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Production of Synthetic Liquid Fuel: Status and Trends of Development

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Abstract

The state of the problem concerning the production of synthetic hydrocarbon fuel abroad and in Russia is considered. It is shown that in connection with the limitation of oil resources new energy strategies are accepted and realized abroad, aimed at diversification of energy carriers, involvement of nonconventional kinds of organic raw material (first of all coal and natural gas) into industrial processing, and also plant raw material, with obtaining ecologically safe and high-quality liquid fuel, establishment of the corresponding industrial works. It is stressed that the technologies of the production of synthetic liquid fuel from coal have achieved the level of commercial efficiency. In Russia, it is necessary to work out and accept, as soon as possible, the new energy strategy aimed at the creation of competitive technologies for advanced oil processing and obtaining high-quality and ecologically safe liquid hydrocarbons from coal and natural gas.

Key words: synthetic fuel, oil, coal, gas, industrial processing

INTRODUCTION

Various predicting energy scenarios proceed from the idea that oil will conserve its dominating role in the global consumption of primary energy carriers within the two future decades, and the price of oil will remain the reference value at the world market of fuel and energy. A trend to increase the fraction of oil use in the form of motor fuel is observed in the world pattern of consumption. During the next 25 years no cardinal change of the major type of internal-combustion engine is expected, so petrol and diesel engines will still determine the demand for motor fuel.

According to the data of the annual statistical publication of British Petroleum, the world's proven resources of oil by the end of 2007 account for 1390 milliard barrels (193.4 milliard tons). More than 60 % of the resources are concentrated at a small territory in the countries of the Persian Gulf (Fig. 1) [1–4]. Total world consumption of oil in 2007 reached 85.2 mln barrels/day (about 4 milliard tons per year) [1, 2]. Leaders in oil mining (Fig. 2) are Saudi Arabia with the largest resources exceeding 21 % of the world's resources, and Russia that occupies the 8th place in resources (about 6 % of the world's resources). The largest consumer of oil (more than 25 % of the world

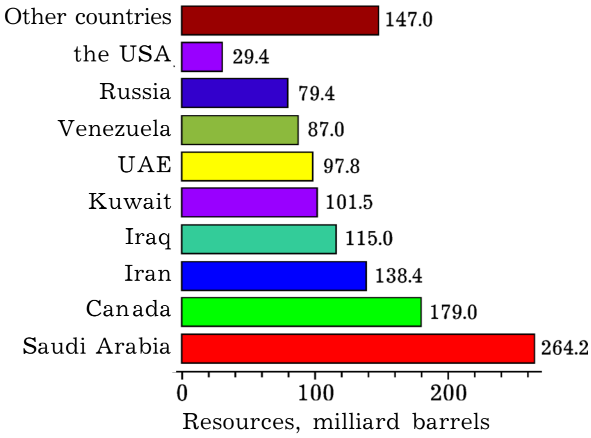

Fig. 1. Proven resources of oil in the major oil-mining countries [1, 3]. Oil-bearing sand is taken into account for the resources of Canada [5].

consumption) is the USA possessing only about 2.4 % of the world's oil resources. With the modern level of consumption, the available proven world resources of oil will last out for 45 years. In this situation, the OPEC countries are provided with oil for 73 years, the USA for 12 years, EEC countries for less than 8 years.

The cost of oil in the world market increases. In general, its dynamics includes the periods of relatively stable prices interchanging with intermittent increase, then similarly sharp drop (Fig. 3). These jumps are unpredictable and have a negative effect on the economics because the fuel and energy branch in developed countries and in many developing ones is to a substantial extent based on oil (Fig. 4). One of the fundamental factors determining an increase of the cost of oil during the current decade has become depletion of traditional oil resources, qualitative worsening of their structure and the absence of hitching technologies of oil production. Together with predictable growth of energy consumption, these trends will cause essential structural changes in the hydrocarbon market, in the fuel and energy branch and, as a consequence, in the whole world's economics within the future 20–30 years.

Taking into account a sharp increase in the price of oil and being afraid that its production has reached its maximum, many countries passed to implementing new energy strategies on diversification of energy carriers. This problem is being solved in each country in its own way depending on the structure of the available resources of energy carriers. Under modern conditions, the determinant importance

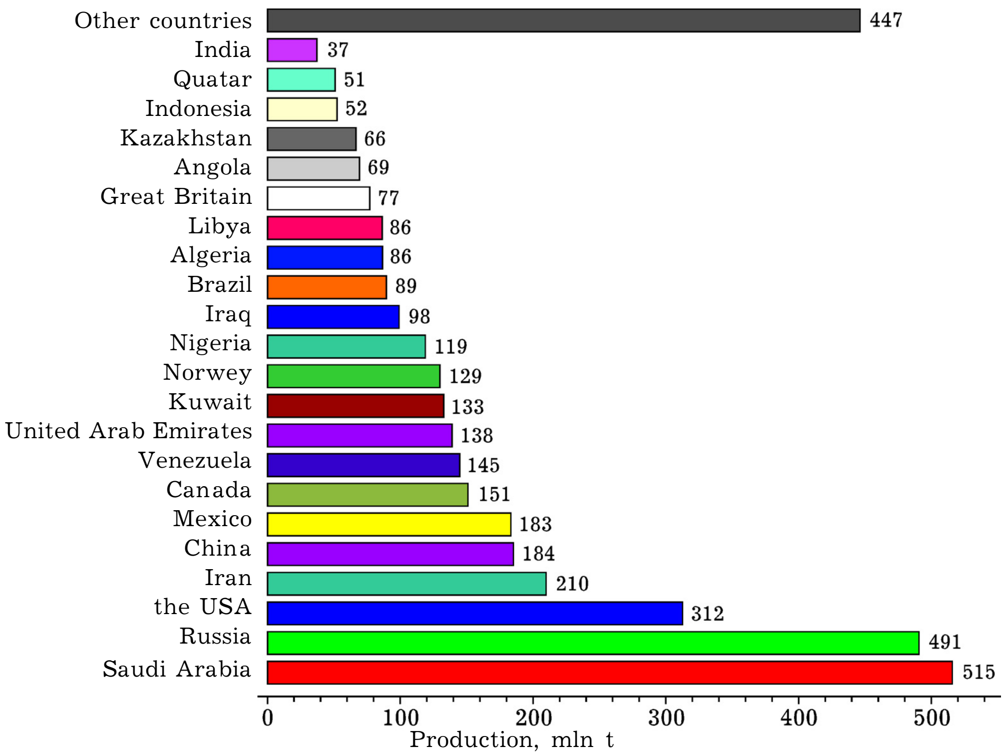

Fig. 2. Oil production in different countries in 2007 [1, 3].

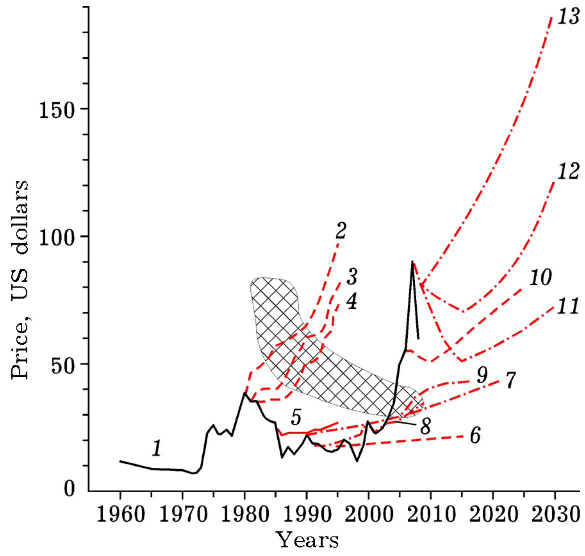

Fig. 3. Dynamics of current price of oil in the world market (*1*) and expected cost of synthetic oil from coal according to data reported in [1, 4–7] (shaded area). Different predictions for oil price: *2–5* – made by the USA analysts in 1980 (*2*), 1981 (*3*), 1982 (*4*) and in 1984 (*5*) [6]; *6* – US Ministry of Power Engineering; *7* – NEDO Co. (Japan); *8* – Ministry of Power Engineering of the USSR; *9* – International Energy Agency; *10* – Rosneft Co.; *11–13* – Energy Information Agency according to the scenarios with low (*11*), moderate (*12*) and high (*13*) growth of oil price.

is rendered to national energy safety but not only to the economical efficiency of production. The strategies of the majority of developed countries are aimed at the development of the so-called CtL (Coal to Liquids) and GtL (Gas to Liquids) technologies for obtaining high-quality transportable synthetic liquid fuel (SLF) from coal and natural gas.

OBTAINING LIQUID FUEL FROM NATURAL GAS

Among organic kinds of energy carriers, natural gas occupies a special position because it belongs to not only the most efficient and technologically feasible but also most ecologically safe ones. Producible resources of natural gas in the world account for about 170 trillion m^3 (6400 trillion cubic ft), while the annual global gas production, according to the data of Energy Information Administration (EIA, the USA) exceeds 2.7 trillion m^3 [3, 4]. In the strategies of countries possessing substantial gas resources (Fig. 5, *a*), priority is given to the construction of industrial gas-processing enterprises with obtaining transportable liquid hydrocarbons, chemical substances and other products with high added value.

The first GtL installations for chemical processing of natural gas through its conversion into $CO + H_2$ mixture and subsequent synthesis of liquid hydrocarbons according to Fischer–Tropsch were built in the South African Republic and in Malaysia as early as in 1993 [9, 10]. At present, such companies as Shell, Exxon-

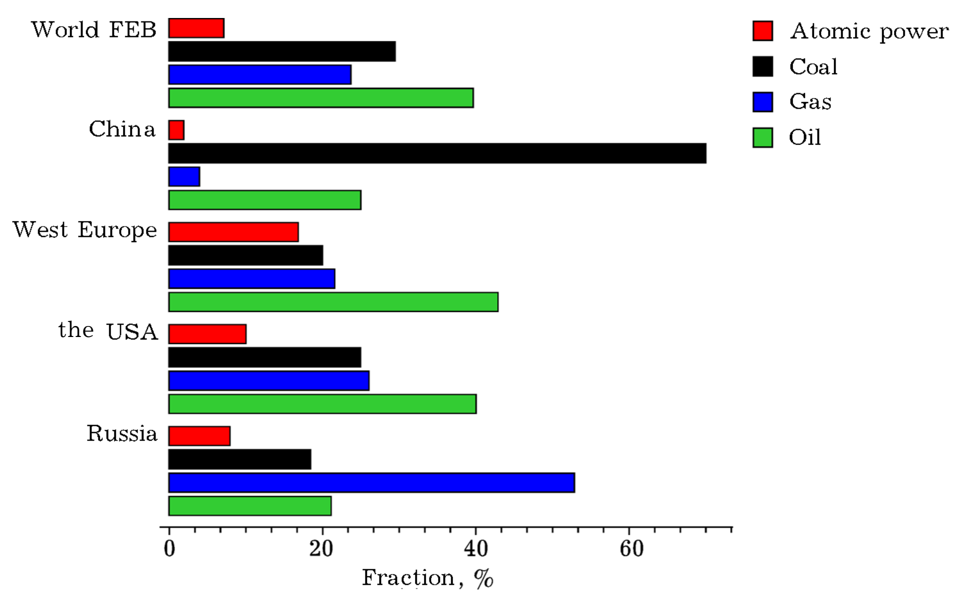

Fig. 4. Fraction of fossil kinds of fuel in the fuel-and-energy balance of different countries [8].

Mobil, Sasol, Syntroleum use the experience of the operation of these installations, develop new technologies and industrial gas chemical works in many countries [11]. The leading position in constructing the branch is occupied by Quatar where about 14 % of the world resources of natural gas is concentrated at a limited territory 11 thousand km^3 in area (the 3rd position in the world following Russia and Iran) (see Fig. 5, *b*). Against contracts with the national company Qatar General Petroleum Corp., gas chemical plants to manufacture liquid motor fuel and various chemicals, with the productivity of 70 to 154 barrels/day, are under construction in the country. The active gas chemical strategy is purposively realized in Algeria (the 9th position in gas resources): using the super-revenue from the export of oil and natural gas, it is planned to launch the construction of several integrated gas-processing plants. The planned general productivity of the two plants of the first succession is 9 mln t of liquid products per year.

Intense development of the gas chemical branch is observed in the USA, Nigeria, Bolivia, Australia and other countries. As a total, more than 50 projects with the total productivity of installations about 110 mln t/y are set for implementation in the world. Capital investment into the construction of plants, depending on the raw material, technologies used, and other conditions, is US 510–810 dollars, calculated for 1 t of liquid product per year [12, 13]. The main expenses fall at gasification processes and manufacture of syngas and oxygen. It should also be noted that along with the development of the gas chemical branch many gas-producing countries create new plants on natural gas liquefaction for the purpose of its long-term transportation with methane tankers [14]. At present, about a quarter of natural gas is supplied in the liquid form.

A promising direction of energy resource diversification is connected with the use of natural gas from carbohydrates; their resources may be sufficient for more than 100 years. However, at present any real approaches to developing the technology of their production have not been developed yet.

OBTAINING LIQUID FUEL FROM COAL AND OTHER SOLID COMBUSTIBLE FOSSILS

Economical, scientific, technological and ecological policy of the USA, China, India, Australia, South African Republic and other countries possessing large coal resources (see Fig. 5, *b*) is based on the construction of coal-processing plants. According to the data of EIA for 2007, the world mineable resources of coal are 905 milliard tons, which many times exceeds in the fuel equivalent the resources of oil and gas. The level of coal mining has already exceeded 6 milliard t/y.

Liquid products can be obtained from coal using two methods proposed in 1920–1930 by Germal scientists Friedrich Bergius, Franz Fischer and Hans Tropsch, namely:

– by means of direct hydrogenation of coal under hydrogen pressure to obtain synthetic oil;

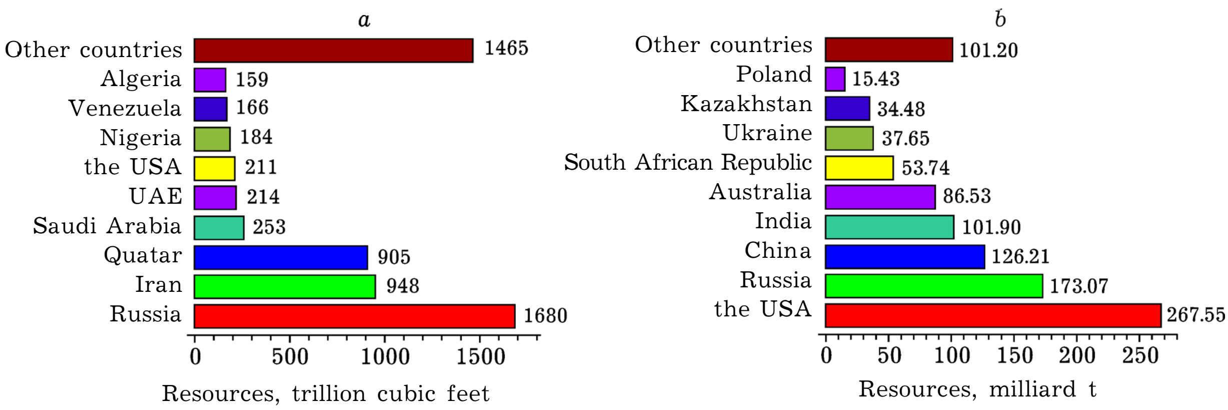

Fig. 5. Mineable resources of natural gas (*a*) and coal (*b*) in major gas- and coal-producing countries, respectively [3] (coal resources are listed in milliards of net tons).

– through coal gasification into simple molecules CO and H_2 followed by catalytic synthesis of hydrocarbons and other liquid products.

In 1931, F. Bergius (together with Karl Bosch) was awarded Nobel Prize for achievements in introduction and development of high-pressure methods in chemistry. At the same time, pre-eminence in the development of the indicated methods of carrying out various hydrogenation reactions under high hydrogen pressure justly belongs to Russian chemist Vladimir Nikolaevich Ipatyev.

Both methods indicated above were realized in the industry of a number of countries in 1930–1940. At the end of the Second World War in Germany more than 4.0 mln t of motor fuel was obtained from coal; the major part of this amount was manufactured at 18 installations of direct hydrogenation, and 600 thousand t was manufactured at nine more expensive Fischer–Tropsch installations. After the discovery of the deposits of cheap oil in Saudi Arabia and some other regions (in Alaska, in the North Sea) in 1959es and its arrival to the world market, coal-processing technologies turned out to be noncompetitive, that is why the plants were closed or upgraded for processing oil raw material.

South African Republic was an exception; a small plant Sasol-1 producing 250 thousand t/y of synthetic motor fuel from coal according to Fischer–Tropsch method was launched there in 1955. The choice of this technology of coal processing was due to the fact that South African Republic possesses enormous coal resources (occupying the sixth position in the world); its coal, however, has high ash content and thus it is unsuitable for direct hydrogenation but quite suitable for gasification. At present, South Africa is the only country where large-scale commercially efficient coal-chemical production is organized: about 80 % of the entire liquid fuel consumed in the country is manufactured by means of Fischer–Tropsch method.

In 1970–1980, oil crises initiated the problem of the production of synthetic liquid fuel in many countries. The expected cost of oil reached US 100 dollars per barrel (see Fig. 3). However, in middle 1980es, against predictions, a sharp decrease in oil cost occurred (to a level of US 15–20 dollars per barrel). In this connection, the problem lost its urgency; realization of industrial technologies stopped being funded; in this situation, research continued developing abroad, though with lower intensity.

The modern energy technological strategy of the USA is directed towards saving the home oil and gas resources, decreasing their export. Possessing the largest coal resources in the world and relying upon the newest scientific and technological advances in the area of its chemical processing, the USA builds up a novel energy order which is in the centre of attention of the state authorities, is supported by the administrations of coal-mining regions, oil and coal mining companies. An immense coal project is implemented in Illinois state in processing large resources of coal; because of the high sulphur content (more than 3–4 %), it has not won broad application yet [15, 16]. The Clean Coal Power Resources Co. together with partners is organizing there a large mining and processing complex which is to manufacture low-sulphur synthetic oil from coal at a rate of more than 10 mln t/y. As a total, 18 large CtL projects are realized in the USA; they provide the construction of a complete set of industrial enterprises on the production of different kinds of motor fuel and chemical raw material. Much attention is paid to the investigation of performance characteristics of synthetic fuel. In the military branch of the USA, the flight tests of B52 bomber with synthetic fuel have finished [17]. By the end of 2011, it is planned to carry out the tests with all the carriers of air, naval, armoured forces and other divisions.

China with its 3rd position in the world (after the USA and Russia) in coal resources is the world leader in coal mining (more than 2 milliard t/y), consumption (34 % of the global level) and construction of industrial CtL plants [16–19]. About 60 % of the mined coal is consumed in the fuel and energy complex. About 70 % of energy is produced in coal combustion, but this practice causes damage to ecology: China is second to the USA in total emission of greenhouse gases. China has a large-scale industry manufacturing methanol from coal; methanol is used in the internal market and is exported abroad in the substantial amount. The needs of the country in oil products are provided to almost a half due to oil import [18].

The State energy program adopted in China is aimed at a decrease in the dependence of dynamically developing economics on imported oil and a decrease of the ecological load on the environment. Within this program, large-scale industrial production of SLF from coal is to be established. It is planned to construct a number of CtL plants, first of all in coal-mining northern provinces (in autonomous regions Internal Mongolia, Sintszyan-Uigur, in Shansi, Shensi, Ninsya provinces). In 2008, the world's first industrial plant on coal hydrogenation has been constructed in the Internal Mongolia region (Fig. 6) [18]. At that plant, using iron-containing catalyst, it is planned to obtain 1.08 mln t of low-sulphur liquid fuel per year from 3.45 min t of coal. By 2010, the amount of production will increase to reach 5 mln t/y. Capital investment is about US 1400 dollars per 1 t of liquid product per year [19, 20]. The plant will be profitable if oil cost is higher than US 35–40 dollars per barrel. The development of technology was participated by Axens, Headwaters/HTI and NEDO companies. At large-scale demonstration installations with the productivity 15 and 2 t/day, technology mastering according to Fischer–Tropsch method is carried out. It is planned to construct industrial plants during 2010–2011. As a total, it was announced that 30 different CtL projects are to be realized in China [21]; this will allow one to bring the fraction of SLP to 10 % of the total consumption of oil products, which exceeds the world average rate of development of this branch.

India occupies the 4th position in the world in coal resources, coming after the USA, Russia and China, and the 3rd position in consumption coming after China and the USA. The fuel and energy complex of the country consumes 75 % of mines coal, it accounts for 69 % of power generation. The 1st industrial plant on coal hydrogenation (with the productivity of 3.5–4.0 mln t/y) at the cost of US 2.5 milliard dollars will be constructed at the north-east of the country [19]. The second plant will process coal by means of gasification and synthesis according to Fischer–Tropsch using the Sasol technology.

Indonesia possesses definite resources of natural gas and until recently has been one of

Fig. 6. Appearance of the industrial plant on coal hydrogenation in China (Ordos).

gas-exporting countries. However, during the recent years gas deposits of Indonesia have been close to depletion. Diversification of the fuel and energy balance is brought in connection with the development of coal processing. The construction of the first plant of coal hydrogenation, with the productivity of 750 thousand t/y and cost of US 1.3 milliard dollars, at the Island of Kalimantan will start in 2009; the plant will be put into operation in 2013 [22, 23]. The Japanese company NEDO participates in developing the technology. By 2025, seven industrial plants will be constructed in Indonesia.

In the Philippines, construction of coal chemical complex is planned. It will include the installations of coal gasification, hydrogenation and synthesis according to Fischer–Tropsch; with the productivity of about 3.3 mln t of liquid fuel.

Liquid hydrocarbons can be obtained also form other solid combustible fossils (oil-bearing sand and shale, shale oil, natural bitumen). For instance, the world's largest deposits of oil-bearing sands are situated in Canada; they contain 12.3 of the world's oil resources. At present, about 4 mln t/y of oil products are obtained according to the Shell technology [24]. Their production is planned to increase by 2015 to 12.5 mln t/y. In the USA, works aimed at the development of technologies of shale oil processing are carried out. There are enormous resources of shale oil in the world (about 450 trillion tons). In Australia, about 2 mln t of liquid oil products per year are produced from this raw material. In Estonia, shale oil is processed by means of semi-coking according to the technology developed at the Energy Institute in 1980es. Processing is carried out with UTT-3000 installations; their productivity is about 1 mln t of shale oil per year. The yield of liquid hydrocarbons exceeds 12 %, their prime const in 2007 was about US 24.4 dollars per barrel [24]. It is planned to construct several installations more (one installation in 2010 and six by 2015). Capital investment into one UTT-3000 installation is US 40 mln dollars with the pay-back period of about three years.

Much attention is paid in the EEC countries, in the USA, Brazil and other countries to processing different kinds of plant raw material into synthetic fuel (bioethanol, biodiesel, biogas) [25, 26]. Attention to biofuel follows from the general strategy of the search of new directions in power engineering, rational use of the national resources to provide its reliable functioning, the possibility to develop a renewable energy carrier, decrease the dependence on central energy supply and decrease in ecologically dangerous emissions. In EEC countries, a directive concerning promotion of biofuel for vehicles has been adopted; it obliges to use it as an additive to any kinds of motor fuel. As a total, about 47 mln t of biofuel per year is manufactured in the world. The largest installations operate in the USA and Brazil. In the USA, the state investment into the branch is about US 2.3 milliard dollars per year, additional amount of more than 1 milliard dollars is allocated for these purposes to the agricultural branch. In 2030, 1.2 mln barrel/day will be manufactured in the USA. However, it should be noted that the possibility to realize large-scale production of biofuel without any damage to the environment and food supply for population causes definite doubt.

STATE OF THE PROBLEM OF PROFOUND PROCESSING OF OIL, NATURAL GAS AND COAL IN RUSSIA

The fuel-energy complex of Russia is an important part of the world power economy. More than 6 % of the world's resources of oil, 26–33 % of the explored resources of natural gas and 16–23 % of coal resources are concentrated at the territory of Russia [3, 27, 28]. With the existing amount of production, the proven resources of Russian oil will be sufficient for 23 years, gas for 67 years, and coal for several hundred years.

Until the end of 1980es, production of all the kinds of organic fossil fuel in Russia had been developing in a rather balanced and intense manner (Fig. 7) [27–29]. In 1988, oil production was 569 mln t/y. The reproduction of mineral raw materials was developing in the anticipatory manner; processing facilities were planned and built, including coal-processing ones. However, after 1990, a sharp decrease in the amount of oil and coal production occurred: it dropped by a factor of 1.8–2 within

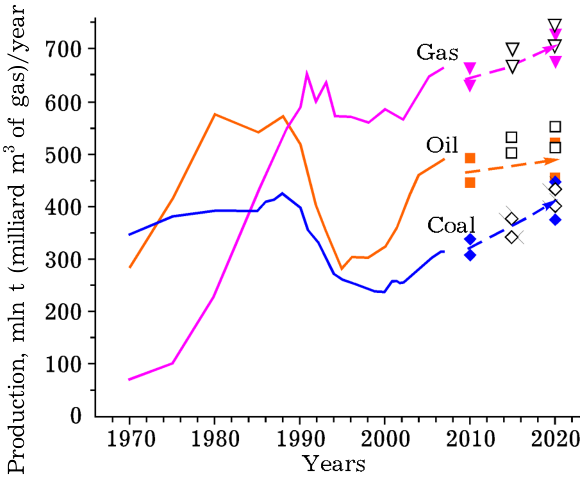

Fig. 7. Dynamics of energy resource production in Russia. Coloured marks stand for the prediction of ES 2020; non-coloured ones for the tentative project of the new ES 2030.

only five years. Production of natural gas is functioning rather stably during the two decades. During the recent years, a positive trend has appeared in the production of oil and coal, but the level that existed twenty years ago has not been achieved yet.

In 2002, the Government of RF adopted the strategy of economic development of Siberia in which special attention is paid to mining and improvement of transporting gas and oil facilities. On the basis of this document, the Energy strategy of Russia for the period up to 2020 was adopted in 2003 (ES 2020). According to it, the annual oil production is to be increased to a level of 445–490 mln t, gas to 635–665 milliard m^3, coal to 310–330 mln t, and by 2020 to 450–520 mln t, 680–730 milliard m^3, and 375–430 mln t, respectively. In fact, the annual production in 2007 was: oil 491 mln t, gas 653 milliard m^3, coal 314 mln t (see Fig. 7). So, four years after the adoption of the ES, the amount of oil and gas production has almost reached the level of 2020 year, which is the evidence of unsatisfactory work-up of the strategy and predicted estimations.

Deformation of the fuel-and-energy balance of Russia to the side of natural gas causes anxiety; according to the ES, the fraction of natural gas was planned to decrease due to an increase in the fraction of coal to 27 % by 2015. The raw material strategy aimed at an increase in the production of energy resources and diversification of the directions of their export (including the countries of the Asia-Pacific region) continues to dominate in the oil and gas branches, while oil processing, oil and gas chemistry are undergoing anticipatory development in comparison with the corresponding mining sectors in the developed countries. Recently, Russia has taken the obligation of a kind of regulator of oil and gas supply to the world market, which will additionally require substantial increase in the export. At the same time, the potential of the growth of oil production created during the Soviet period has been depleted to a high extent. Due to decreased amount of exploration works, an increase in resources does not compensate for production. Since 1995 till 2007, the excess of oil production over resource recovery reached 1.3 milliard t. The structure of current industrial reserves in the major oil-and-gas-producing regions also worsens. Increase in output will be achieved mainly due to more expensive projects in East Siberia, Republic of Sakha (Yakutia), Far East and the Arctic coast [1, 30–34]. Under these conditions, with the existing production level, it will be difficult for Russia with its 6 % of world oil resources to hold its place among the leading exporters by 2020. What is more, under the conditions of large-scale construction of GtL and CtL plants abroad, including the countries of Asia-Pacific region, demand for Russian oil may decrease substantially. The situation may become even worse in the case if the oil branch requires essential investment for maintaining its functioning.

Though the adopted Programs and ES declare the necessity to make new centres of profound oil and gas processing centres, nevertheless, no large oil-processing plants have been constructed in Russia within the past two decades. The fraction of processed to mined oil decreased to 47 %, the average degree of processing is about 71 % (at the major part of oil-processing plants it does not exceed 65 %), while in the developed countries this parameter is 85–90 %, and at leading OPP it is 95–97 %. The structure of Russian oil-processing branch is characterized by the low fraction of catalytic processes allowing one to obtain high-quality products. For example, the fraction of hydrofining and catalytic cracking is 28 and

9.3 % of the total amount of primary oil processing, respectively, while in the developed countries these parameters vary within the range 30–43.6 % and 14–34.2 %, respectively [8, 35]. The production of motor petrol lags behind the world level substantially, too: only 16 % petrol and not less than 30 % black oil are manufactured from 1 t of oil at Russian OPP, while in the developed countries up to 43 % petrol and not more than 5–10 % black oil are obtained. The conservation of such a structure may lead to the situation in the market of commercial oil products when our country will be in complete dependence on the processing complex of West and East Europe. Only in the recent years oil companies started to consider the possibilities of technology upgrading and the construction of new installations and OPP. As an example, Tatneft Co. may be mentioned: it is constructing a plant in Nizhnekamsk for processing high-sulphur oil of Tatarstan, with the productivity of 7 mln t/y, and Rosneft Co. that started to upgrade the technologies at a series of OPP and to construct a large new OPP at the Far East [36].

The raw material based strategy dominates also in forming new gas centres in East Siberia, Republic of Sakha (Yakutia) and in the Far East with orientation to long-range pipeline transportation of the raw material (for export as well). At the same time, the level of expenses for the pipeline transportation of natural gas in Russia is one of the highest in the world, which is connected with the large distances from deposits to consumers, technical and technological problems of the construction of main gas pipelines due to complicated mining and geological conditions, climate of the northern and eastern regions. What is more, a large number of deposits in gas-bearing regions of East Siberia and Yakutia are characterized by the low gas pressure, which requires the construction of additional compressor stations and therefore increases the cost of the pipeline system. The ES 2020 document provides broadening of gas transportation system owing to even more expensive methane tankers. For this purpose, within the project Sakhalin-2, the first plant for obtaining liquefied natural gas is being constructed at the Far East; gas export will start in 2009 [37]. As a total, it is planned to construct several plants of this kind in Russia.

At the same time, taking into account the above-stressed features of the main pipeline transportation of natural gas in Russia, risks arising in its trans-boundary trade and the experience accumulated in leading gas-producing countries, in order to provide competitiveness of the Russian gas branch, it is necessary, in addition to diversification of transportation schemes, to rapidly construct modern gas chemical plants near deposits for obtaining high-quality liquid hydrocarbons and other transportable products with high added value [33, 38]. On the basis of the deposits in the eastern regions, several gas processing complexes can be established [33]. One of the best ready sites is Central Yakutia possessing sufficient explored resources of natural gas (more than 400 milliard m^3), the experience of its production and transportation is accumulated, and the necessary infrastructure is formed [39, 40]. The production possibilities that already exist there exceed 3 milliard m^3/y, to be increased up to 6 milliard m^3/y by 2011. A large modern centre of gas chemistry may be formed on the basis of these deposits, aimed at the production of transportable liquid products – motor fuel, methanol and other organic substances. In turn, well prepared modern home technologies of chemical processing of natural gas, which are almost absent from Russia at present, with an exception for methanol production, are necessary for the establishment of these complexes.

Russia occupies the 5th position in the world in coal mining (314 mln t in 2007), which does not correspond to the potential possibilities of the mineral raw material basis of coal industry, one of the largest in the world. Unlike for oil and gas industry, the degree of the provision of coal production with reserves prepared for industrial development reaches 65 years as a mean, and for some enterprises it reaches up to 100 years. Coal in mined in 24 regions of Russia; two Siberian regions (Kuznetsk and Kansk-Achinsk) account for almost 70 % of total amount mined [29]. Coal is used mainly for energy purposes, nevertheless, its fraction in the structure of the fuel energy complex (FEC) is less than 19 %. According to the ES

2020, the fraction of coal in FEC must increase to 27 % by 2015, and the fraction of natural gas is to decrease correspondingly. However, the actual dynamics does not correspond to this prediction. In 2007, in comparison with the previous period, the internal consumption of coal in Russia decreased substantially, and the positive dynamics in the branch is due to an increase in export.

The conversion of power engineering to natural gas at the end of 1970es was decided in the Soviet Union only as a 15–20-years maneuver in order to gain time for assimilating new technologies of efficient ecologically safe use of coal, so it was called the gas pause. Within the framework of realization of state programmes, intense works was carried our in the 1980es to develop efficient and ecologically safe technologies of the energy-related use and chemical processing of coal from the largest Siberian deposits (Kuznetsk, Kansk-Achinsk, Lena basins). At that time, the most advanced chemical technology of hydrogenation of brown coal from the Kansk-Achinsk basin, developed at the Institute of Fossil Fuel, SB RAS, was mastered at the recently constructed experimental plant ST-5 with the productivity up to 7 t of coal per day [27, 41]. The construction of the experimental industrial hydrogenation plant started at the Berezovo Open-Pit Mine; technologies of gasification were prepared, large installations for thermal processing of coal and shale oil to obtain carbon materials for various purposes and liquid tar were constructed. However, with the start of the market reforms, financing of the construction of coal-processing plants, technological and experimental design works was stopped; the amount of research in coal chemistry decreased sharply. As a result, at present there are no economically efficient and ecologically safe technologies of coal processing prepared for industrial use in Russia.

Research on coal chemical area is carried out mainly at the Siberian Branch of RAS at some institutes. At the Institute of Chemistry and Chemical Technology, SB RAS (Krasnoyarsk), investigations are carried out, aimed at the development of scientific foundations for efficient and ecologically safe methods of energy-related use of coal, processes of its integrated processing into the products with high added value: liquid hydrocarbons, chemicals, carbon materials *etc.* Important factors of the formation of supramolecular structure of the organic mass of coal were established [42, 43]; new methods of burning, gasification and carbonization of the Kansk-Achinsk brown coal were proposed [44]; fundamental bases for stimulating destructive transformations into hydrocarbon products by means of preliminary activating treatment [43, 45]. Within the Programs of integration projects of SB RAS together with the Institute of Solid State Chemistry and Mechanochemistry, SB RAS (Novosibirsk), new efficient catalysts of brown coal hydrogenation using mechanochemical activation were developed [46–48]. Together with the Institute of Oil and Gas Problems, SB RAS (Yakutsk), within the integration project of SB RAS technological properties of the coal from new northern deposits of the Lena basin were studied, substantial content (5–10 times exceeding the industrially significant level) of valuable rare earth elements in it was detected [49]. The possibility to process coal in large-scale installations for providing remote coal-mining regions with high-quality motor fuel was demonstrated. At the Institute of Oil and Gas Problems, SB RAS, geochemical investigation of coal from different deposits of the Lena basin are carried out [50], as well as experimental work on brown coal briquetting using the heavy fractions of oil processing as the binding material. At the Institute of Coal and Coal Chemistry, SB RAS, scientific foundations for the technologies of processing coal and other solid combustible fossils for obtaining a broad range of products: liquid hydrocarbons, wax, tar, humic acids.

CONCLUSIONS

Thus, programmes of diversification of energy carriers involving into production various non-conventional kinds of organic raw material, firs of all coal, are actively realized at present abroad. The situation at the hydrocarbon market is principally different from the situation of the years 1970–1980 when the establishment of SLF production was determined by the geopolitical aspects. At present, there are all reasons to suppose that the world market of SLF is standing on the verge of technical revolution: its production from coal according to new technologies, in view of the present price of crude oil, has reached the level of economic efficiency, and the expected cost, according to different estimations, varies within the range US 30-45 dollars per barrel. It may be assumed that under the conditions of large-scale financing it will be possible to achieve essential technological advance in this area. It should be noted that the formation of the new branch will require rather long time. In this connection, it is necessary to stress that coal chemical enterprises created abroad solve another important problem – to accumulate the industrial technological experience and to prepare conditions for rapid full-scale transition to the coal raw material when the situation with energy carriers changes.

The most typical negative parameter of the export strategy of the oil production branch of Russia at present is the transfer of the major part of the revenue from processing to international oil companies importing Russian oil. The new directions of the development of the world energy sector, augmentation of actual deviations from the predictions estimated in ES 2020 determine the necessity to develop and adopt, as soon as possible, a new energy strategy which is, on the one hand, to take into account the features of the world FEC, stimulate competitiveness and ecological safety of Russia FEC, on the other hand, to take adequate account of the provision with energy resources for long-term outlook. The new energy strategy should not only provide the development of producing branches but also the priority accelerated development modern processing plants (including coal processing) on this basis, for the purpose of obtaining high-quality competitive products. Russia possesses enormous coal resources distinguished by relatively low mining cost, especially coal from the Kansk-Achinsk basin, and are able to provide the needs of the country for several centuries in the reliable manner. Nevertheless, in the tentative version of energy strategy prepared for the period till 2030, the raw material approach continues to dominate, with more pretentious plants in oil and gas mining (see Fig. 7). The problems of the priority development of processing branches are not put forward, no relevant significance is attached to the development of the coal branch, though it is evident that one cannot ignore the trends of the world market where the centre of competition is steadily shifting from crude energy carriers towards processing branches. In connection with the situation formed with the structure of FEC in the country, which is based to a decisive extent on the energy resources of Siberian regions, the important part in the formation and realization of the new strategy belongs to the Siberian Branch of RAS. For this purpose, it is necessary to stimulate scientific and applied research aimed at the creation of high technologies of processing organic raw material, first of all coal.

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