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WORLD HELIUM RESOURCES AND THE PERSPECTIVES OF HELIUM INDUSTRY DEVELOPMENT

The data on helium production in the world, its scales and the major countries–helium producers are presented. Particular emphasis is placed upon the composition of helium-contented natural gases. World helium reserves related to helium resource quality are estimated as of 2009. It is shown that helium main resources (reserves) are located in natural gases of Russian Siberian platform and in gases of the Midcontinent region and Rocky Mountains in the USA. Helium resources are also present in small quantities in other countries. Particular attention is given in Russia to the necessity of taking steps to protect high-qualitative gas-helium resources from losses during fuel processing or exporting Eastern Siberia natural gases in which helium is present as a < 1% component.

Key words: *helium, gases with high content of helium, helium sources, consumption volumes, helium resources, helium-gas-storage.*

1. Geological and geochemical patterns of the deep seated helium accumulation

The processes of helium concentration and dispersion defined both by its genesis and by unique physical and chemical properties of this element, such as lightness, permeability and complete inertia, represents the basis of productive helium accumulation in natural gases. The processes of the deep seated of helium accumulation is relatively well studied, beginning with the time-honoured work of G.S. Rogers "Helium-bearing natural gases", published in the U.S. in 1921 [Rogers, 1921], as well as more recent studies of Russian scientists – V.V. Belousov, V.P. Savchenko, V.A. Sokolov, A.L. Kozlov, V.P. Yakutseni, V.V. Tikhomirov, etc.

Genetically the main component of helium balance in the lithosphere, its sedimentary cover and natural gases, including the atmosphere, is represented by its heavy isotope ^{4}He that have radiogenic genesis. It is continuously formed during radioactive α-radiation by heavy elements, mainly of uranium-thorium series. Radiated α-particle is a helium nucleus with double positive charge. When passing through matter it interacts with him and by joining two electrons becomes neutral helium atom - its heavy isotope ^{4}He.

According to with the law of radioactive decay - the more α-emitters elements in the rocks and the older their age, i.e. the greater the duration and intensity of radioactive decay process, the more heavy isotope of helium generates in rocks. In the lithosphere to the greatest extent these conditions are met by the oldest rocks predominantly of felsic composition - Archean granites, which are widespread in the basement and therefore in the gases of sedimentary cover of ancient platforms.

Light isotope of helium (^3He) is widely distributed in cosmic space. In rocks and gases of lithosphere it is less distributed (10^{-6}-10^{-7}) than ^4He; and only in gases that flow together with mantle exhalation, i.e. from deep geospheres of planet, its ratio increases slightly: $^3He/^4He \sim n \cdot 10^{-5}$, though still remains significantly lower than in the outer solar space - 10^{-2}-10^{-1} (Fig. 1).

Thus, the genetic basis for the forecast of the extent of helium generation in the lithosphere is presented primarily by enrichment of lithosphere rocks by elements of U-Th series and their age - the intensity and duration of the process of radiogenic helium generation (^4He).

Considering only genetic parameter for the forecast of helium-bearing potential of natural gases in sedimentary cover is insufficient, since helium should not only be formed in sufficient quantities in rocks-generators, but also during migration into sedimentary cover it should be preserved, that is accumulated in it and, above all, in natural gases. However, due to the unique physical and chemical properties, helium tends to scattering rather than concentration.

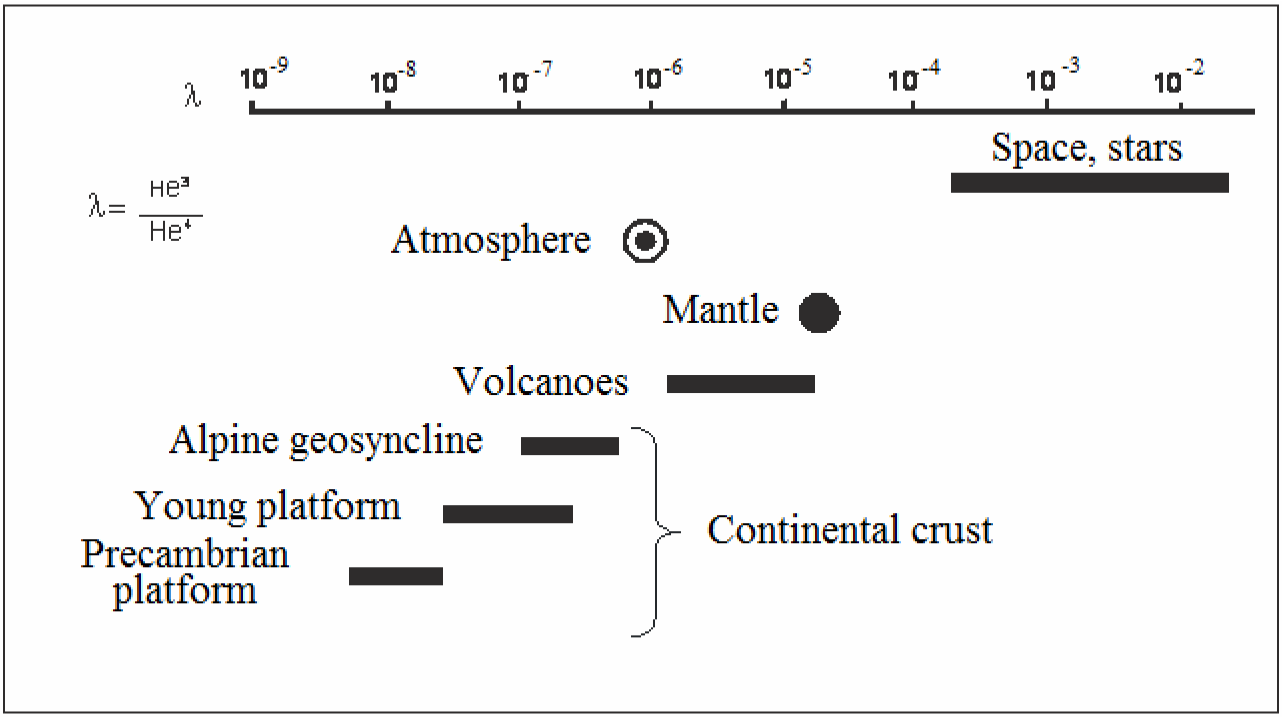

Fig. 1. General helium isotopic location and composition

In terms of lightness and permeability helium is second only to hydrogen, but unlike the latter, it is completely inert in natural conditions, it does not enter into any reaction in the inner of the earth and does not accumulate, which, coupled with high permeability contributes to its scattering. Therefore, helium is not found in free accumulations in nature. Actually, these properties of helium led to the fact that it is the only one among inert gases (Ne, Ar, Xe, Kr) that does not accumulate in the atmosphere and is lost by dissipating in the space of near-Earth together with hydrogen and form helium-hydrogen loop according to A.I. Vernadsky, predicted by him as early as 1911 and subsequently confirmed by space research.

There are other factors that can disturb the processes of accumulation of helium in the sedimentary cover and natural gases. They relate not to helium genesis and properties, but to such helium-independent processes as scale of gas generation and tectonic-magmatic activity of the mantle. The latter promotes pulse-coupled release of helium accumulated in the ancient crystalline basement rocks and its migration into the sedimentary cover, increasing its content in natural gases. Recent time intensive gas generation, especially methane, on the contrary reduces the relative content of helium in free gas accumulations. There are many additional factors that can mask primary helium content in these accumulations. In particular, recurrent gas generation accompanying immersion of gas-producing strata to a greater depth (>5 km) leads to decrease in initial helium content in them. That is why in areas of deep subsidence of basement the helium content usually sharply reduced even in the Paleozoic sediments.

However, despite some uncertainty in direct forecast of helium-bearing potential of natural gases on the basis of genetic parameters and properties of helium, a high degree of study of its content in the composition of natural gases of majority petroleum basins of the world (more than 200 thousand analyzes) allows to forecast quite correctly the content of helium in some petroleum basins and provinces depending on their geotectonic belonging and mineralogical composition as well as the age of the basement and sedimentary cover and, therefore, to assess its resource base.

The main volume of planetary geological resources of helium is located in the ancient basement rocks and overlying gas-producing platform sediments of Late Proterozoic and Paleozoic period. In the free accumulations of hydrocarbon gases they are concentrated mainly at depths less than 3.5 km in continental structures of ancient platforms with granite basement mainly of pre-Proterozoic age.

Helium-bearing potential of offshore natural gases are usually lower compared to the continent, even in Paleozoic sediments on the shelf, which is apparently due to the influence of younger oceanic crust and its basaltic composition depleted by α-emitters of U-Th series.

In the Mesozoic-Cenozoic deposits of young platforms, as well as areas of deep subsidence of basement the helium content in natural gases usually decreases sharply, averaging 0.01-0.02% at Epihercynian platforms and 0,001-0,005% in the areas of modern deep subsidence (Table 1). Exceptions to this rule up to “giant” helium content (> 1%) are usually associated with gas manifestations in the intermountain depressions formed in areas of recent (Mesozoic-Cenozoic) tectonic-magmatic activity within the ancient basement rock outcrops (Rocky Mountains, USA; perhaps Tarim petroleum basin, China), especially in nitrogen and carbon dioxide gases.

Table 1

Classification of natural gases related to their helium-bearing potential

Predominant ranges of helium concentration, %	Helium content in gases*	Predominant age of productive deposits	$^3He/^4He$	Main geostructural confinement of petroleum basin
< 0.005	Very low	Cenozoic	10^{-7}-10^{-6}	Modern mobile belt; different structural elements of the Alpine belt and transition zones, deep deflections (>5 km)
0.005-0.009	Low			
0.010-0.049	Slightly lower	Mesozoic	10^{-7}	Epihercynian platform, more rarely - boundary zones of ancient platforms with deep subsidence areas. Shelf zones
0.050-0.099	Slightly high	Paleozoic and Proterozoic	10^{-8}	Ancient platform stable and moderately activated in the early era of tectogenetic
0.100-1.000	High			
> 1.000*	Very high	Paleozoic, more rarely Mesozoic	10^{-6}-10^{-8}	Sharply intensified areas of ancient platforms with Meso-Cenozoic tectonic and magmatic activity

**In gases of mainly nitrogen and carbon dioxide composition the "giant" concentration up to 10% (sometimes more) are more frequent. In hydrocarbon gases they are rare.*

2. Helium resources in the world

The assessment of helium resource base is based on two independent parameters - resources (reserves) of natural gases (free gases), differentiated by age and depth; and the weighted average helium content in them.

There are no conventional conditions for helium content in gases used for its commercial production around the world. Because the wide variety of its concentrations in gases of petroleum provinces individual countries are obliged to recover it out of those gases, which they possess. Thus, in France the helium plant operates for a long period of time (approximately since 1960) on the basis of gases with high nitrogen content (12-14%) and helium content of 0.045 % imported from the Groningen field (Netherlands), in Russia – Orenburg plant operates with helium content of about – 0.056%. Yet, the main production of helium is now being conducted in the USA (70% of the world) from gases with more than 0.4% helium content.

The approach to the selection of helium resource for its extraction oblige to consider helium in natural gases at different helium content during helium resources assessing in the world. This is justified by the fact that the qualitative gas-helium resource potential inevitably run out together with increasing gas production during the petroleum appraising and development activity primarily in the onshore areas within well exploration and developing within ancient platforms.

Helium reserves are estimated in gases of any chemical composition. If necessary, resources (reserves) of helium dissolved in oil (associated gases) can also be considered, but their volumes are negligible - less than 0.5-0.8% of the total volume of helium in free gases; so it does not change the overall evaluation within the possible precision of calculations.

Accounting of reserves of all kinds of row materials, including helium, shall be carried out subject to the availability of technologies of its extraction from the deep seated areas with economically viable indicators of industrial production taking into account the progress in technology. Extraction of helium from gases is technologically available not only at its content of 0.005%, but even from the air - 0.000527% (in air separation plants). But the cost of helium extraction in this case increases almost in directly invers ratio to its content.

Currently, about 85% of the world total production of helium is carried out from gases with helium content exceeding 0.3% at cost of 0.5-0.7 $\$/m^3$ (ex-factory). Another 14% helium production comes from gases with helium content 0.09-0.17%, with the same cost, due to its associated production at the liquefied natural gas plants (Table 2).

Table 2

Estimated cost of helium (excluding NGL process)

Helium content in gas, %	Cost of helium recovery, \$ per m^3 1995 prices	Sources of gas feedstock taking into account the cost of associated commercial product
0.0005	> 100	Air on air separation plants. Ar, Ne, Kr, Xe, liquid nitrogen and oxygen
0.010-0.030	20-40	Gases of Western Siberia, Alaska, the Barents Sea: broad fraction of light hydrocarbons, ethane and liquefied propane-butane.
0.050-0.060	10-15	Orenburg field: broad fraction of light hydrocarbons, sulfur, liquefied propane-butane. Groningen field: broad fraction of light hydrocarbons, ethane, liquefied propane-butane and nitrogen.
0.10-0.30	0.8-2.0	Hassi R'Mel field and In Salah province (Algeria), as well as Kovykta field (Russia). Broad fraction of light hydrocarbons, ethane, liquefied propane-butane and nitrogen.
0.30-0.50	0.5-1.2	Fields of Midcontinent region (USA), Odolyanovo (Poland), and the south of Eastern Siberia (Russia). Broad fraction of light hydrocarbons, ethane, liquefied propane-butane and nitrogen.
> 0.50	0.3-0.8	Fields of Midcontinent region (USA), Riley Ridge (Wyoming, USA). The whole complex of hydrocarbon products, liquid nitrogen, and for the latter - sulfur and solid carbon dioxide.

Previous calculations (1995) showed that the cost of commercial extraction of 1 m^3 of helium from gases with helium content of 0.020% can reach 20$, taking into account the additional commodities, with helium content 0.005% - at least 80-100$ for the same conditions. For the last 20 years the price for helium in the world market has changed from 1.8 to 2.5-3.0 $ per m^3 (ex-factory). The price is predicted at approximately the same level, with a slight increase for the next 15-20 years at least given the current availability of high-quality raw material base (He > 0,15%), its rational development and expected volumes of consumption in the world.

At the beginning of 2009 the world reserves of hydrocarbon gases amounted to 175.50 trillion m^3 [Worldwide Look…, 2008]. Their indicative allocation by age, as well as the weighted average helium content is given in Table 3.

Table 3

World's helium reserves in hydrocarbon gases as of 1st January 2009

Age of gas producing deposits	Gas reserves		$He_{av.}$, %	Helium reserves	
	trillion m^3	% from total reserves		billion m^3	% from total reserves
Cenozoic	28.10	16	0.003	0.84	1.2
Mesozoic	108.79	62	0.018	19.58	29.3
Paleozoic and Proterozoic	38.60	22	0.12	46.32	69.5
Total	**175.50**	**100**	**~ 0.038**	**66.74**	**100**

As Table 3 shows, the total reserves of helium in hydrocarbon gases of the world as of 1st January 2009 by reserves categories close to ABC_1 in Russian reserves totaled 66.78 billion m^3. They have increased significantly compared to 2006 due to the inclusion of additional gas reserves discoveries in the Persian Gulf (Qatar, North Arch, Huff Formation) and adoption of modern production technology of their associated production on the liquefied natural gas plants.

The total reserves of helium in gases with helium content from and more than 0.15% is approximately 36 billion m^3. For the latter the increase is possible due to new discoveries of high-helium-content gas reserves in Eastern Siberia (Russia) and Rocky Mountains (USA).

The majority of the hydrocarbon gas reserves of the world (78%) contain less than 0.05% of helium in its composition (Fig. 2).

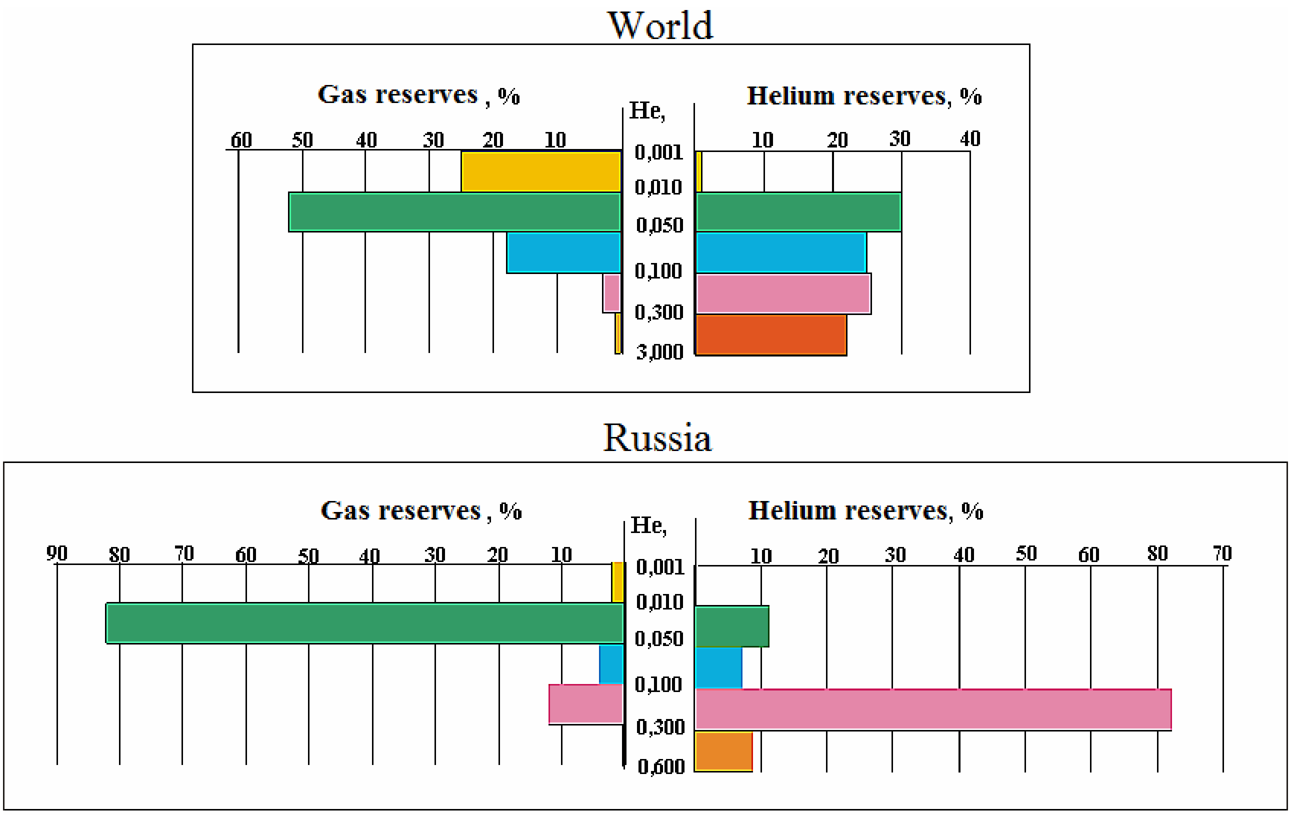

Fig. 2. Distribution of hydrocarbon gases and helium reserves in the world and in Russia

Helium content in hydrocarbon gases at great depths (> 4.5-5.0 km) even in the Paleozoic sediments, as well as in gases of almost all of the gas giants of the Russian Arctic onshore of and North America onshore, along with shelves of the North Sea, Barents Sea, Kara Sea, Bering Sea, Beaufort and other Arctic seas varies predominantly in the range of 0.012-0.035%. This predominance in discovered gas reserves of later generation (Cenozoic, Mesozoic, Paleozoic) has predetermined lower average helium-bearing potential of natural gases of the world ~ 0.038% (Table 3).

Only four regions, which geological conditions provide the possibilities for commercial helium accumulation in natural gases (He > 0.15%) were revealed during oil and gas exploration activity overall in the world. All of them are confined to the ancient platforms - Eastern European, Siberian, North American and African.

The most significant reserves of high quality (> 0.5 %) gas-helium raw materials abroad were identified in petroleum basins of the Midcontinent region and Rocky Mountains (USA). In the latter area, in some petroleum basins (San Juan, etc.) associated with remnants of ancient rocks of the North American Plate, processed during tectono-magmatic activity in the era of Laramide (Late Cretaceous - Early Paleocene), the richest (in terms of helium content) gas fields in the world were identified - 5-10% with commercial reserves of primarily nitrogen gas (Table 4). Nowadays almost all of them are worked out; but here one of the largest in terms of helium reserves field of carbon dioxide gases in the United States are explored and developed - Riley Ridge with He - 0,55% and helium reserves about 2.5 billion m^3; the Ridgeway field that is being developed now.

The richest deposits of the Midcontinent region in terms of reserves and helium content are gradually depleted due to intensive long-term gas production, but still remain significant residual reserves for operating of the main active helium plant here (Keyes).

The largest gas-helium field in the Sahara-Libyan petroleum province - Hassi R'Mel - contains 0.17% of helium with initial gas reserves of 1.5 trillion m^3 is significantly worked out. Nowadays its counterparts in terms of helium content but not in terms of reserves were revealed in In Salah province, Ahnet depression (Algeria).

Within the outer part of the Poland Eastern European platform in Presudetic monocline the Ostrow-Wielkopolski (Odolyanove) helium field with high nitrogen content (30-40%) is almost worked out.

In the 1970s in Kazakhstan within the Turan plate the group of deposits of nitrogen gases has few reserves, but high helium content - 0.5-0.6% (Uch-Aral, Aznagul, Kempir-Tube, etc.) were explored.

In China the identification of helium-bearing gases is most likely in the Tarim Basin due to geological and tectonic conditions, but the information about them is not yet published.

The reserves of natural gases in Pacific Asia, overseas Europe, Middle East, South-Western Africa and South America, mainly focused in productive sediments of Mesozoic and Cenozoic on onshore and offshore, usually have poor helium-bearing potential (0.001-0.020%). In recent years the main increase in helium reserves of foreign Asia was related to the exploration of the Permian deposits primarily in the area of the Persian Gulf offshore (Qatar, North Dome).

Table 5 provides information on the dynamics of helium reserves by major foreign countries.

A number of papers discuss unconventional sources of helium. Among them - coal and mine gases, aqueous gases and gas-saturated fractured rocks of ancient basements. These are definitely considered as helium sources, but they are not comparable with free gases in terms of cost of development and, what is most important - possible production volumes.

In the middle of the XX century the helium industry of the former USSR experienced an acute shortage of quality gas-helium raw materials, therefore even gases dissolved in oils of Romashkinskoye and Mukhanovskoye fields were used for helium extraction (He – 0.04-0.07%), which, after liquefaction of methane homologues almost doubled helium content.

Table 4

Some world gas-helium deposits (including deposits with "huge" helium content in petroleum basins of Rocky Mountains in USA)

Country	Petroleum basin	Field	Age	Depth, m	Main gas composition, %					
					CH_4	Σheavy hydrocarbons	N_2	CO_2	H_2S	He
USA	Rocky Mountains, New Mexico	Hogback	C_2	1879	29.1	6.1	54.6	2.0	-	7.17
		Bitlebito	T	297	14.4	6.4	78.9	0.3	-	8.9
		Table Mesa	C_1	2287	5.9	1.6	83.8	1.4	-	5.7
		Rattlesnake	C_1+D	2119	14.2	2.8	86.2	2.8	-	7.81
		Tosito	C_1	2036	2.6	0.8	96.3	0.3	-	7.27
		Riley Ridge	J	1900-2100	19-20	-	7.8	68.69	3.7-4.2	0.55
	Rocky Mountains, Arizona	Navajo-Chambers	P-T	~300	0.1	-	90	0.8	-	8-10
		Pinta Dome	P	~350	-	-	85	1.5	-	8
		Bounder Butte	C_1	1695	43.7	4	36.9	9.6	-	3.79
		Harley Dome	J_3	262	5.1	2.3	91.5	1.1	-	7.02
	West Inner, Texas-Oklahoma	Hugoton-Panhandle	C_2-P	430-1670	50-77	7-14	10-41	0.1	-	cp 0.47
		Keyes	C	1431	64.3	6.2	26.6	0.7	-	2.2
		Cliffside	P	1011	65.5	7.2	25.1	0.4	-	1.8
Algeria	Sahara-Libyan	Hassi R'Mel	T_2	2150	82.2	12	5.6	0.2	-	0.17-0.19
Poland	Presudetic monocline	Odolyanovo	P_2	1400-1720	60-68	1.5	30-40	0.2	-	0.32-0.4
Netherlands	Central European	Groningen	P_1	2800-2975	82	4	12-14	0.9	-	0.037-0.055

Table 5

Dynamics of helium reserves (billion m^3) in some selected countries [Fettakh, 2006, with amendments]

Country	1997	2001	2005	$He_{av.}$, %
USA	11.0	8.9	8.9	0.4
Canada	2.1	2.0	2.0	0.15
Algeria	2.1	3.0	3.0	0.18
Qatar	1.0	2.0	2.0* (10)	0.09 (0.09-0.2)
China	1.1	1.1	1.01	0.15
Poland	0.28	0.28	0.28	0.4
Total	**17.58**	**17.28**	**17.28 (27.28)**	**-**

*According to the latest data the helium reserves in Qatar increased by 2005 to 10 billion m^3 with helium content 0.09-0.2%.

Source: US Geological Survey, Mineral Commodity Summaries, 2006

Nowadays free gases only with slightly increased helium-bearing potential 0.05-0.06% are mainly distributed in the fields of European part of Russia. A small part of gas reserves with helium-bearing potential 0.10-0.25% in the western fields of Russia has almost been worked out by now (Saratov region, Komi Republic, etc.).

The bulk of natural gas reserves identified in Russia are characterized by relative low concentrations of helium. Among them all productive Mesozoic sediments of Ciscaucasia, the Caspian Sea region, Western Siberia, Arctic latitudes territories including the northern shelf, as well as the north and east of Eastern Siberia and the Far East (Fig. 3). Helium-bearing potential of natural gases therein varies mainly in the range of 0.008-0.025%. In productive deposits of Cenozoic of Ciscaucasia Sakhalin and Pacific shelf the helium-bearing potential of gases is low, mostly 0.001-0.006%.

In the second half of the XX century the discovery of large reserves of high-quality gas-helium fields in Eastern Siberia (0.2-0.6% helium content) has begun. Among them, first of all, the Kovykta field which specific feature of gas composition was extremely low nitrogen content – 1.5%. Although the helium content there (0.26-0.28%) is lower than in fields of the Midcontinent region (USA), where the helium content varies from 0.7 to 2.0%, but the latter are highly nitrogen (15-26%) (Table 4). Therefore helium concentrate obtained after liquefaction of hydrocarbons and flowed in Cliffside storage, was of lower quality (He ~ 70%) than the He which can be obtained with the same energy consumption from gases of Kovykta field - 85.6%.

On the far south of the ancient Siberian platform 26 gas-helium deposits have been already discovered, some of them with very large (> 200 million m^3) or even unique (> 1 billion m^3) helium reserves (ABC_1+C_2) with helium content 0.15-0.57%. Among them Kovykta and Dulisminskoye fields in Irkutsk region, Sobinskoe and Yurubcheno-Tokhomskoye in Evenkiya region, Verkhnevilyuchanskoye, Tas-Yuryakhskoye, Sredne-Botuobinskoye and Chayandinskoe in the Republic of Sakha (Yakutia) (Fig. 4, Table 6). Summary reserves of helium (category ABC_1+C_2) only for the fields of Eastern Siberia are estimated to about 16 billion m^3 with helium content varying in different regions on average from 0.2 to 0.6%. Helium reserves are concentrated in free gas deposits or in gas caps. Many of them are prepared for commercial development, some even developed for local gas supply, but in small amounts (0.1-0.2% of prepared reserves).

It should be noted that helium resources in the region are not limited by already identified fields because the prospecting activity will be continued, and the inferred and the prospective resources of helium in the Eastern Siberian (category C_3+D) are estimated to about 30-35 billion m^3. In other words, the largest (in terms of already prepared for development reserves and inferred resources) gas-helium province was identified within the south of the ancient Siberian platform; and it has no counterpart in the entire Eurasian continent. It is also important to emphasize that, unlike the North American fields of the Midcontinent region, resource base of which is largely exhausted, the Eastern Siberian resource base have not began to developed. However Russia will face the same problem as the USA in due time - the need to maintain reserves of helium resources in the future, as the discovery of new zones with high helium-bearing potential gases are not expected within the entire territory of Russia and neighboring countries (former USSR). New gas-potential on their territories will be associated with Mesozoic-Cenozoic gases with poor helium-bearing potential, or from greater depths in the Paleozoic.

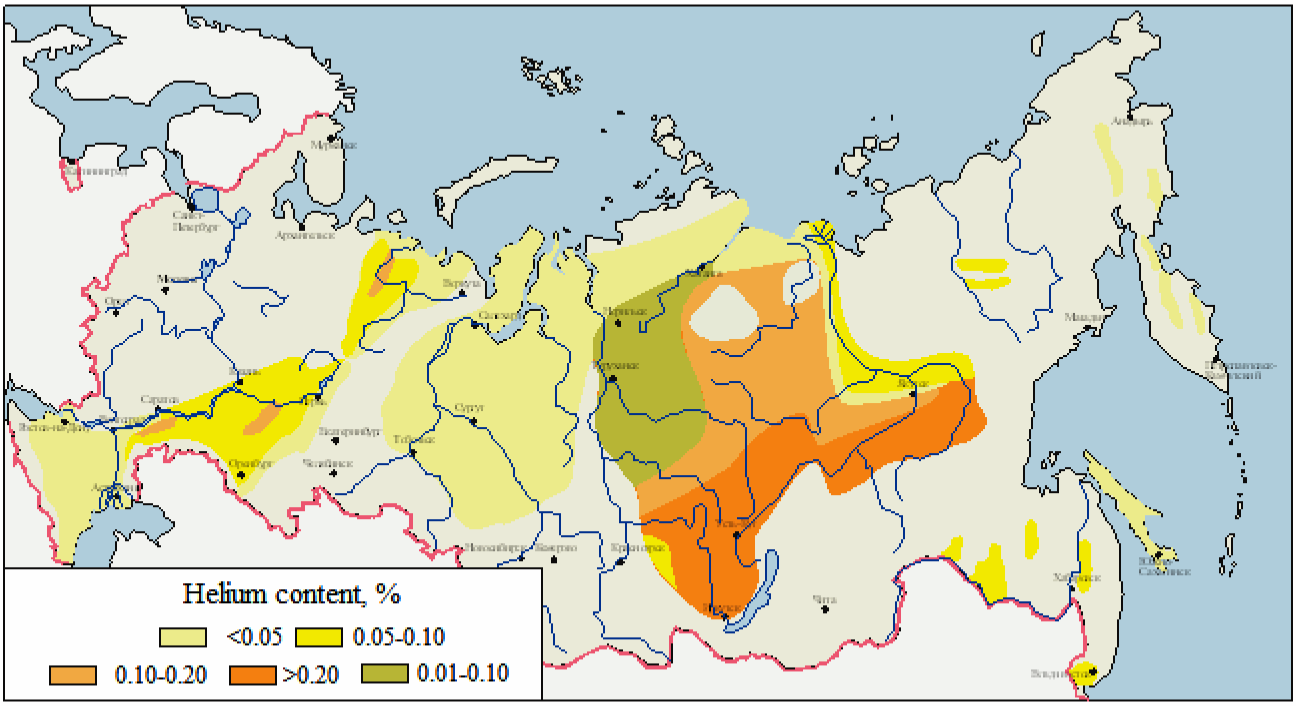

Fig. 3. Scheme of helium content distribution within the Russian petroleum basins

3. World production of helium and dynamic of its consumption

Commercial extraction of helium was launched in 1917 almost simultaneously in Canada (Hamilton city, from gases of Black Hills field) and in USA (Petroleum city and field), i.e. the 100th anniversary of the creation of the helium industry is closed. The impetus for the beginning of its commercial extraction from natural gases was the development of the airships during the First World War. Both plants were quickly exhausted their resource base and were relocated in Canada to Calgary city (Bow Island field) and in the U.S. to Amarillo city (Cliffside field). A total of 57 thousand m^3 of helium were extracted from gases by 1921 at cost of 17.2 $/$m^3$ for 1921 [Kauter, 1962]. For comparison, in 1960 on the Keyes plant (Oklahoma, USA) it was already 0.3 $/$m^3$ [Deaton, Haynes, 1961].

Long years, the USA had a monopoly on resource base of helium, who identified the richest in terms of reserves and quality (He > 1%) gas-helium fields and dramatically expanded the scope of its consumption and production. The peak of demand on helium in the USA (140 million m^3) coincided with the implementation of the space program "Apollo".

Accelerated use of gas reserves as an energy source, in which helium is only a small admixture, leads to its losses. Therefore, on September 13, 1960 the U.S. Congress had amended the Law "On helium", operating in the country since 3rd March 1925. The amendments were adopted "in order to protect the safety and general welfare of the United States" and contained a detailed description of phased actions for execution of the Law "On helium". Creation of a reserve of helium was stipulated as nitrogen-helium concentrate extracted from gases with helium content from 0.3% and higher with the volume close to 1 billion m^3 of helium equivalent, given approximately 10 years of the world's natural gas consumption. The government has pledged to give a credit for construction of new plants for production of nitrogen-helium concentrate, as well as its purchase and transport of helium to storage space - especially equipped with state underground structural helium-gas storage place in depleted gas-helium Cliffside field with an initial helium content about 2%.

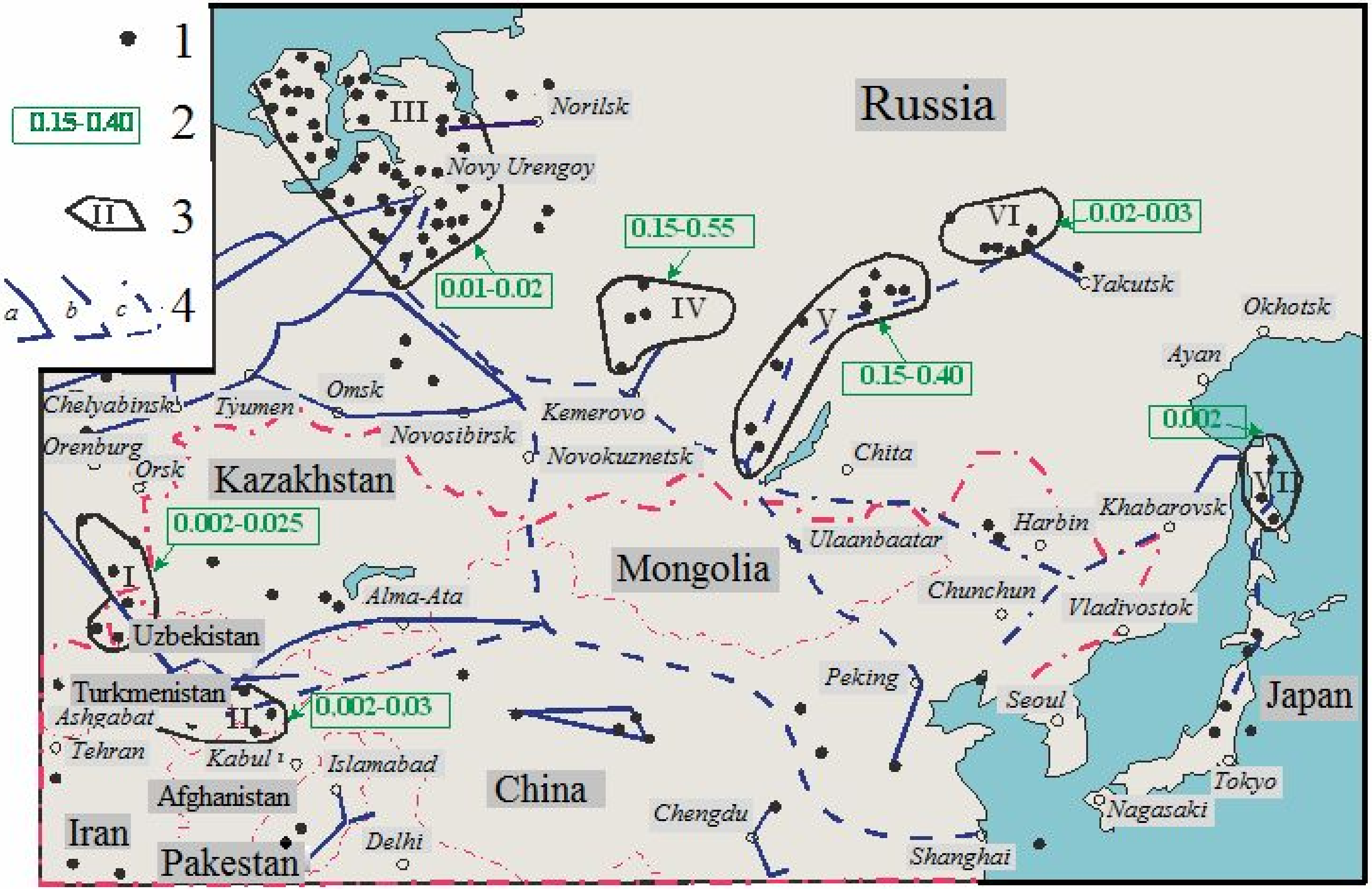

Fig. 4. Possible directions of gas-main pipelines in countries of the Asia-Pacific region and characterization of helium-bearing potential of natural gases based on their main raw material bases

1 - main gas fields; 2 – helium-content intervals of natural gas (mostly by reserves); 3 - base of natural gas: I and II – Pre-Caspian depression and Central Asia basins, III - Western Siberia, IV - Yurubchenskaya, V - Nepa-Botuobinskaya with Angara-Lena step, VI - Viluiskaya, VII – Sakhalin; 4 – gas pipelines: a) current, b) possible into the Asia-Pacific countries (by JSC "Gazprom"), c) possible with the advice of the PRC.

Table 6

Main gas-helium fields of Eastern Siberia with helium reserves of C_1 category > 100 million m^3 and helium content > 0.15% (as of 1st January 2009)

Field	Gas type	Reservoir depth, m	Helium reserves of categories ABC_1+C_2, million m^3	Main gas components, % (об)			
				CH_4	∑ heavy hydrocarbons	N_2	He
Krasnoyarsk Territory (Evenkia)							
Sobinskoe, oil-gas-condensate	free gas	V, 2499-2591	907	67.5	6.4	25.3	0.57
Yurubcheno-Tokhomskoye, oil-gas-condensate	free gas	Rf, 2250-2450	724	83.0	8.4	7.8	0.18
Irkutsk region:							
Dulisminskoye, oil-gas-condensate	free gas	Є-V, 2600-2750	205	84.1	9.0	6.8	0.16
Kovyktinskoye, gas-condensate	free gas	Є, 3110	5062	92.3	5.7	1.5	0.26-0.28
The Republic of Sakha (Yakutia)							
Verkhnevilyuchanskoye, oil-gas	gascap+ free gas	Є-V, 1620-1720	280	84.5	7.5	7.5	0.13-0.17
Tas-Yuryakhskoye, oil-gas-condensate	gascap + free gas	V^{Bot}*, 1908-2011	459	84.4	7.0	8.1	0.38
Srednebotuobinskoe, oil-gas-condensate	gascap + free gas	Є-V, 1550-1900	664	83.8	6.9	8.0	0.2-0.67 (av. 0.48)
Chayandinskoe, oil-gas-condensate	gascap	V^{Bot},1450-1800	1400	85.6	6.9	8.2	0.43
Chayandinskoe, oil-gas-condensate	free gas	$V^{Kham+Tal}$**, 1470-1800	5790	no data	no data	н.с.	0.65

**Botuobinsky layer;*

*** Khamakinsky + Talakhsky layer.*

Program of accomplishment of a reserve of helium in the amount of 0.9-1.2 billion m^3 was completed ahead-of-schedule and in 1973 the purchase of concentrate by government was stopped.

Many years the Cliffside helium-gas storage place was used and replenished as state property and only in 1996 the Congress supported the proposal to privatize reserve of helium resource, which was accepted by amending the Law "On helium" with a number of limitations protecting the interests of the state, as well as with aim not to harm the market. The privatization process was extended until January 2015 with preservation of the part of technological assets and concentrate as the state property (170 million m^3 in the helium equivalent).

The main reason for the adoption of amendment "On Privatization of helium in 1996" to the Law "On helium" was the loss of the world monopoly on helium quality raw material and its production by the U.S. The reason was, of course, the other - the fiscal debt for maintenance of storage in Cliffside[1].

As shown above, in the second half of the last century in Russia as a result of oil and gas exploration the opening of a unique high-quality gas-helium resource base in Eastern Siberia took place. A real opportunity to create a new major scale helium industry was defined and although helium production on the basis of this industry in Russia had still not begun. The U.S. monopoly on raw materials for production of helium, considered in the U.S. as a strategic raw material, was lost.

In the field of helium production the U.S. has also lost the leading position in connection with the development of gas transport in liquefied form. Residual free gas after the liquefaction of hydrocarbon part of its components consists essentially of nitrogen, helium, argon and neon (Table 7). And, if there is little nitrogen in gas (<2-3%), even under moderate helium content (0.07-0.10%) the residual gas phase is greatly enriched by helium and serves as a cost-effective source of its extraction as an additional valuable commodity product.

Table 7

Boiling temperatures of the major components of natural gas mixtures and air at atmospheric pressure

Component	t_b, °C	Component	t_b, °C
He	-268.78	CH_4	-161.49
H_2	-252.72	C_2H_6	-88.63
Ne	-245.93	CO_2	-78.50 (subliming)
N_2	-195.78	H_2S	-60.28
Air	-194.28	C_3H_8	-42.07
Ar	-185.71	n-C_4H_{10}	-0.49

[1] *By the end of 1992 the amount of debt on the Helium program totaled $ 1.2 billion, of which more than 1 billion consisted of interest, i.e. was the operation of the bill and could be canceled without prejudice to the deficit by "accounting write-offs', which was confirmed by the Central financial management, as well as by the Inspector General of the Interior [Campbell, 1994].*

At the turn of XX-XXI centuries, there was a group of plants for production of liquid methane and helium at the same time. Among them Arzew and Skikda plants in Algeria, acting on the basis of the main gas pipelines from fields of Insalah province (Hassi R'Mel and other) on the Mediterranean Sea and Ras Laffane in Qatar (North Dome) on the Persian Gulf. Investors of these plants beside the national companies were mostly U.S. companies; but the situation with the prospects of the global production of commercial helium has changed radically. And although even nowadays a priority in the annual production scale of helium still belong to the U.S. - 80-100 million m^3, but the monopoly on its helium resource base was lost along with the incentive to maintain reserve helium reserves for the future from the state budget. Nowadays the store in Cliffside continues to operate using its reserves, but on market principles, and a considerable percentage of the sales of helium (25-34%) is provided by its withdrawal from the reserve storage.

Eleven helium plants were built in the U.S. until 1962 (Table 8, Fig. 5), excluding short-term operating plants for helium extraction from nitrogen gases with helium content 5-10% on small gas fields in the basins of the Rocky Mountains (New Mexico, Arizona, Utah, Colorado).

Extension of the scope of helium use, which began in the middle of the XX century, continues today. New, large, and thus capital intensive helium consumers arise. For example, the network of high-speed railways on magnetic levitation (500-600 km/h) is extending. Helium production is increasing accordingly (Table 9). Therefore, the question of the adequacy of its resource base, guaranteeing stable and long-term development of helium industry, becomes urgent.

Modern technology of helium extraction from natural gases in the world is based on cryogenic methods proposed in the 20-ies of the last century by H. Kamerlingh Onnes and K. Linde. The attempts to move on the adsorptive or diffuse methods of its extraction from gases based on the differences in permeability of the individual gas components through molecular sieves (polymers) have been unsuccessful during attempts to its extraction on an industrial scale. According to DuPont company, built Pilot Plant in Canada to assess the opportunities of this method, the inevitable deposition of micro dispersed particles on the diffuse surface carried by natural gas, and the need for regular cleaning (replacement) nullify the expected technical and economic advantages of diffuse method compared with cryogenic one. Moreover, it has a very low productivity.

The cryogenic technology of helium extraction from gases widely implemented in the world for almost a century have been based on the liquefaction process (condensation) of all major gas components (CH_4, heavy hydrocarbons, CO_2, H_2S) in accordance with their critical parameters (Table 7), generally to the boiling point of methane - minus 160 °C (under elevated pressure). Then the gas residue - nitrogen-helium concentrate - is decontaminated of the impurities (N_2, H_2, Ar, Ne, etc.) for the production of marketable helium (technical or different levels of purity), or injection of nitrogen-helium concentrate without its decontamination in the storage place.

The helium production using NGL process in Algeria and Qatar is based on the same principle.

Full-scale liquefaction of natural gases to the boiling point of helium, based on the adiabatic "compression-expansion" (condensation-stripping method) is a metal- and energy-intensive process. The more nitrogen contains in the gas - the greater the amount of residual nitrogen-helium concentrate, the lower the helium content, the higher energy costs of nitrogen condensation and the higher the cost of commercial helium.

For example, according to LenNIICHimMash (2002), a nitrogen-helium concentrate, produced from natural gases of Kovykta field (N_2 – 1.56%; He – 0.26%) contain 85.6% of helium, while from Sobinskoye field (N_2 – 25.4%; He – 0.56%) - only 1.88% of helium. Accordingly, the cost of helium produced from them changes, even if all other things being equal, which in fact are far from such. That is why during quality assessment of gas-helium raw material as a source of industrial helium recovery it is necessary to consider not only helium content in gases, but also content of other its components, particularly low boiling point nitrogen.

Virtually all modern helium plants in the world (16 to date) operate using the same principle - the low-temperature condensation of all major gas fractions, including low-temperature nitrogen. In the remaining gas part of technical helium H_2 and Ne are removed by oxidation (burning) using hydrogen on catalyst and neon adsorption. Inevitable residual impurities are removed from technical helium (99.8%) up to degrees of purity ordered by customer, up to 4-5 decimals, accordingly, the price of high purity helium increases.

Table 8

Major gas-helium plants built in USA until 1963 [Campbell, 1994]

Belonging to (until 1996)	Plant, location	Processing capacity for helium, million m^3/year	Selected gas components, % (vol.)		Production start year	Price of plant, million $ 1965 price
			helium	nitrogen		
Government - as well as plants of the American Iron Ore Management (Bureau of Mines), releasing "A" helium (99.995% purity)	Amarillo (Cliffside), Texas	1.7	1.8	25	1929	2.1
	Excel (Panhandle), Texas	6.79	0.9	10-18	1943	8.5
	Otis, Kansas	1.42	0.7-1.4	14.5	1943	3.0
	Shiprock (Rattlesnake), New Mexico	1.42	5.8	80	1944	2.7
	Keyes (Keyes), Oklahoma	8.5	2.0	26.5	1959	11.1
	Kerr-Mc Guise (Pinta Dome), Arizona	no data	8.2	90.1	1962	н.с.
Private plants (mainly in gas pipelines) - produces crude helium (nitrogen-helium concentrate containing an average of 70% helium) for sale to Bureau of Mines for storage, as well as helium for sale	Bushton, Kansas	no data	0.46	-	1962	23.0
	Ulysses, Kansas	no data	0.43	-	1963	22.0
	Liberal, Kansas	90	0.30	-	1963	30.0
	Dumas, Kansas	110	0.66-0.71	-	1963	25.0
	Hensford, Texas	no data	0.66-0.71	-	1962	25.0

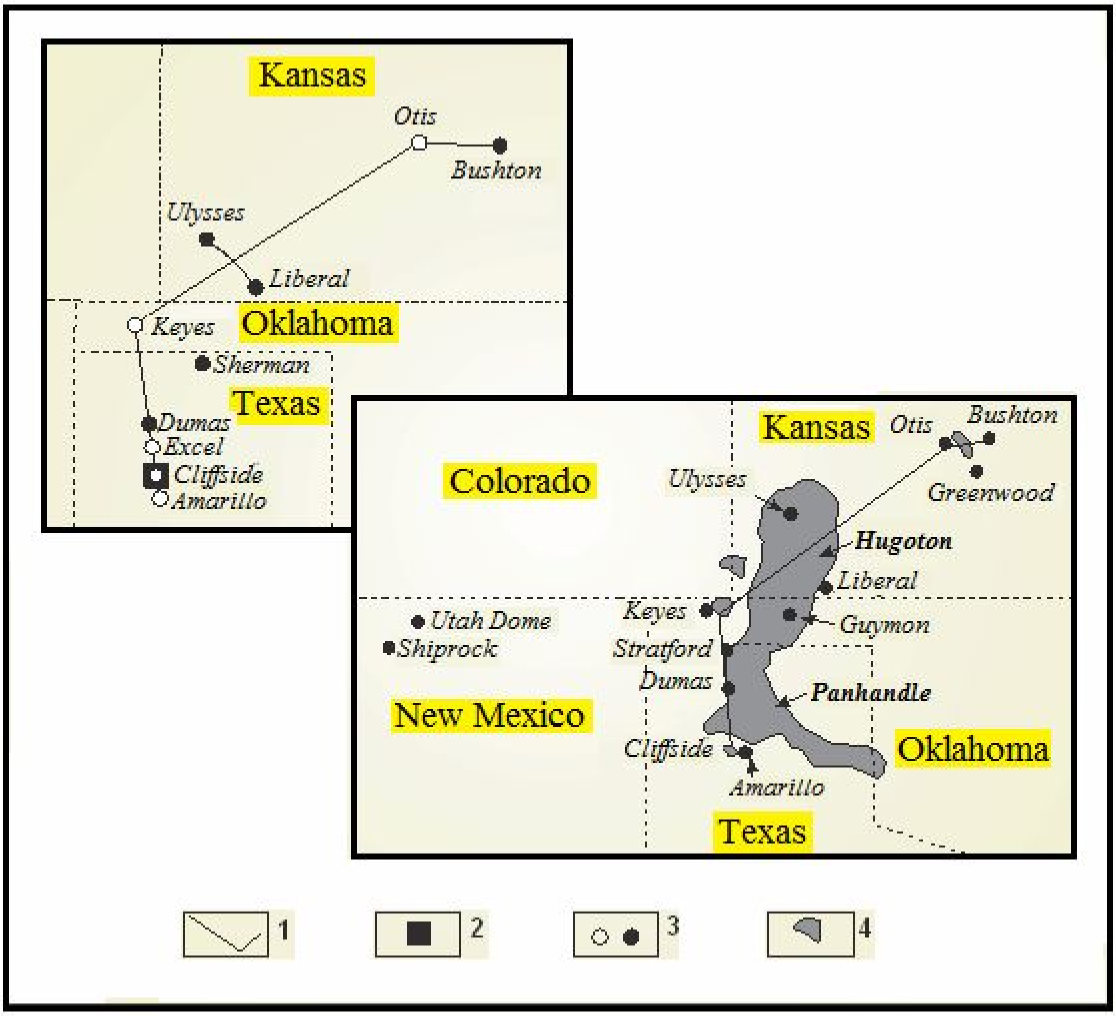

Fig. 5. Scheme of location of helium plants, pipelines and fields of Midcontinent region, USA
[Hamak, Gage, 1993, with amendments]

1 - helium pipeline to gas-helium storage in Cliffside; 2 - gas-helium storage in a depleted gas-helium field Cliffside; 3 – helium-extraction plants producing marketable helium and nitrogen-helium concentrate; 4 - gas-helium fields.

Table 9

Helium production in the world from natural gas (million m^3) [Fettakh, 2006, with amendments]

Country	1997	1998	1999	2000	2001	2002	2005
USA	116	118	114	117	87*	87*	87*
Algeria	16	16	16	16	16	17	17
Russia	4.2	4.2	4	5.3	5.3	6.1	3.8 (2006)
Poland	1.4	1.4	1	1	1	1	1
Qatar	-	-	-	8	8	8	17
Canada, China, Netherland and other	no data	no data	no data	no data	no data	no data	no data
Total	137.6	139.6	135	147.3	115.3*	119.1*	125.8*

** excluding stockpile of helium reserves from storage in Cliffside in 2001-2005.*
Source: US Geological Survey, Mineral Commodity Summaries, 2006

Now in Algeria and Canada the further increase of production of liquefied gas and, consequently, helium concentrate as an associated product is expected, i.e. production of helium based on NGL processes will increase. The base portion of commercial helium in the coming years will come on the world market still from the U.S., and if necessary, it may even be increased due to its picking from storage. The role of other countries of the world, including Russia, in modern helium industry (China, Poland, France, etc.) is insignificant.

The total consumption of helium in the world, based on an annual rate of growth of demand for it for the period 1995-2002 - 5.7% [Fettakh, 2006] - could be estimated to 210-220 million m^3 in 2010, and 380-410 million m^3 by 2020. But let's take into account the lowering effect of the current world financial crisis, which primarily affect the development and implementation of innovative projects, many of which based on the use of helium. Let's assume too that the world consumption of helium in 2020 will not exceed 300 million m^3. To the beginning of 2009 reserves 36 billion m^3 helium raw materials (> 0.15%) reserves already have been prepared for developing in the world. As shown above, i.e. at the 2006 level of world consumption of helium around 160 million m^3 its existing stocks can provide consumption for over 200 years, and even if we take into account that not all quality gas-helium raw materials will be used for the extraction of helium, but only part thereof, the helium industry in the world holds promising developing perspective and consequently good opportunities of the expansion of areas and volumes of helium consumption.

But we must remember that there is no direct link between maintaining of demand for helium and its reserves since helium is associated component-impurities in natural gases and therefore it is in a strong depending on the increasing gas production rates, including high-helium-bearing gas. This fact oblige to take measures to protect against losses at least the highest-quality part of gas-helium raw materials, for example, with gas content more than 0.2-0.3%. Methods of such protection are limited – either to mothball (not develop) fields with high helium content, keeping them in the future as a reserve, or to extract from them not only commercial helium, but also nitrogen-helium concentrate for wholly or partly storage and that was implemented in the United States under the Helium Program of 1960-1973. The choice between these opportunities will be determined by energy supply and economy of country, which owns high-quality resources of helium. A special role in this matter belongs to Russia, as it focuses on its territory a significant portion of the planet's resources of helium in high-quality gas-helium raw material (0.2-0.6%). If reserves of helium in many countries are declining due to prolonged gas production, in Russia they are practically not yet. There are good perspectives that exploration activity can increase the current Eastern Siberia helium reserves.

In close future, 2015-2017 in Eastern Siberia the intensive gas production is planned for the internal gas supply of the east of Russia, and mainly for gas exports to Asia-Pacific countries. It is referred to high-helium-bearing gases as there are no low-helium-bearing gases among the fields discovered in the southern Eastern Siberian platform.

If you focus on gas production only from Chayandinskoye field gas cap (He - 0.43%) in the initial amount of 30 billion m^3, the annual loss of helium reserves amount to about 130 million m^3, i.e. in the amount close to modern world consumption. Over time, due to development of Eastern Siberian gas-helium field with fuel, technology and export purposes, these losses will increase sharply. Therefore the problem of the rational and integrated development of gas-helium raw materials must be addressed in a timely manner, not only in conjunction with its high commodity significance in the domestic and global markets, but also in view of its unique properties and indispensability in many innovative industries, its limited high-quality resources on a global scale and, accordingly, their irreplaceability and especially taking into account the associated nature of its reserves in natural gases, the production intensification of which with fuel and energy targets is increasing worldwide.

In 2006, at Cambridge University three-year study were launched under the project "Resources of helium" under the sponsorship of BOC companies (British company for industrial and special gases) and program UKAE's Fusion Engineering Outreach. The expected result of the research is to "determine how long the industry can count on this scarce resource". The question is fundamental, because it either opens or inhibits the critical to world civilization research directions in the field of safe nuclear energy, cryogenic technology, ground speed magnetic levitation transport, ubiquitous formation in world systems of health care the wide network of magnetic scanners (NMR), microelectronics, aerospace and defense research. Many others only nascent consumers based on the unique properties of helium, which cannot be replaced by other elements [Yakutseni, 2009]. The positive answer to this fundamental question can be done on the basis of current discoveries of high-quality gas-helium raw materials within Russia (Eastern Siberian platform) the positive answer is valuable above all for the next century, depending of the rational development and conservation of existing and projected resources of quality gas-helium raw materials.

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