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Current state of the rare earth industry in Russia and Siberia

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Abstract

The paper presents an evaluation of the rare earth industry in the former Soviet Union, Russia and the world. Main areas of use of rare earth metals, primary resources of rare earth metals are considered, forecast for the industry development is given. The conclusion about the prospects and opportunities of the organization of production and separation of rare earth metals at the Siberian Chemical Combine in the West Siberian region is made, and possible sources of raw materials for this production are analyzed.

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1. Introduction

The rare earth industry produced up to 8500 tons of REE a year in the USSR in 1989-1990 and was out-grossed only by the USA on its scale. As the result of the collapse of the USSR, Russia remained without a complex of enterprises engaged in the processing of ore materials of REM obtaining concentrates of both mixtures and individual REE[1,2].

Full technological cycle from mining of RE raw materials to finished products implied close production ties between companies-producers of rare earths of the USSR, such as Solikamsk Magnesium Plant (Russia), Sillamae CMP (Estonia), Irtysh CMP and Caspian Mining and Milling Combine (Kazakhstan), Pridneprovsky chemical plant (Ukraine), Kyrgyz MMC. Basic volume of RE products was manufactured in Estonia and Kazakhstan, but it was mainly (70-80%) consumed in Russia. Sources of REE raw materials were loparite concentrate (Russia, complex

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oxides - (Na, Ce, Ca, Ti, Nb, Ta,) O3), which consists of 99% of REE of light group and practically does not contain more deficient REE of medium-heavy group, uranium-bearing phosphorites (Kazakhstan), yttrium parisites and yttrium synchisites (Kyrgyzstan). Thus loparite concentrate satisfied the demand of the REM of cerium group, sources of raw materials in Kazakhstan and Kyrgyzstan satisfied the demand of the REM of yttrium group.

Currently, due to violation of industrial relations between the CIS and the Baltic States, and the absence of a full production cycle of REM in Russia, there is a contradiction between the needs of the industry in the RE production and availability of raw sources of REM in Russia, as well as opportunities of enterprises for their processing.

2. Consumers of REE

Current consumption of REM (individual oxides and metals) by Russian manufacturers of certain types of high-tech products (magnets, catalysts, optics, etc.) in Russia is insignificant and makes about 2000 tons a year, or 2-3% of the world consumption with the ratio of light and medium-heavy group of about 90% and 10% respectively. According to estimates of the largest consumers, predictive needs of the Russian economy in rare earth elements will increase by several times and will reach 5-7 thousand tons per year by 2020 with the bulk of the demand formed by neodymium, praseodymium and dysprosium, in the amount of more than 40% (in the world - less than 20%). The main is the State Corporation “Russian Technologies” which will consume about 4 thousand tons a year in 2020 [1].

The second major group of consumers of REM is the enterprises of the military-industrial complex.

The number of other customers of REM is significant, but their current needs are small. The development of domestic industry of REM will create a window of opportunities for the development of innovative industries in this group of consumers who mainly produce high-energy magnets in the amount of 80-100 tons a year.

Today, domestic demand is fully met by imports of REM from China, which poses a risk for national security and the development of domestic industry.

Distribution of REM consumption by fields of application of REM will have the following structure by 2020.

The key consumer of REM is magnetic production with the capacity of up to 5 thousand tons of magnets for alternative energy production, which will require about 3 thousand tons of individual REM oxides a year. For the production of magnets neodymium, praseodymium and dysprosium are required which are highly deficient in world market.

The second most important group of consumers of REM is the enterprises which produce catalysts for petrochemical production (900 tons of individual REM oxides per year). The demand in lanthanum and cerium which are used in REM catalysts can be fully satisfied by any source of REM.

The third most important REM consumer group is a group of innovative projects, including the production of automobile catalysts, catalytic converters and exhaust systems; production of plastic displays of a new generation, products from nanostructured ceramics, optical fiber with protective nanocoating from amorphous carbon, monolithic carbide cutting tools with nanostructured coating and others.

Considering the trend of the last decade in the growth of consumption of high-strength steels and cast iron in the automobile, construction and other industries, the demand of metallurgy for Russian REM can increase by thousands of tons per year.

3. The raw material base of REM in Russia

Russia currently takes the second place in the world for rare earth materials inventory, with a share of 22% of world reserves [3].

Russian raw material composition is different from that used in the world and represents a complex raw material from which the rare earth elements are extracted simultaneously as one of the components of the ore.

In most Russian deposits total content of rare earth elements trioxides is less than in foreign: it rarely exceeds 1.0%, while the average content of TR_2O_3 in ores of the developed Chinese deposits is 5.0%.

The main source of REM in Russia is loparite because its inventory, as well as the concentration of REE in the ore is quite high, but due to the collapse of the USSR, all the plants on primary treatment were left outside Russia [4].

Apatite, containing about 1% of REE, could become one of the most basic and readily available sources of REE, as the volumes of its processing reach 20 million tons a year, which corresponds to 200 thousand tons a year of

REE. Besides, it contains rare earths in easily retrievable form. Unfortunately, currently, REE are not extracted from this raw material, but are lost, getting on the fields together with fertilizers. However, a number of enterprises engaged in processing of apatite, have already started work in this direction [5–8].

REE are also not extracted from monazite in Russia for various reasons, among which is the high content of thorium (5-10%), although the work in this direction is also being activated [9].

In connection with the above the Russian government formed the Russian Federation State Program "Development of the industry and increase of its competitiveness to 2020" [10] in 2014 for the recovery of rare earth industry, in the framework of which Sub-program №15 was developed, namely "Industrial development of rare metals" which provides for the development of rare earth industry with state financing and extra-budgetary funds.

The fastest solution for the implementation of this program is the use of existing enterprises capable of producing rare earth products in the near future, using their expertise in their manufacture.

Prerequisites to the establishment of such a production are available, for example, in the West Siberian region in JSC "SCC" (nuclear-chemical profile company). First prerequisite is the existence of REM inventory in Siberia. Second, is the research and production experience in creating and operating of enterprises for refining uranium ore concentrates, as well as producing oxides, fluorides, alloys, master alloys and high-energy magnets based on rare-earth metals in JSC "SCC". Third, is the scientific potential of universities of Tomsk and Seversk, which train personnel of radiochemical profile in Tomsk region.

It should be noted that production of finished rare earth products was developed and functioned in "SCC" in 1992-2002: REE fluorides - up to 50 tons a year; alloys and rare earth alloys - 30 tons a year and magnets - up to 10 tons a year. These products met all requirements and were fully demanded by the Russian industry.

Development of full technological cycle of competitive RM and REM production at JSC "SCC", in our view, will include the following 3 steps:

- development of the site to produce alloys on the basis of REM – 2014-2015;
- development of area for extraction refining and separation of rare earth elements – 2015-2016;
- development of the site on opening REE concentrates – 2015-2017.

Thus, at every stage the production is established, producing a particular product, claimed by Russian industry, and based on scientific and manufacturing expertise available to the performers.

The concept of high-tech innovation REM-production is shown in Figure 1.

The concept includes the possibility of processing of various raw materials containing REE and obtaining 400-500 tons of oxides from each 1000 tons of concentrate, 150 tons of fluorides, 300 tons of alloys and master alloys, 300 tons of high-energy magnets annually.

REM concentrates can be extracted from a number of primary sources: Tugansk zircon-ilmenite sands (JSC "TMPC" Ilmenite", Tomsk region); ortite ores (South –Bogatyrsk inventory, Kemerovo region); monazite, located in the Sverdlovsk region near Krasnoufimsk; collective REE carbonates produced by JSC "Solikamskiy MP" from loparite concentrates. These sources can partially meet the basic needs of the Russian industry.

All these ore concentrates contain from 30 to 50% of REE, and the rest are the ballast and radioactive impurities.

To evaluate the cost-effectiveness of the project a business plan was developed [11], with the participation of the specialists from SRNU MEPhI and JSC "SCC" on the basis of a Technical and economic assessment "Experimental production on opening of ore concentrates of rare earth metals (REM) with the content of REM oxides of 25% and 45% by weight and their pre-processing".

Some of the assumptions made in the business plan are different from those adopted previously for TEA:

- TEA specified the allocation of production at the site of the Radiochemical Plant (RCP) SCC and the use of existing infrastructure. This decision is due to the plan of RCP decommissioning at the expense of the federal budget as the object of the "nuclear legacy";
- the business plan takes into account additional costs for disposal of radioactive waste at the rates of the national operator;
- expenses for purchasing a car and rail way transport are eliminated;
- costs of shipping of raw materials are considered as payment for the services of the third-party organization.

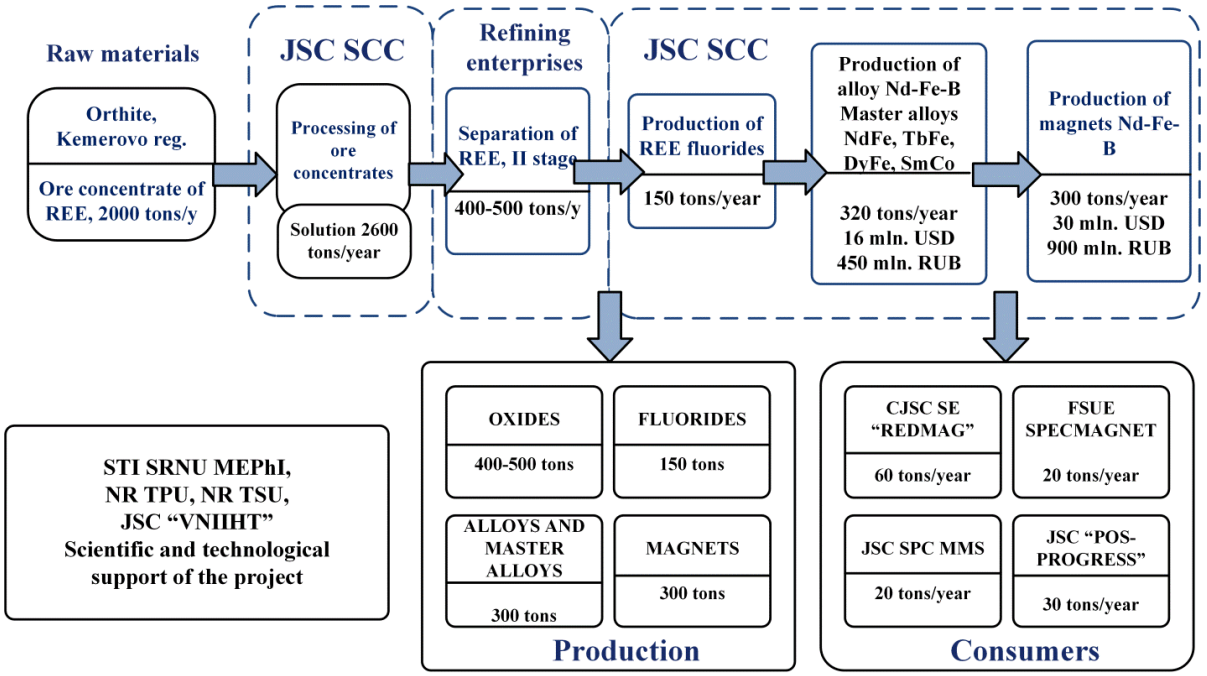

Fig. 1. The concept of development of JSC "SCC" rare earth production

The following parameters of the project are accepted as main:

- performance by ore concentrate - 2000 t/y;
- content of REO in ore concentrate - 45%;
- performance by solution ~ 2627 t/y, by REOs ~ 827 t/y;
- finished products - a solution of nitrates of REM (mixture);
- technology - extraction-precipitation refining of ore concentrates;
- volume of liquid LAW - 4100 m^3/g;
- volume of solid VLAW (20 kBq/kg) - 1228 tons/year.

Figure 2 shows a diagram of hydrometallurgical processing of ore concentrates.

Hydrometallurgical processing scheme includes:

- opening (nitrate, sulfate, alkaline, fluoride);
- settling the solution in centrifuge and control filtration of solutions;
- solvent refining with 100% tributyl phosphate (TBP) in vertical vessels;
- hydrolytic purification and separation of the phases by centrifugation;
- inter-cycle reduction;
- extraction purification with 60% solution TBP in a hydrocarbon solvent in centrifugal extractors.

Approbation of the scheme in Fig. 2 was made for 1 ton of orthite concentrate to the stage of obtaining REE nitrate solution (REE $(NO_3)_3$) satisfying the requirements of the GSP-K4-91 on radionuclide content, satisfying the requirements of the potential at the time consumer "Uralredmet".

During this processing the market product was obtained, namely REM solution, meeting the requirement of TC [REM] = 100-150 g/l and activity of less than 10^{-8} Ku/(kg REM). Coefficients of purification from radioactive and ballast impurities made: from thorium-232, 228 more than 10000, from Fe, Ca, Mn, Al – more than 1000.

Table 1 shows the predicted technical and economic indicators according to the project developed in the business plan [11].

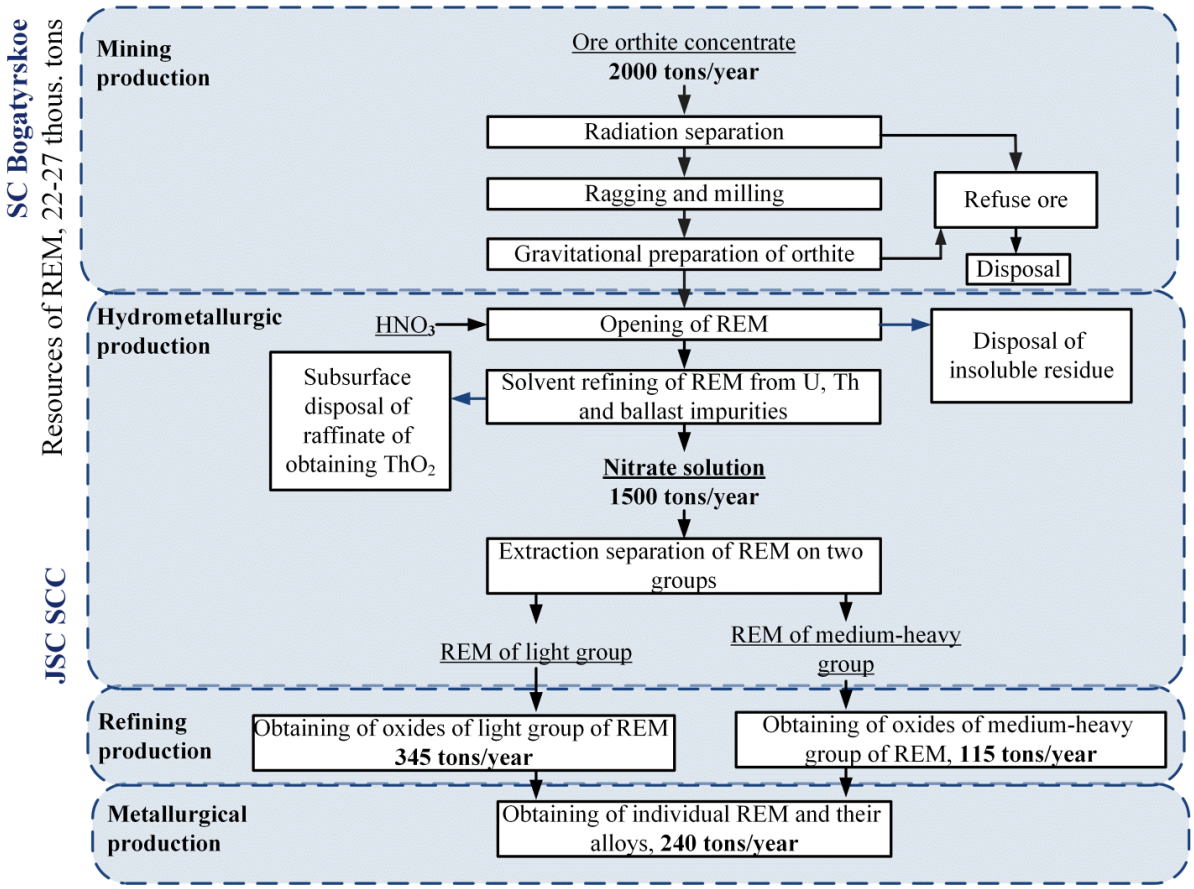

Fig. 2. The scheme of hydrometallurgical processing of ore concentrates

We find it necessary to once again draw attention to the location of this production in Seversk, Tomsk region. The advantages of such a placement is the ability to work with concentrates of uranium and thorium and radioactive waste disposition in the enterprise of Rosatom JSC “SCC”, which performs the processing of various types of raw uranium.

Currently, the technology of radioactive waste management is worked out in collaboration with STI SRNU MEPhI at JSC “SCC” in the form of R & D and test benches are created for R & D for the new conversion production.

In addition, RCP is being closed down and the issue of conservation of unique radiochemical equipment is being discussed. However, the same equipment could be used for the processing of rare earth materials containing thorium. It would be beneficial from all sides, and most importantly, new job places would appear.

Finally, if the resulting solution (either melt or oxides) is delivered to processors, the latter, in their turn, could deliver individual oxides of REE (Nd, Dy, Tb, Pr) to produce high-technology products on the developed ladle fluoride technology using elemental fluorine: fluorides, alloys and magnets. As technical and economic calculations in the business plan showed, manufacturing costs on the alloy obtaining are in the range of 10-11 dollars per kg, which is comparable with the prices of Chinese manufacturers.

Table 1. Predicted technical and economic indicators

Production redistribution	The product (semi-finished / finished products), overall production	Production costs of redistribution (departmental costs for processing), RUB/kg	
Nitrate opening of ore orthite concentrate containing 45% REOs by weight, solvent refining of REM from the ballast and radioactive impurities	Semi-finished product: a mixture of REM nitrate solution containing La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Y – 2627.25 t (of solution)/year - (in conversion to REM oxides - 827.40 tons/year)	RUB/kg of solution	49.05
		RUB/kg of REM oxides	155.76
Extraction-precipitation scheme of semi-finished product processing with obtaining of group-by-group fractions of REM and oxides of independent REM	Semi-finished product: concentrates of oxides of light group of REE (La, Ce, Pr, Nd, Sm) – 603 tons/year;	Concentrate of LREE	77.70
	samarium oxide (Sm_2O_3) – 9.4 tons/year;	Sm_2O_3	680.13
	yttrium oxide (Y_2O_3) – 114.8 tons/year;		
	concentrate of oxides of medium-heavy group of REE (Ho, Er, Tm, Yb, Lu, Y) – 25.2 tons/year;	Concentrate of MHREE	375.36
	concentrate of oxides of medium-heavy group of REE (Eu, Gd, Tb, Dy) – 33.8 tons/year	Concentrate of HREE	244.61
		Y_2O_3	194.73
Obtaining of ferrous fluorides, neodymium from their oxides	Semi-finished product: NdF_3 – 58.8 tons/year, FeF_3 – 32.9 tons/year	NdF_3	457.41
		FeF_3	343.01
Obtaining of alloy Nd-Fe-B from neodymium and ferrous fluorides	Finished product: alloy – 95 tons/year	Alloy Nd-Fe-B	310.62

4. Conclusions

Due to the collapse of the USSR, Russia, which has a large number of potential sources of raw materials, was left without capacities for extracting REE, as well as the production of oxides, concentrates and individual REM, including Nd, Dy, Tb, Sm, necessary for the manufacturing of magnets.

It is proposed to establish the enterprise for processing of various rare earth raw materials to obtain REE oxides and further highly profitable rare earth products: fluorides, rare earth metals and magnetic alloys based on them, as well as high-energy magnets and articles on their basis by ladle fluoride technology in the West-Siberian region on the basis of SCC (Seversk, Tomsk region) for the restoration and development of this sector of economy.

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