature on the surface of up to 39 °C, but the deep water temperature is much higher.

Tarys sources are located on the border with Mongolia, in 300 kilometers southwest from Choygan in outskirts of the Prehubsugul's plateau, it is a province of nitrogen water. The water temperature in Tarys springs reaches 50 °C. The water is considered as medicinal and used by local residents.

Hydrothermal springs of Choygan and Tarys are the hydrothermal system belongs to the southwestern flank of the Baikal Rift Zone, which is formed by heating groundwater of the regional thermal field in the process of deep circulation. The formation of these sources is associated with areas of young volcanism in the Eastern Tuva and, probably, is controlled by a large single submeridional fault [1, 5]. According to the helium isotope, the heat flow rate is 68 mW/m^2 in Tarys and 84 mW/m^2 in Choygan [3].

Table

Reservoir temperatures in geothermal systems of Tarys and Choygan

Tarys				Choygan			
№ Spring	Measured T(ºC)	Na-K-Ca Fournier and Truesdell (1973), ºC	h, km	№ Spring	T(ºC) on a surface	Na-K-Ca Fournier and Truesdell (1973), ºC	h, km
1	48	118,1	4,3	1	22,6	116,6	3,5
2	43	117,0	4,3	6	29,5	113,8	3,4
3	45	119,3	4,4	7	23,8	115,0	3,4
4	47	112,9	4,2	8	25,3	99,9	3,0
5	47	120,2	4,4	9	27	112,3	3,3
6	48	113,3	4,2	10	30,2	118,0	3,5
7	47	105,4	3,9	11	31,5	118,9	3,5
8	45	120,6	4,4	12	38,5	116,0	3,5
9	30	111,9	4,1	13	36,8	118,4	3,5
10	21	81,7	3,0	15	24,9	98,6	2,9
11	20	90,1	3,3	16	27	108,3	3,2
15	46	119,2	4,4	17	22,4	83,7	2,5
16	25	109,4	4,0	19	30,9	91,5	2,7
17	34	120,5	4,4	26	20,2	83,7	2,5
18	43	92,1	3,4	27	21,4	82,0	2,4
20	32	74,9	2,8	31	27,4	103,7	3,1
21	30	106,2	3,9	32	26,6	107,7	3,2
22	36	121,2	4,5				
23	37	111,3	4,1				
Average	*38,1*	*108,7*	*4,0*		*27,4*	*105,2*	*3,1*

The results of the chemical composition analysis of 19 Tarys thermal springs and 17 Choygan springs were used [4, 6]. Based on these results and water saturation [4] the reservoir temperatures were calculated using Na-K-Ca geothermometers (Fournier and Truesdell, 1973): $T = 1647/(\lg(Na/K) + \beta\lg(Ca^{0,5}/Na) + 2,24) - 273,15$, Na, K, Ca – concentrations are in mol/L, $\beta = 4/3$ for $t < 100$ ºC.

Determination of the fluid formation depth was carried out by the formula: $h = T/\gamma$, γ – geothermic degree [1]. The geothermic degree for Tarys is 27,2 ºC/km. Taking into account the heat flow rate in Tarys and Choygan, the average heat conduction of metamorphic and igneous rocks in the mountainous regions of Southern Siberia (2,5 W/ m ºC), and for Choygan – 33,6 ºC/km. The results of geothermometric are given in Table.

As can be seen from the Table, despite the fact that the measured temperature of the Tarys springs are higher than that of Choygan, their reservoir temperatures are close to each other and range from 75 to 121 °C and from 81 to 118 °C at Choygan (Figure). The range of the formation depth of Tarys thermal waters is from 2,8 km to 4,5 km, the average is 4 km. For Choygan, the average depth of water circulation is 1 km higher and ranged from 2,4 to 3,5 km. This implies that the Choygan thermal springs formed at a lower depth than Tarys springs at equal temperatures, due to the higher heat flow in Choygan.

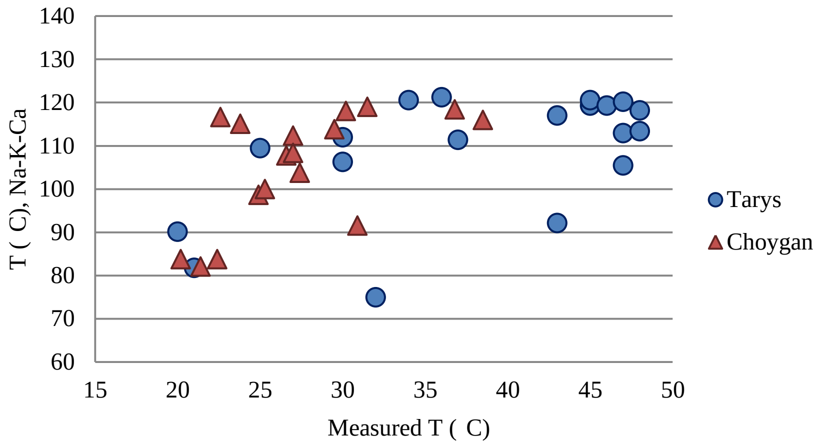

Fig. Graph of linking measured temperature at the discharge of springs and the reservoir temperature of Tarys and Choygan springs

Generally, the results of geothermometry showed that thermal waters of Tarys and Choygan have similar formation temperature. Groundwater reaches temperatures of 100 ° C at the depth of at least 2,5 km due to heating of the percolating water on fractured rocks. Thus, the presence of a single deep fault, fracturing the surrounding rock and high geothermic degree of the region are the main factors for the thermal waters formation.

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PETROLEUM PRODUCTION IN THE ARCTIC: COST-EFFECTIVE TECHNOLOGIES AND APPROACHES

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According to the United States Geological Survey (USGS), the area of the Arctic Circle holds enormous reserves of hydrocarbons estimated at 90 billion barrels and could also contain up to 1,770 trillion cubic feet of natural gas. Five countries have claimed some of the resources – Russia, Canada, Denmark, Norway, and the USA. .

However, Arctic oil exploration and production is much more technically challenging compared to other environments [1], [5]. It is considered to be a high cost venture with many risks and facing numerous obstacles such as an extreme climate, a poor existing infrastructure, very long project lead times, more complex spill containment contingencies and competition from other sources of hydrocarbons. Despite these challenges, technological improvements are making Arctic oil more accessible, and though the oil price is not as high as it used to be, some countries have implemented approaches and technologies, which allow reducing the cost of Arctic oil production.

This paper describes the experience of different countries in applying enhanced oil recovery (EOR) technologies and implementing cost-effective approaches to petroleum production under the harsh climate and fragile environmental conditions of the Arctic.

Since exploration activities in the Arctic are connected with high costs and short operating time, Schlumberger is focusing on integrating techniques to prioritize exploitation targets. For instance, PetroMod petroleum system modelling software is used to assess basin potential by tracking hydrocarbon generation, maturation and accumulation. The results are presented as 3D geologic models that are fully scalable from regional to prospect scale. The experts believe that such modelling allows improving exploitation risk assessment in advance of field operations, and time and effort can be concentrated in the areas with greatest exploration potential, while avoiding the areas with lower chances for success.

As for the next stage of oil production, i.e. drilling operations, one of the improving measures is using casing while drilling (CWD) [1]. This technique employs well casing as a drillstring: the casing is equipped with a drill bit at the bottom rotated until the target depth is reached and then cemented. CWD allows drilling and setting casing through problematic zones in one operation with relatively low flow rates to avoid hole enlargement. The low flow rates, in their turn, make it possible to use lighter rig equipment reducing the minimum ice thickness required during rig moves, thereby lengthening the winter-season operating time.

Since well cementing in the Arctic area is particularly challenging, Schlumberger developed ARCTICSET, the cement designed for low-temperature operations across