CONTENT:

Introduction ........................................................................................................................................ 13

I. Technology of the petroleum coke production, and resources used in the industry .......................................................... 15
   I.1. Raw materials for obtaining petroleum coke ............................................................................... 15
   I.2. Methods of obtaining green and calcined petroleum coke ............................................................. 18
   I.3. Classification of green coke, produced in the CIS, by its quality, standards on coke in the CIS .......................................................................................................................... 24

II. Production of petroleum coke (green and calcined) in the CIS ............................................................. 29
   II.1. Production of petroleum coke in the former USSR (until 1991) and in the CIS in 1996-2018 .......................................................... 29
   II.2. The state of main enterprises producing petroleum coke in Russia .............................................. 36
      II.2.1. OOO Lukoil-Permnefteorgsintez (Perm) ............................................................................... 37
      II.2.2. OOO Lukoil-Volgogradneftepererabotka (Volgograd) ......................................................... 41
      II.2.3. AO TANEKO (Nizhnekamsk, Tatarstan) ............................................................................... 45
      II.2.4. Branch of PAO NK Bashneft – Ufaneftekhim (Ufa, Republic of Bashkortostan) ............. 46
      II.2.5. Branch of PAO NK Bashneft – Novoil (Ufa, Republic of Bashkortostan) ... 50
      II.2.6. AO Antipinsk oil refinery (Tyumen region) ........................................................................... 53
      II.2.7. AO Gazpromneft-Omsk oil refinery (Omsk) ....................................................................... 54
      II.2.8. OAO Rosneft-Novokuibyshevsk oil refinery (Novokuibyshevsk, Samara region) ......................... 58
      II.2.9. AO OAO Rosneft - Angarsk petrochemical company (Angarsk, Irkutsk region) .... 61
      II.2.10. OOO Rosneft-Komsomolsk oil refinery (Komsomolsk-on-Amur, Khabarovsk Territory) .................................................................................................................. 64
      II.2.11. OAO Plant Slantsy (Slantsy, Leningrad region) ................................................................. 66
   II.3. Producers of petroleum coke in other CIS countries ................................................................. 67
      II.3.1. Kazakhstan ....................................................................................................................... 67
      TOO Pavlodar Petrochemical Plant (Pavlodar) ............................................................................ 69
      TOO Atyrau oil refinery (Atyrau) ................................................................................................. 73
      II.3.2. Azerbaijan ....................................................................................................................... 76
      Baku oil refinery named after G. Aliyev (Baku) ........................................................................... 76
      II.3.3. Turkmenistan .................................................................................................................... 79
      Turkmenbashi Complex of oil refineries ......................................................................................... 79
      II.3.4. Uzbekistan ........................................................................................................................ 83
      SE Fergana oil refinery (Fergana) ............................................................................................... 83
      II.3.5. Ukraine .............................................................................................................................. 85
      II.3.6. Belarus .............................................................................................................................. 86

III. Export-import of petroleum coke in the CIS .............................................. 87
   III.1. Export-import of petroleum coke in Russia in 1996-2019 ...................................................... 87
      III.1.1. Volumes of export-import .............................................................................................. 87
      III.1.2. Main directions of export-import supplies ...................................................................... 91
III.2. Export-import of petroleum coke in Ukraine in 1999-2018... 100
III.3. Export-import of petroleum coke in other CIS countries in 1998-2018 ... 104

IV. Review of prices on petroleum coke................................. 105
IV.1. Domestic prices on petroleum coke in Russia in 2002-2019.......... 105
IV.2. Dynamics of export-import prices in Russia in 1999-2019 .......... 107
IV.3. Forecast of export-import prices in Russia until 2025 ............... 113

V. Consumption of petroleum coke (green and calcined) in the CIS........ 119
V.1. Balance of consumption of petroleum coke in Russia in 1996-2018 .... 119
V.2. Structure of consumption of petroleum coke in Russia.................... 122
V.3. Main areas of use of petroleum coke in RF .......................... 125
V.3.1. Production of the anode mass and anodes ............................. 125
V.3.2. Production of graphite electrodes ........................................ 128
V.3.3. Other areas of application .................................................. 132
V.4. Balance of consumption of petroleum coke in Ukraine in 1999-2018 .... 133
V.5. Main enterprisers-consumers of petroleum coke in the CIS, their projects 136
V.5.1. Aluminum enterprises of the CIS .......................................... 137
AO RUSAL-Krasnoyarsk (Krasnoyarsk) ........................................ 140
AO RUSAL-Bratsk (Bratsk, Irkutsk region) ................................... 143
AO RUSAL-Sayanogorsk (Sayanogorsk, Republic of Khakassia) ....... 145
AO RUSAL-Novokuznetsk (Novokuznetsk, Kemerovo region) .......... 147
AO Volgograd aluminum plant (Volgograd) .................................. 149
SUE Tajik Aluminum Company (Talco) (Tursunzade, Tajikistan) ....... 151
V.5.2. Electrode plants of Russia and Ukraine .............................. 154
AO Eneproprom-Novocherkassk electrode plant (EPM-NEZ, Novocherkassk, Rostov region) ...... 155
AO Energomprom-Novosibirsk electrode plant (EPM-NovEZ, Linevo, Novosibirsk region) .......... 158
AO Energomprom-Chelyabinsk Electrode Plant (EPM-ChEZ, Chelyabinsk) .... 161
AO Chelyabinsk electrometallurgical combine (ChEMK, Chelyabinsk) .... 164
PAO Ukrainian graphite (Zaporozhye, Ukraine) ............................... 167

VI. Development prospects of the market of petroleum coke in Russia and the CIS countries until 2025 ......................................................... 170
VI.1. Forecast of production of petroleum coke (green and calcined) in Russia and the CIS until 2025 ............................................................... 170
VI.2. Forecast of consumption of petroleum coke (green and calcined) in Russia until 2025........................................................................ 173
VI.3. Balance of production and consumption of petroleum coke (green and calcined) in Russia up to 2025 ......................................................... 174

Appendix 1: Address directory of producers of petroleum coke in the CIS
Appendix 2: Address directory of largest consumers of petroleum coke in the CIS
LIST OF TABLES:

Table 1: Properties of green coke
Table 2: Specifications on petroleum for oil refineries (according to GOST 9965-76)
Table 3: Suppliers of petroleum to oil refineries of the CIS, producing coke
Table 4: Yield of products at the delayed coking unit, mass %
Table 5: Basic characteristics of different types of delayed coking units, used at the CIS oil refineries
Table 6: Capacities for calcination of green petroleum at refineries of the CIS
Table 7: Requirements imposed on quality of coke of delayed coking process (KZ-8) (according to GOST 22898-78)
Table 8: Requirements imposed on quality of calcined needle petroleum coke (KZI) of a delayed coking process according to GOST 26132-84
Table 9: Requirements imposed on quality of sulfur petroleum coke of delayed coking process, TU 38101525-75
Table 10: Requirements imposed on quality of calcined petroleum coke
Table 11 Quality indicators of petroleum coke, produced at the Russian oil refineries
Table 12: Production of petroleum coke in the CIS by grades
Table 13: Type and quantity of delayed coking units at enterprises-producers of petroleum coke
Table 14: Production of petroleum coke in the CIS countries in 1996-2018, thousand tons
Table 15: Capacities for production of petroleum coke in the CIS countries
Table 16: Production of commodity green petroleum coke at the CIS enterprises in 2001-2018, thousand tons
Table 17: Production of calcined petroleum coke at the CIS enterprises in 1998-2018, thousand tons
Table 18: Consumers of petroleum coke of production of OOO Lukoil-Permnefteorgsintez in 2005-2018, thousand tons
Table 19: Consumers of petroleum coke of production of OOO Lukoil-Volgogradneftepererabotka in 2005-2018, thousand tons
Table 20: Consumers of petroleum coke produced at AO TANEKO in 2016-2018, thousand tons
Table 21: Material balance of DCU at AO Ufaneftekhim before and after reconstruction
Table 22: Technical specifications on the coke additive of the production of OAO Ufaneftekhim
Table 23: Consumers of petroleum coke and the coke additive of production of AO Ufaneftekhim in 2009-2018, thousand tons
Table 24: Consumers of petroleum coke of production of AO Novoil in 2004-2018, thousand tons
Table 25: Consumers of petroleum coke of production of AO Antipinsk oil refinery in 2016-2018, thousand tons
Table 26: Consumers of petroleum coke of production of OAO Gazpromneft-Omsk oil refinery in 2005-2018, thousand tons
Table 27: Consumers of petroleum coke of production of AO Novokuibyshevsk oil refinery in 2005-2018, thousand tons
Table 28: Consumers of petroleum coke of production of Angarsk petrochemical company in 2005-2018, thousand tons
Table 29: Exports of green coke by Pavlodar Petrochemical Plant in 2005-2018, thousand tons
Table 30 Exports of coke (green and calcined) by Atyrau oil refinery in 2005-2018, thousand tons
Table 31: Supplies of petroleum coke of Baku oil refinery to enterprises of Russia and other countries in 2002-2018, thousand tons
Table 32: Supplies of petroleum coke of Turkmenbashi oil refineries to enterprises of Russia and the CIS countries in 2002-2018, thousand tons
Table 33: Export-import of coke (green and calcined) in Russia in 1998-2019, thousand tons
Table 34: Russian exports of green petroleum coke by countries-recipients in 1998-2019, thousand tons
Table 35: Russian export of green petroleum coke by the enterprises in 2002-2019, thousand tons
Table 36: Russian exports of calcined petroleum coke by countries-recipients in 1998-2019, thousand tons
Table 37: Russian export of calcined petroleum coke by the enterprises in 2002-2019, thousand tons
Table 38: Russian imports of green petroleum coke by countries-suppliers in 1998-2019, thousand tons
Table 39: Main suppliers of green petroleum coke to Russia in 2010-2019, thousand tons
Table 40: Imports of calcined petroleum coke by the Russian enterprises in 2004-2019, thousand tons
Table 41: Russian imports of calcined petroleum coke by countries-suppliers in 1998-2019, thousand tons
Table 42: Main suppliers of calcined petroleum coke to Russia in 2008-2016, thousand tons
Table 43: Import of calcined petroleum coke by the Russian enterprises in 2004-2019, thousand tons
Table 44: Export-import of coke in Ukraine in 1999-2018, thousand tons
Table 45: Imports of petroleum coke to Ukraine in 1999-2018, thousand tons
Table 46: Ukrainian consumers of imported petroleum coke in 2001-2018, thousand tons
Table 47: Export of petroleum coke from other CIS countries in 1998-2018, thousand tons
Table 48: Average prices for petroleum coke by Federal Districts of RF in 2012-2019, rub/ton (excluding VAT)
Table 49: Annual average export-import prices on green and calcined petroleum coke in Russia in 1999-2019, $/ton
Table 50: Average annual import prices of calcined petroleum coke for main Russian consumers in 2006-2019, $/ton
Table 51: Average annual import prices of green petroleum coke for main Russian consumers in 2006-2019, $/ton
Table 52: Russian export prices on calcined petroleum coke by companies-suppliers in 2016-2019, $/ton
Table 53: Russian export prices on calcined petroleum coke by recipient countries in 2007-2019, $/ton
Table 54: Russian export prices on calcined petroleum coke by suppliers in 2011-2019, $/ton
Table 55: Average import prices on coke, supplied to Ukraine by various countries in 2004-2018, $/ton
Table 56: Average import prices on petroleum coke for Ukrainian consumers in 2004-2018, $/ton
Table 57: Domestic consumption of petroleum coke (green and calcined) in Russia in 2001-2018, thousand tons
Table 58: Structure of consumption of petroleum coke in the USSR (1990-1991), %
Table 59: Structure of consumption of petroleum coke in Russia in 2002-2018, %
Table 60: Deliveries of petroleum coke to aluminum plants of Russia in 2012-2018, thousand tons
Table 61: Deliveries of petroleum coke to the Russian electrode plants in 2012-2018, thousand tons
Table 62: Domestic consumption of petroleum coke in Ukraine in 2001-2018, thousand tons, %
Table 63: Supply scheme of petroleum coke to main consumers in the CIS in 2011-2018
Table 64: Calcination of petroleum coke at aluminum plants in Russia in 2005-2018, thousand tons
Table 65: Supplies of petroleum coke to AO RUSAL-Krasnoyarsk in 2005-2018, thousand tons
Table 66: Supplies of petroleum coke to AO RUSAL-Bratsk in 2005-2018, thousand tons
Table 67: Supplies of calcined petroleum coke to AO RUSAL-Sayanogorsk in 2005-2018, thousand tons
Table 68: Supplies of calcined petroleum coke to AO RUSAL-Novokuznetsk in 2005-2018, thousand tons
Table 69: Supplies of calcined petroleum coke to AO Volgograd aluminum plant in 2005-2018, thousand tons
Table 70: Imports of petroleum coke from the CIS countries to Tajikistan in 2001-2018, thousand tons
Table 71: Supplies of petroleum coke to AO Enegroprom-NEZ in 2005-2018, thousand tons
Table 72: Supplies of petroleum coke to AO EPM-NovEZ in 2005-2018, thousand tons
Table 73: Supplies of calcined coke of production of AO EPM-NovEZ in 2006-2018, thousand tons
Table 74: Production volumes at AO EPM-ChEZ 2001-2018, thousand tons, million rubles
Table 75: Supplies of calcined petroleum coke to AO EPM-ChEZ in 2003-2018, thousand tons
Table 76: Supplies of petroleum coke to ChEMK in 2004-2018, thousand tons
Table 77: Supplies of imported coke to PAO Ukrainian graphite in 2004-2018, thousand tons
Table 78: Russian enterprises, which plan the construction of delayed coking units
Table 79: Forecast of consumption of petroleum coke in Russia by industries for the period up to 2025
LIST OF FIGURES

Figure 1: Shares of countries of the CIS in the coke production in 2005-2018, %
Figure 2: Dynamics of production of petroleum coke in the CIS by countries in 1996-2018, thousand tons
Figure 3: Dynamics of production of petroleum coke at OOO Lukoil-Permnefteorgsintez in 1996-2018, thousand tons
Figure 4: Dynamics of production of petroleum coke at OOO Lukoil-Volgogradneftepererabotka in 1995-2018, thousand tons
Figure 5: Applications of petroleum coke and coke additive of production of OAO Ufaneftekhim
Figure 6: Dynamics of petroleum coke production at AO Ufaneftekhim in 2009-2018, thousand tons
Figure 7: Dynamics of production of petroleum coke at AO Novoil in 1996-2018, thousand tons
Figure 8: Dynamics of production of green and calcined coke at OAO Gazpromneft-Omsk oil refinery in 1998-2018, thousand tons
Figure 9: Dynamics of production of petroleum coke at OAO Novokuibyshevsk oil refinery in 1996-2018, thousand tons
Figure 10: Dynamics of production of petroleum coke at AO Angarsk petrochemical company in 1996-2018, thousand tons
Figure 11: Dynamics of production of petroleum coke at OOO Rosneft-Komsomolsk oil refinery in 2012-2018, thousand tons
Figure 12: Dynamics of production and refining of oil in Kazakhstan in 2008-2018, million tons
Figure 13: Dynamics of production of petroleum coke by Kazakhstan enterprises in 1995-2015, thousand tons
Figure 14: Dynamics of production of petroleum coke (green and calcined) at TOO Pavlodar Petrochemical Plant in 1995-2015, thousand tons
Figure 15: Technological scheme of the installation for calcination of petroleum coke UPNK
Figure 16: Dynamics of production of petroleum coke (green and calcined) at TOO Atyrau oil refinery in 1995-2018, thousand tons
Figure 17: Dynamics of production of petroleum coke at Baku oil refinery named after G. Aliyev in 1996-2018, thousand tons
Figure 18: Dynamics of production of petroleum coke (green and calcined) at Turkmenbashi Complex of oil refineries in 1995-2018, thousand tons
Figure 19: Dynamics of export-import deliveries of petroleum coke in Russa in 1995-2019, thousand tons
Figure 20: Import of calcined and green petroleum coke to Russia in 1996-2018, thousand tons
Figure 21: Geographical structure of the Russian import of green coke in 2002-2019, thousand tons
Figure 22: Geographical structure of Russian imports of calcined petroleum coke in 2002-2019, thousand tons
Figure 23: Dynamics of export-import deliveries of petroleum coke in Ukraine in 1999-2018, thousand tons

Figure 24: Dynamics of the average Russian prices on petroleum coke (including shale coke) in 2008-2019, rub/ton, $/ton, without VAT

Figure 25: Quarterly dynamics of import prices of oil ($/barrel) and petroleum coke ($/ton) in RF in 2006-2019.

Figure 26: Dynamics of export-import prices in RF for green petroleum coke in 1999-2019 and forecast until 2025, $/ton, $/barrel

Figure 27: Dynamics of average import prices ($/ton) on calcined coke and its imports (thousand tons) to Ukraine in 2003-2018

Figure 28: Dynamics of export-import prices in Ukraine on green coke in 2003-2016, $/ton

Figure 29: "Apparent" consumption (million tons) and growth rates of consumption (%) of petroleum coke in Russia in 1997-2018

Figure 30: Production, export-import and consumption of petroleum coke in RF in 1996-2018, thousand tons

Figure 31: Sectoral structure of consumption of petroleum coke in Russia in 2007-2018, %

Figure 32: Dynamics of production of primary aluminum in Russia in 2000-2018, thousand tons

Figure 33: Dynamics of release of graphite electrodes in RF in 1996-2018, thousand tons

Figure 34: Dynamics of major indicators of the petroleum coke market in Ukraine in 1999-2018, thousand tons

Figure 35: Sectoral structure of consumption of petroleum coke in Ukraine in 2011, 2013, 2015, 2017 and 2018, %

Figure 36: Dynamics of supplies of petroleum coke (green and calcined) to aluminum plants of Russia in 2004-2018, thousand tons

Figure 37: Dynamics of production of primary aluminum and pre-baked anodes at Talco in 2006-2018, thousand tons

Figure 38: Dynamics of supplies of coke to Talco in 2001-2018, thousand tons

Figure 39: Dynamics of production of graphite electrodes at AO Enegroprom-Novocherkassk electrode plant in 2004-2018, thousand tons

Figure 40: Dynamics of production of graphite electrodes

Figure 41: Dynamics of the output of electrode products at AO ChEMK in 2001-2018, thousand tons

Figure 42: Dynamics of production of electrodes (including graphite electrodes) at PAO Ukrainian graphite in 2000-2018, thousand tons

Figure 43: Dynamics of production of petroleum coke in Russia in 1999-2018 and forecast up to 2025, thousand tons

Figure 44: Dynamics of production of petroleum coke in other CIS countries in 1998-2018 and forecast until 2025, thousand tons

Figure 45: Balance of production and consumption of petroleum coke in Russia in 2014-2018 and forecast up to 2025, million tons
Annotation

This report is the twenty first edition of the study of the petroleum coke market in Russia and the CIS.

The purpose of the study is the analysis of the petroleum coke market in the CIS.

The object of this study is petroleum coke (green and calcined).

The work is a desk study. As information sources, we used the UN database (UNdata), the data of Statistical committees of the CIS countries (including the Federal State Statistics Service (Rosstat), State Statistics Service of Ukraine, the Statistics Agency of the Republic of Kazakhstan, etc.), of customs statistics of the Russian Federation and Ukraine, of the official railway statistics; of the sectoral (industrial) and regional press, annual and quarterly reports of companies-issuers of securities, as well as data from websites of companies producing and consuming petroleum coke, and the database of Infomine.

In addition, some data were verified and refined through telephone interviews with specialists of enterprises, considered in this report.

All this has allowed experts to draw a picture of the petroleum coke market in the CIS and prospects of its development.

A distinctive feature of this study is a detailed description of the largest manufacturers and consumers of the products in question in Russia and the CIS countries (including Ukraine), directions of supplies of raw materials, volumes and directions of sales of green and calcined coke. The structure of the petroleum coke consumption by industries and major consuming enterprises is examined in detail, the current state and development prospects of the main consuming industries are described. Forecasts of prices, production and consumption of petroleum coke are presented, as well as the largest projects for expanding production capacities.

The chronological scope of the study: 1996-2018 and the first half of 2019; the forecast for the 2019-2025 period.

Geography of the study: the Russian Federation - a comprehensive detailed analysis of the market; Ukraine, Kazakhstan, Azerbaijan and other CIS countries - an overall retrospective analysis of the market.

The report is composed of 6 chapters, contains 179 pages, including 45 Figures, 79 Tables and 2 Appendices.

The first chapter of the report presents data on raw material resources, required for production of petroleum coke, and their characteristics. The section also describes in detail the technology of the coke production and quality parameters of the final products.

The second chapter is devoted to production of petroleum coke (green and calcined) in the CIS countries. This section presents statistical and estimated data on the coke production in Russia and the CIS countries. The chapter describes in detail all
companies—producers of petroleum coke in Russia and the CIS, their current standing and prospects of development.

The **third chapter** of the report presents data on foreign trade operations in petroleum coke in Russia and the CIS countries.

The **fourth chapter** of the report presents data on producers’ prices on various grades of coke on the Russian market. Besides, it analyses data on dynamics of export-import prices on the products in Russia and Ukraine. In addition, this section gives a forecast of the prices up to 2025.

The **fifth chapter** analyses consumption of petroleum coke. The section presents the supply-demand balance of petroleum coke in Russia and Ukraine, a sectoral structure of its consumption in Russia, describes the main consumers in Russia and the CIS, and analyzes their current standing and prospects of development.

The **sixth chapter** presents a forecast of development of the petroleum coke market in Russia until 2025.

The Appendices present contact information on producers and consumers of petroleum coke in the CIS.

**The target audience of the study:**
- Participants of the petroleum coke market - producers, consumers, traders;
- Potential investors.

The presented research claims to be the reference source for marketing services and for specialists, making management decisions on the market of petroleum coke.
Introduction

Petroleum coke (carbon of petroleum origin) is a porous solid, infusible and insoluble, dark gray to black mass. It is composed of high-condensed high-aromatic polycyclic hydrocarbons with a small content of hydrogen, as well as other organic compounds.

The elementary composition of green (non-calcined) petroleum coke is as follows:

C: 91-99.5
H: 0.035-4
S: 0.5-8
(N+O): 1.3-3.8,
the rest are metals

Petroleum coke is a complex disperse system, in which the disperse phase is composed of crystalline elements of various sizes and of ordering in the mutual position of molecules and pores, and the disperse medium, filling pores in a crystalline matter, is presented by a continuous gaseous or liquid phase, forming adsorption-solvate layers, or solvated complexes.

Carbon is ordered in fragments of the graphite structure. A degree of ordering depends on a raw material and the technology of its preparation. For instance, directly distilled heavy oil residues yield a low-ordered structure, whereas distilled cracking residues yield a high-ordered one. The degree of ordering governs the graphitization ability of petroleum cokes and properties of the obtained graphite.

The main indicators of quality of petroleum coke are the content of sulfur, ash, moisture and volatile compounds, a grain size, and a mechanical strength.

The main properties of green cokes are given in Table 1.

By method of obtaining, petroleum cokes can be divided into cokes, obtained by a delayed coking, and by coking in heated stills.

Before the use, petroleum coke is usually subjected to the refining (calcination) at oil refineries directly after obtaining, or by customers themselves.

Petroleum coke is used mainly in the metallurgy.
Table 1: Properties of green coke

<table>
<thead>
<tr>
<th>Indicator</th>
<th>low-sulfurous</th>
<th>sulfurous</th>
<th>high-sulfurous</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt; 25 mm</td>
<td>&lt; 25 mm</td>
<td>&gt; 25 mm</td>
</tr>
<tr>
<td>Yield, mass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of fractions</td>
<td>41.5</td>
<td>58.5</td>
<td>35.7</td>
</tr>
<tr>
<td>of volatile components</td>
<td>8.7</td>
<td>10.2</td>
<td>6.8</td>
</tr>
<tr>
<td>Content, mass %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sulfur</td>
<td>0.52</td>
<td>0.53</td>
<td>1.2</td>
</tr>
<tr>
<td>ash</td>
<td>0.43</td>
<td>0.50</td>
<td>0.27</td>
</tr>
<tr>
<td>Mechanical strength, MPa</td>
<td>5.7</td>
<td>4.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Porosity, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk mass, kg/m³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific electric resistance, Ohm·m</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: review of the scientific and technical literature

Areas of the use of petroleum coke are as follows: for obtaining the anode paste in the aluminum production, graphite electrodes for arc furnaces in the steelmaking industry, for obtaining sulfidizing agents in the non-ferrous metallurgy (for the conversion of metals or their oxides into sulfides to simplify the metals extraction from ores, for instance, in the production of Cu, Ni and Co).

Besides, in the chemical industry petroleum coke is applied as a reducer, for instance, in production of BaS₂ from barite, in obtaining CS₂, carbides of Ca and Si.

Special grades of coke are used as a structural material in the manufacture of corrosion-resistant apparatus. In the food industry, coke is applied in the sugar production as a substitute of the blast furnace coke. A low quality sulfurous coke is used as a fuel.
I. Technology of the petroleum coke production, and resources used in the industry

I.1. Raw materials for obtaining petroleum coke

The quality of raw materials is a priority parameter, governing properties of the final product – petroleum coke.

Production of coke in the CIS is mainly conducted at delayed coking units (DCU). A feature of the DCU operation is that they use, as resources, various semis and wastes of the oil refining at refineries.

As raw materials, the following materials are used: heavy oil fractions, obtained by distillation (fuel oil, tar), cracking-residues of the thermal cracking of fuel oil and tar, heavy gas-oil of catalytic cracking, oil production residues (asphalt, extracts of the phenolic cleaning of oils, etc.).

Of all oil residues, prone to the formation of various types of structures of coke, the most preferred are aromatic concentrates (residues of the distillate cracking), and some other high molecular weight hydrocarbons. For this reason, raw distillates are considered promising feedstocks.

Refineries initially have different operating conditions and run on different oils. This fact is an important parameter for the production of coke of a given quality, so for each oil refinery the delayed coking units have been built with the specific conditions in mind.

Among the main parameters that determine the quality of oils, such as the density, the fractional and chemical composition of petroleum products, the most significant are the density and the sulfur content index.

Sulfur is one of the most undesirable impurities in the composition of crude oils and of the final product - petroleum coke. Depending on the mass fraction of sulfur, cokes, as well as oils, are classified into low-sulfurous, sulfurous, and high-sulfurous.

Sulfurous cokes possess less favorable properties as compared to low-sulfurous cokes: they cause the corrosion of the equipment, an increased number of cracks in the electrode products, the destruction of the refractory masonry of calcination furnaces, so that their use is restricted to certain areas.

Oil coming to refineries varies in the composition, particularly on the sulfur content. The former Soviet Union, and especially Russia, usually process mainly sulfurous and high-sulfurous oils.

In the territory of the ex-USSR, a large share of the Baku, Grozny, Sakhalin, Turkmen and some Ukrainian and Kazakh oils belong to the low-sulfurous oils (below 0.5%).

Sulfurous petroleum (0.5-2.5% S) is produced in the Ural-Povolzh’e (Tuimazy, Romashinskoe oil fields, etc.), and the Western Siberia oil fields (Samotlor, Nizhnevartovsk, Megion, etc.).

High-sulfurous oils (above 2.5% S) are produced in the Ural-Povolzh’e – the Arlanskoe, Radaevskoe, and Pokrovskoe oil fields.

Currently, the main raw material for the coke production in the CIS is sulfurous oil.
According to Specifications, GOST 9965-76 (Table 2), petroleum is subdivided into 3 groups depending on degree of preparation, and into 3 classes by the sulfur content. The each class is subdivided into 3 types (depending on the density at 20°C).

**Table 2: Specifications on petroleum for oil refineries (according to GOST 9965-76)**

<table>
<thead>
<tr>
<th></th>
<th>Depending on the mass fraction of sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>up to 0.60%</td>
</tr>
<tr>
<td></td>
<td>from 0.61% to 1.80%</td>
</tr>
<tr>
<td></td>
<td>above 1.80%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Depending on density at 20°C, kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Up to 850</td>
</tr>
<tr>
<td>Medium</td>
<td>from 851 to 885</td>
</tr>
<tr>
<td>Heavy</td>
<td>above 885</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>By parameters of degree of preparation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>Chlorides concentration, mg/dm³</td>
</tr>
<tr>
<td></td>
<td>Mass fraction of water, %</td>
</tr>
<tr>
<td></td>
<td>Mass fraction of mechanical impurities, %</td>
</tr>
<tr>
<td></td>
<td>Saturated vapor pressure, kPa</td>
</tr>
<tr>
<td>I</td>
<td>maximum 100</td>
</tr>
<tr>
<td></td>
<td>maximum 0.5</td>
</tr>
<tr>
<td></td>
<td>-</td>
</tr>
<tr>
<td>II</td>
<td>maximum 300</td>
</tr>
<tr>
<td></td>
<td>maximum 1.0</td>
</tr>
<tr>
<td></td>
<td>maximum 0.05</td>
</tr>
<tr>
<td></td>
<td>maximum 66.7</td>
</tr>
<tr>
<td>III</td>
<td>maximum 900</td>
</tr>
<tr>
<td></td>
<td>maximum 1.0</td>
</tr>
<tr>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

Source: FSUE Standartinform

Application of technologies, allowing to obtain a high-grade coke independent of the initial petroleum composition, solves many problems: provides the electrode industry with quality resources, allows to use wider ranges of oils, and to deepen the refining of petroleum at oil refineries.

To de-sulfurize a final product, the calcination of coke is applied. One more way to obtain the de-sulfurized coke from high sulfurous oils is the preliminary oil cleaning of sulfur by methods of the hydro-desulfurization, hydro-cracking or de-asphaltization. This variant is considered to be more efficient, in spite of its complexity and additional expenditures.

To the Russian refineries, oil is mainly supplied by the system of main pipelines of AK Transneft, in which the West-Siberian oil of the grade Siberian Light is mixed with the more heavy and sulfurous oil of the grade Urals.

Table 3 presents the main suppliers of petroleum to oil refineries of the CIS, producing coke.
### Table 3: Suppliers of petroleum to oil refineries of the CIS, producing coke

<table>
<thead>
<tr>
<th>Oil refineries/Petroleum companies</th>
<th>Bashneft*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novoil</td>
<td>+</td>
</tr>
</tbody>
</table>

* joined Rosneft in 2016

*Source: Infomine*
I.2. Methods of obtaining green and calcined petroleum coke

The coking of petroleum is the most extreme form of the thermal cracking of petroleum residues. It is conducted at a low pressure and temperatures of 480-560°C to obtain petroleum coke, as well as hydrocarbon gases, petrol and kerosene-gas-oil fractions.

The coking breaks all components of the raw materials to obtain liquid distillate fractions and hydrocarbon gases; causes the destruction and cyclization of hydrocarbons with an intensive release of kerosene-gas-oil fractions; the condensation and polycondensation of hydrocarbons and a deep compression of high-molecular compounds with the formation of massive coke residues.

The industrial process of coking is conducted at units of 3 types: the periodical coking in coke stills, the delayed coking in chambers, and the continuous coking in a pseudo-liquefied layer of a coke-carrier.

In the CIS, petroleum coke is obtained by the delayed coking and the coking in coke stills.

Delayed coking

The delayed (semi-continuous) coking is the most widespread method in the world. Raw materials, preliminarily heated in tube furnaces up to 350-380°C, are continuously fed to cascade dishes of the rectification column (working at an atmospheric pressure) and contacts with vapors, rising from the reaction apparatus.

As a result of the mass- and heat-exchange, a part of vapors is condensed, forming with initial raw materials so-called secondary resources, which are heated in tube furnaces up to 490-510°C and then go to coke chambers – the hollow vertical cylindrical apparatus of 3-7 m in diameter and of the height of 22-30 m.

The reaction mass is continuously fed in coke chambers for 24-26 hours and is coked thanks to the accumulated heat. After filling the chamber with coke by 70-90%, the accumulated coke is removed from the chamber, usually by the water jet under a high pressure (up to 15 MPa). Coke goes to the crusher, where it is crushed into pieces of the maximum size of 150 mm, and then is screened to fractions 150-25, 25-6 and 6-0.5 mm. The chamber is heated by steam and vapors from operating coke chambers, and is filled with the coking mass again.

Volatile products of coking, being a vapor-liquid mixture, are continuously discharged from operating chambers and separated consequently in the rectification tower, the water-separator, the gas block and the evaporation column into gases, petrols and kerosene-gas-oil fractions (see Table 4).

Typical parameters of the process: the temperature in the chambers is 450-480°C, the pressure is 0.2-0.6 MPa, and the duration is up to 48 hours.
### Table 4: Yield of products at the delayed coking unit, mass %

<table>
<thead>
<tr>
<th>Product</th>
<th>Raw materials</th>
<th>Coke (density 0.950 g/cm³)</th>
<th>Tar (density 0.991 g/cm³)</th>
<th>Cracking-residue (density 1.024 g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tar</td>
<td>4-5</td>
<td>6-7</td>
<td>7-8</td>
</tr>
<tr>
<td></td>
<td>Cracking-residue</td>
<td>7-8</td>
<td>15-16</td>
<td>6-7</td>
</tr>
<tr>
<td></td>
<td>Kerosene-gas-oil fractions</td>
<td>68-69</td>
<td>58-59</td>
<td>46-47</td>
</tr>
</tbody>
</table>

Source: Infomine based on data of enterprises

The advantage of the delayed coking is a high yield of low-ash coke. The method yields by 1.5-1.6 times more coke than the continuous coking (from the same amount of resources).

Russian oil refineries operate the one-block and twin-block DCUs (each block includes 2-3 reactors) of various types. DCU are designed by Institutes Giproneftezavody and VNIPIneft. DCU are classified by the yield of the final product.

Twin-block DCU are subdivided into four types.

1. **DCU of the first type (21-10/300, 21-10/600)** are equipped with reaction chambers with the inner diameter of 4.6 or 5 m and heating furnaces of the tent-shaped type. The DCU unit includes devices of absorption and stabilization of petrol, they also yield kerosene, gas-oil, the furnace fuel, heat of which is used for heating. Four chambers operate in pairs, independently of each other; therefore each pair can be switched off independently for repair.

2. **DCU units of the second type 21-10/3M** have a similar design, but with reaction chambers of the inner diameter of 5.5 m. The DCU units of this type use direct distilled petroleum residues, with high-aromatic components (the aromatization of the coking resources promote an increasing yield and the quality of coke and prolongs a service-life of DCU).

3. In 1975-1990, a number of oil refineries commissioned **twin-block DCU of the type 21-10/6 (6M)**. These DCU are equipped with highly efficient equipment: reaction chambers of alloyed steel of 5.5 m in diameter and of the height of 27.6 m (operating at a pressure of up to 0.6 MPa); tube furnaces of a volume flame for heating initial resources and the heat-carrier and vertical-torch furnaces (for heating secondary resources) with a bottom position of burners. Three radioactive level gauges, installed at the reactor, register the level of the phase separation (coke-foam). The use of level gauges allows optimizing the utilization of a chamber space.

The increasing efficiency of the DCU operation is also reached at the expense of the use of air-cooling facilities as condensers and by a deep utilization of the exhaust heat. The decreasing temperature of the secondary resources heating and the decreased coke precipitation are reached at the expense of heating primary resources (heavy coking gas-oil) up to 515°C in a special twisted tube; it is also possible to supply the additional heat into the reactor.

The reaction furnace coils are fed with the turbulence promoter and the detergent, which increases the uptime of furnaces. In order to decrease and depress the foam
formation, a special anti-foaming reagent is fed to the top zone of chambers. The coke precipitation in slam lines of chambers is prevented by the supply of cooled gas-oil of coking. Besides, improvements were made in a scheme of catching products of the chamber heating, steaming and the coke cooling.

4. Reaction chambers **DCU 21-10/5K** have a diameter of 7 m and the height of 29.3 m. In addition to modernizations, applied at the earlier built DCUs, this unit was modified to increase the efficiency of the coke production. The unit has an axial feeding of resources into reaction chambers, coke-removing hydraulic complexes with a remote control of cutters, electric-driven valves at transfer pipelines, the mechanization of labor-consuming processes, and a coke warehouse of the floor type.

The main characteristics of delayed coking units of various types, used in the CIS, are presented in Table 5.

### Table 5: Basic characteristics of different types of delayed coking units, used at the CIS oil refineries

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Type of the unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21-10/300</td>
</tr>
<tr>
<td>Production, thousand tons per year:</td>
<td></td>
</tr>
<tr>
<td>By raw material</td>
<td>300</td>
</tr>
<tr>
<td>By green coke</td>
<td>75</td>
</tr>
<tr>
<td>Temperature of reactor, °C</td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>450</td>
</tr>
<tr>
<td>Bottom</td>
<td>475</td>
</tr>
<tr>
<td>Pressure in reactor, MPa:</td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>0,18</td>
</tr>
<tr>
<td>Bottom</td>
<td>0,38</td>
</tr>
<tr>
<td>Height of reactor filling, m</td>
<td>18-20</td>
</tr>
<tr>
<td>Cycle duration, h</td>
<td>48-120</td>
</tr>
<tr>
<td>Inner diameter of reactor, mm</td>
<td>5000</td>
</tr>
</tbody>
</table>

*Source: Infomine, data of enterprises*

In the CIS, the most widespread DCU are those of types 21-10/300, 21-10/600 and 21-10/3M. Note, that by quality the DCU coke is inferior to still coke because of the increased moisture (by 2% in average) and the content of volatile components (by 1-2%).
**Periodical coking**

The process is conducted in horizontal cylindrical apparatus of 2-4 m in diameter and 10-13 m long. Raw materials in a still are gradually heated from the bottom by open fire. Then distillates are separated, coke is dried and calcined (2-3 hours). Then the temperature in the furnace under the still is gradually decreased, and the still is cooled by steam and then by air. After the temperature of coke decreases to 150-200°C, the product is unloaded from the still.

Typical parameters of the process are: the temperature of the vapor phase is 360-400°C, and the pressure is the atmospheric pressure. This method yields the electrode and special high-grade types of coke with a low content of volatiles.

However, this is a low productivity method, it requires a large consumption of fuel and manual labor, and, therefore, it is practically not used in the industry. This method is not used abroad at all, and in the CIS it yields around 1% of coke, by assessment of Infomine.

**Continuous coking in a fluidized bed**

*(thermo-contact cracking)*

Raw materials, preliminarily heated in a heat exchanger, contact in a reactor with a hot inert heat-carrier and coked at its surface for 6-12 minutes. As the heat carrier, usually a powdery coke is used with a particle size of up to 0.3 mm, rarely more.

The formed coke and the heat-carrier are removed from a reaction zone and are fed to a regenerator (a coke heater). There an air flow maintains the heat-carrier in a suspended state, up to 40% of coke are burned in this flow, and the bulk is supplied to customers. The heat, generated from burning a part of coke, heats the carrier, which is returned to the reactor by a pneumo-transport by steam or by a gas flow. Distillate fractions and gases are removed from the reactor and are separated by the same way as in the delayed coking process.

Typical parameters of the process are: the temperature in the heat exchanger is 300-320°C, in the reactor - 510-540°C and in the regenerator 600-620°C, the pressure in the reactor and in the regenerator is 0.14-0.16 and 0.12-0.16 MPa, respectively, the resources/heat-carrier ratio (by mass) – (6.5-8.0):1.

The coking in a fluidized bed is used for the increasing production of light petroleum derivatives. Besides, the combination of a continuous coking with the gasification of the formed coke can be applied for obtaining the diesel and boiler fuels.