

TENDENCY OF ISOMERIZATION PROCESS DEVELOPMENT IN RUSSIA AND FOREIGN COUNTRIES

E.A. Yasakova, A.V. Sitdikova

*JSC "Salavatnefteorgsintez"
katrina85ma@yandex.ru*

A.F. Achmetov

*Ufa State Petroleum Technological University
tng@rusoil.net*

Problems of Russian Refineries in term of toughening of requirements to up-to-date automotive gasoline quality are considered in the article. Review of existing technologies of isomerization process and their main performances are represented here. The data about existing state of isomerization process and tendency of development of this process in Russia and foreign countries are given in the article.

Keywords: isomerization process, high-quality gasoline, isomerization catalyst, technology of isomerization process, reducing of benzene content in gasoline

1. TOUGHENING OF UP-TO-DATE GASOLINE REQUIREMENTS

In worldwide production of automotive gasoline permanent tendency to the toughening of not only its operating but also its ecological characteristics is observed. So, international and domestic regulations to automotive gasoline considerably limit the content of benzene, aromatic hydrocarbons, olefin hydrocarbons and sulfur.

The special technical regulation "About requirements to gasoline, diesel and some fuels and lubricants" was approved in Russia since February of 2008. The date of Euro-2, 3, 4, 5 ecological class automotive gasoline productions are defined in it. Particularly it is necessary to switch over the automotive gasoline of Euro-4 class production with aromatic compounds content equal 35 % including benzene content less than 1 % since 1-st January of 2012 [1,2]. The benzene limits up to 0.96 % have already been introduced in USA currently. The Regulations Mobile Source Air Toxics (MSAT II), which limit the benzene content in gasoline up to 0.62 % become operative since 1st January of 2011 [3].

In 1970s the variants of hydrogenation of the benzene, contained in the reformate, proceeding without the decrease of product octane number have been offered [4]. However for decrease of the total aromatics content the dilution of reformate (being the

base component of high-octane gasoline in Russia) with high-octane nonaromatic components is required. This situation is complicated by refusal from tetraethyl lead (TEL) and deficit of butane-butylene fraction (because of the lack of FCC duty), which is used for the production of high-octane alkylate in the world practice.

Thereby the development of isomerization process is one of the effective methods for solution of this problem. It allows the producing of commercial gasoline which corresponds to the current and perspective requirements to the fuels and provides necessary flexibility of processing.

2. TYPES OF ISOMERIZATION PROCESSES

Three types of industrial isomerization processes are worked out currently [5, 6]:

— high-temperature isomerization process (360-440 °C) on fluorinated-alumina catalysts;

— medium-temperature isomerization process (250-300 °C) on zeolite catalysts;

— low-temperature isomerization process on chlorinated-alumina catalysts (120-180 °C) and sulfated metal oxides (180-210 °C).

3. THERMODYNAMIC AND KINETIC LAWS OF ISOMERIZATION PROCESSES

The schemes of proposing processes are analogous generally. The differences are defined by performances of usable catalysts due to their type. Main parameter which is the octane number of produced isomerizate depends on process temperature.

That's why we will dwell on the issue of thermodynamic of isomerization reaction. First of all hydrocarbons isomerization reaction is balanced reaction, and equilibrium yield of isoparaffins increases with temperature reducing, but it can be reached only after an "infinite residence time" of the feed in reaction zone or an equivalent very small value for LHSV. On the other hand an increase in temperature always corresponds to an increase in reaction velocity. So that at low temperature the actual yield will be far below the equilibrium yield, because of low reaction velocity. On the contrary, at higher temperature, the equilibrium yield will be more easily reached, due to a high reaction rate. Consequently, at higher temperature the yield of isoparaffins is limited by the ther-

modynamic equilibrium, and at lower temperature it is limited by low reaction rate (kinetic limitation) (Figure 1) [7].

The comparative estimation of isopentanes content in sum of pentanes for different types of isomerization catalysts is represented below (Figure 2) [5].

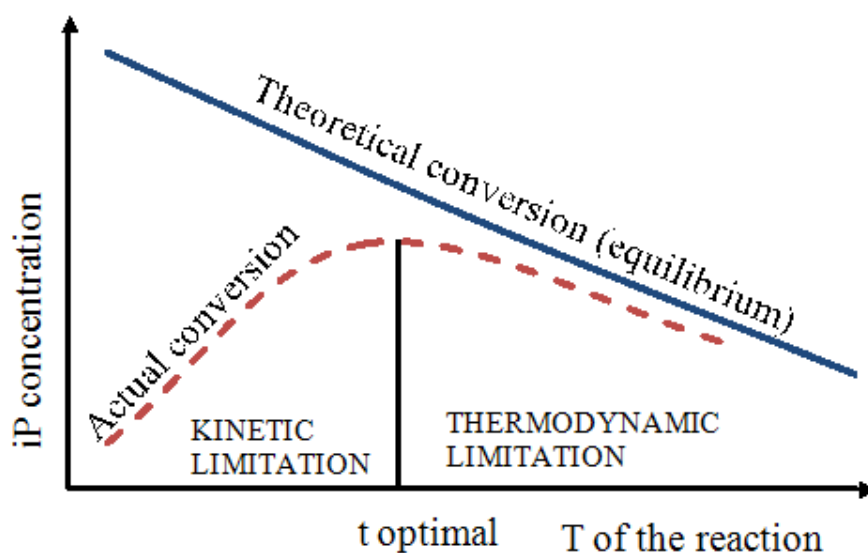


Figure 1. Dependence of n-paraffins conversion on reaction temperature

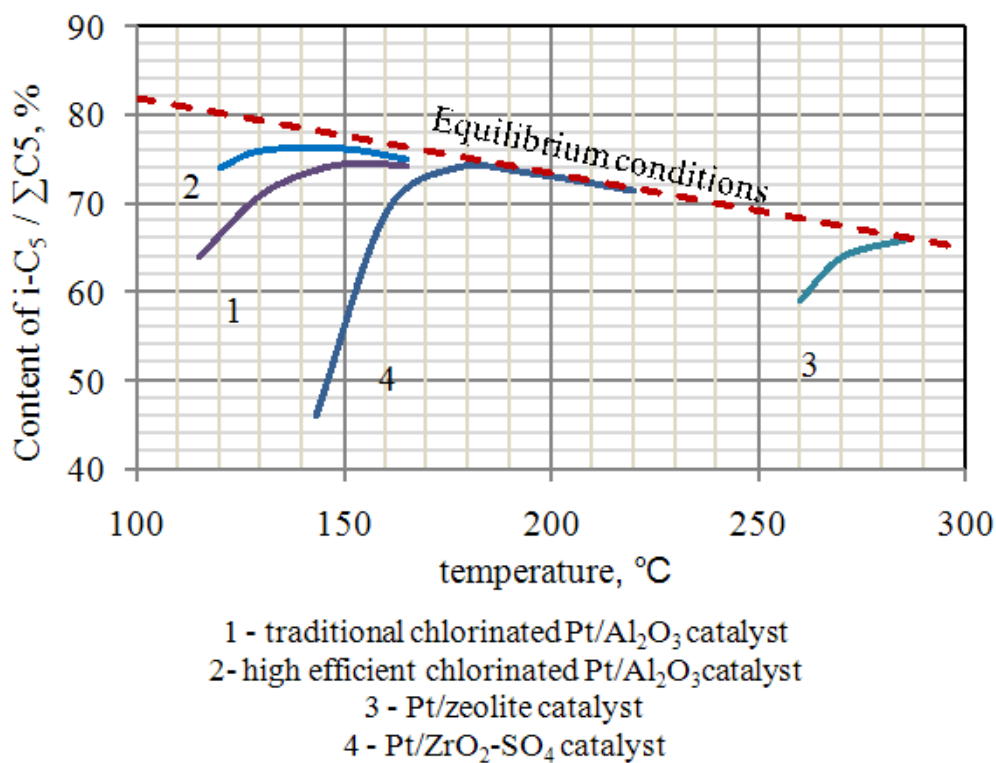


Figure 2. Comparative estimation of isomerization catalysts

The conversion level of n-paraffins on zeolite catalysts is low, as it is limited by thermodynamic equilibrium. In the case of chlorinated-alumina catalysts and sulfated metal oxides conversion of n-paraffins is higher because of high equilibrium content of isocomponents in product.

4. TECHNOLOGIES OF ISOMERIZATION PROCESS ON DIFFERENT CATALYSTS

Zeolite catalysts are less active and used at higher operating temperature compared to another types of catalysts, and consequently the octane number of isomerizate is low. However they possess high resistance to impurities in the feed and capability for total regeneration in the reactor of the unit. The technological scheme of this process is provided with fire-heaters for heating hydrogen and feed mixture up to reaction temperature. It is necessary high ratio of hydrogen to hydrocarbon feed (along with isomerization, hydrogen is spent for hydrotreating and dearomatization of the feed); that's why compressor for supplying of recycle hydrogen-rich gas and separator for separation of hydrogen-rich gas are necessary (Figure 3).

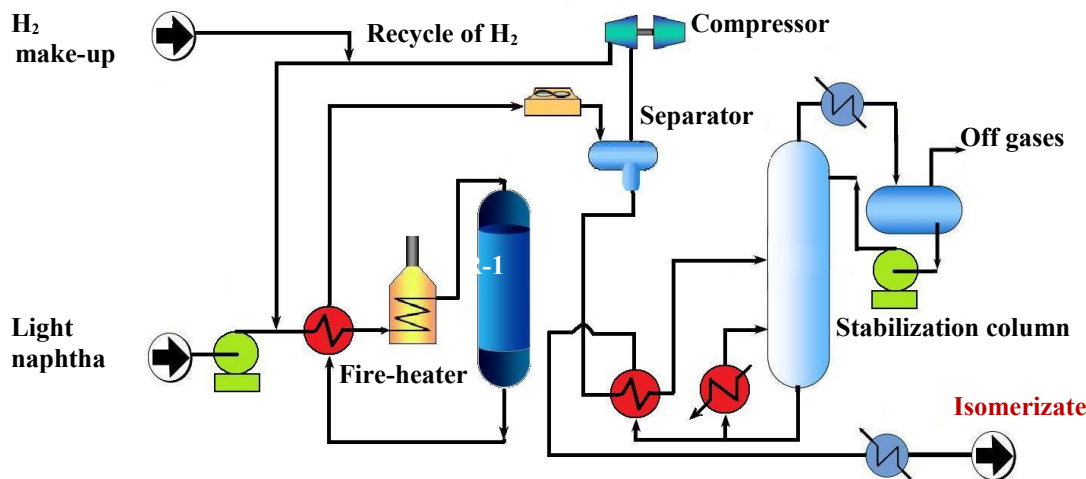


Figure 3. Process flow diagram of zeolite catalyst based isomerization [5]

Main foreign licensors of zeolite catalyst based isomerization process are UOP (HS-10), Axens (IP-632) and Süd Chemie (Hysopar). Main producers in Russia are JSC “NPP Neftehim” (СИ-1 catalyst, Izomalk-1 technology), Co Ltd Scientific production firm “Olkat” (СИП-2А), JSC “VNIINeftehim” (ИИМ-02) [5-9].

Hysopar catalyst should be marked out among zeolite catalysts; it is the most progressive in the world catalyst market, because it considerably exceeds all other catalysts by resistance to impurities in the feed (available sulfur content is 100 ppm permanently and 200 ppm during short periods of time) [5, 10].

Chlorinated-alumina based catalysts are the most active and supply the highest isomerizate yield and isomerizate octane. It should be noted that during isomerization catalysts lose chlorine, consequently the activity is reduced. That's why chlorine compound injection to the feed (usually CCl_4) is provided for keeping of high activity. As a result, caustic soda washing from organic chloride in special scrubbers is necessary. Considerable drawback is that this type of catalyst is very sensible to poisonous impurities (to the oxygen compounds including water, to nitrogen) and requires pre-treatment and drying of the feed. In addition the problems occur at regeneration (Figure 4) [5].

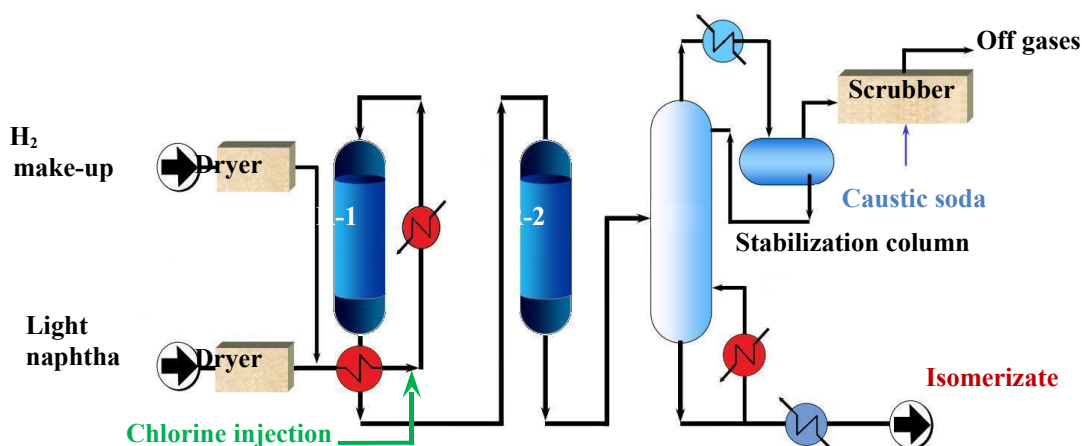


Figure 4. Process flow diagram of chlorinated-alumina based isomerization [5]

Main foreign licensors of this process are UOP and Axens. The first generation catalyst of UOP is I-8, which was improved later in more active I-80 type catalyst. The latest developments of UOP Company are high-performance I-8 Plus, I-82, I-84 catalysts for Penex process and I-122, I-124 catalysts, which are used in Butamer process (n-butane isomerization process with purpose to produce isobutane, which is the feed for alkylation unit). In development of new catalysts UOP has the target to decrease its platinum content without losing the activity, thereby to reduce significantly its operating costs. It is not of small importance for present-day refinery [11, 12].

IS-614A catalyst is one of the first developments of Axens. ATIS-2L catalyst, which is the product of teamwork with Akzo Nobel was developed later on its base. ATIS-2L distinguishes oneself by higher activity (octane number of the isomerizate is one point higher), lower apparent density (catalyst charge decreases by 22 %), lower by 10 % platinum content [8, 12]. So, its application is economically more attractive solution. The first industrial loading was in 2003 year [9, 13].

Main licensors of this process in Russia are Co Ltd Scientific production firm “Olkat” (НИП-3А), JSC “VNIINeftehim” (ИП-05) [5].

Sulfated metal oxides based catalysts get heightened interest last years as they combine main advantages of medium-temperature and low-temperature catalysts. They are active, resistant to poisonous impurities and able for regeneration. The only drawback, as for zeolite catalysts, is necessity in compressor for recycling of hydrogen-rich gas (Figure 5).

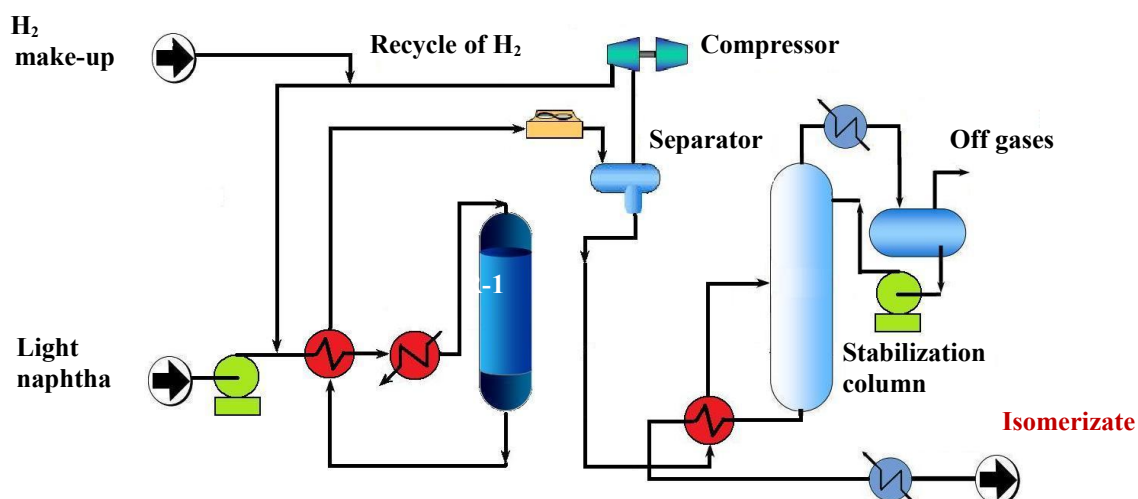


Figure 5. Process flow diagram of sulfated-zirconia catalyst based isomerization [8, 12]

Main developers of sulfated-zirconia catalysts are UOP (Par-Isom technology on LPI-100 and PI-242 catalysts) and JSC “NPP Neftehim” (Izomalk-2 technology on СИ-2 catalyst).

The СИ-2 catalyst has an activity, which is higher than activity of PI-242 [5] and characterized with unique sulfur resistance. If necessary, the process can be carried out without pretreatment of the feed. In this case the octane number of isomerizate is reduced by 2 points, but total lifetime (8-10 years) doesn't changes and service cycle is no

less than 12 months. The feed may contain considerable quantity of benzene which is hydrogenated efficiently on the catalyst. The CH-2 catalyst is produced in JSC “Industrial catalysts” (Ryazan) and JSC “Angarsky factory of catalysts and organic synthesis” by license of JSC “NPP Neftehim” [8].

The Pt/WO₃-ZrO₂ catalyst, which is developed in the University of Hokaydo city (Japan), shows higher activity and selectivity in isomerization reaction of n-alkanes compared to sulfated-zirconia catalysts. The advantage of this type of catalyst is explained by rapid surface diffusion of hydrogen atoms, which are converted into protons and hydrides on the Lewes acid sites, thereby increasing catalyst activity and selectivity [14].

5. TECHNOLOGIES SCHEMES OF ISOMERIZATION PROCESS

Economically efficient “**one- through**” scheme without any recycle can be used with minimum investment in realization of isomerization process (Figure 6).

The scheme with deisopentanizer (DIP) before the reactor section allows the producing of isomerizate with high octane number, increasing of conversion level of n-pentanes and reducing the reactor duty simultaneously. The technology is reasonable in the case of isopentanes content in the feed more than 13-15 % (Figure 7) [9,13,15].

The scheme with **deisohexanizer (DIH)** after the isomerization reactor is the simplest way to produce the isomerizate with higher octane number. In this case non-converted low-octane components (methylcyclopentane and n-hexane) are recycled into reactor. However the given scheme allows only increasing of hexanes conversion, but doesn't raise the content of isopentanes in the product (Figure 8). The scheme of the process may include both deisopentanizer and deisohexanizer (with DIP and DIH) [9,13,15].

Scheme with recycle of n-pentane (with DIP and DP) requires providing with depentanizer of isomerizate after the reaction section and deisopentanizer before the reactor.

Schemes with recycle of n-pentane and n-hexane. For total conversion of all linear paraffins (not only n-C₆ but also n-C₅) into isomers, their total recycle is necessary, which can be realized by set of distillation columns (with DIP, DIH and DP) or by adsorption on molecular sieves.

The method of adsorption on molecular sieves (in liquid or vapor phase) is based on capability of pores with definite size to adsorb selectively the molecules of n-paraffins. The next stage is desorption of n-paraffins from pores and its recycle to the feed stock. Stages of adsorption and desorption are repeated in cycles or pseudo-continuously.

Axens offers two patented isomerization processes on the molecular sieves: **Ipsorb** and **Hexorb** (Figure 9, 10). UOP offers the processes with adsorption systems on the molecular sieves in vapour phase (**Penex/Iso Siv**) and liquid phase (**Penex/Molex** (Figure 11)), and process, which combines adsorptive separation of unconverted n-paraffins from isomers and deisohexanizing **Penex/DIH/PSA** [5, 16].

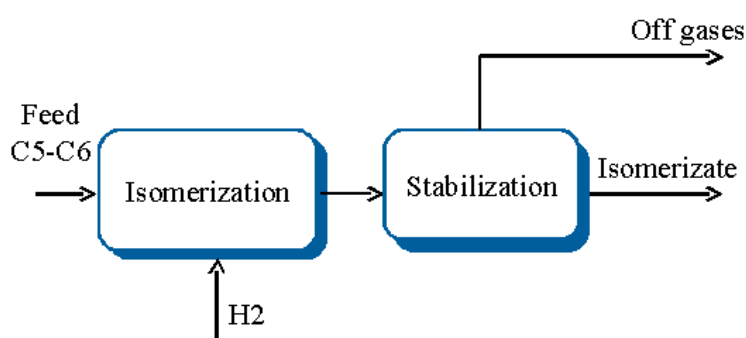


Figure 6. Block diagram of “one- through” process

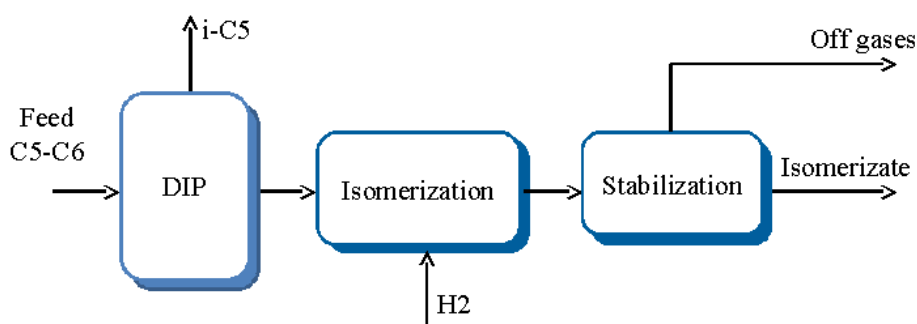


Figure 7. Block diagram of process with DIP

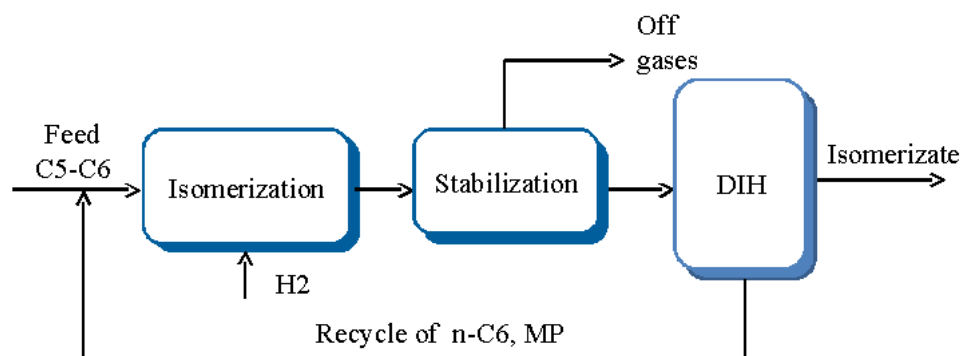


Figure 8. Block diagram of process with DIH

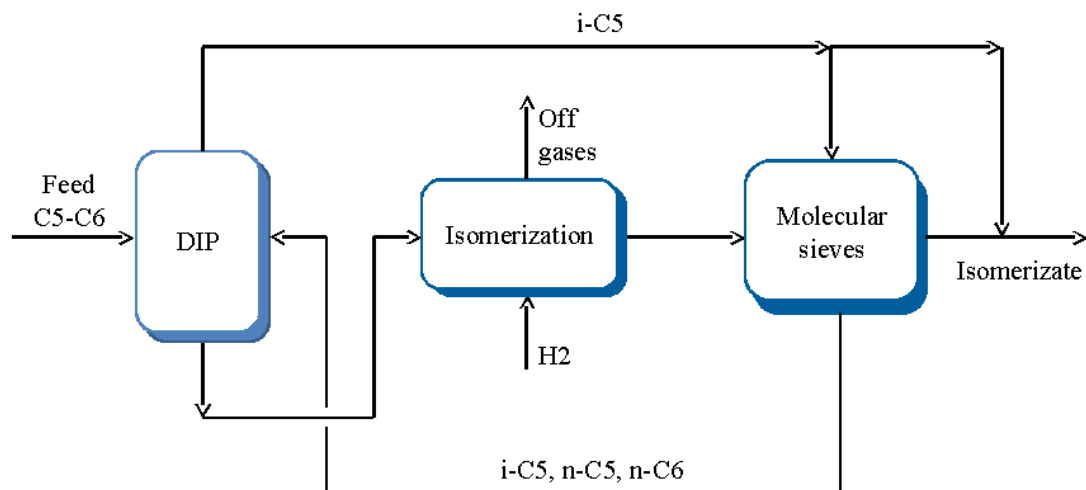


Figure 9. Block diagram of Ipsorb process

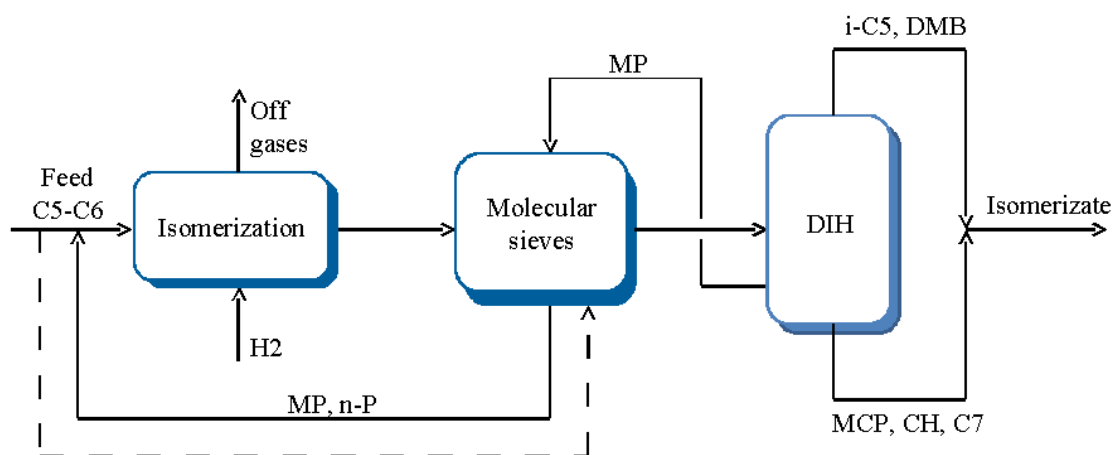


Figure 10. Block diagram of Hexorb process

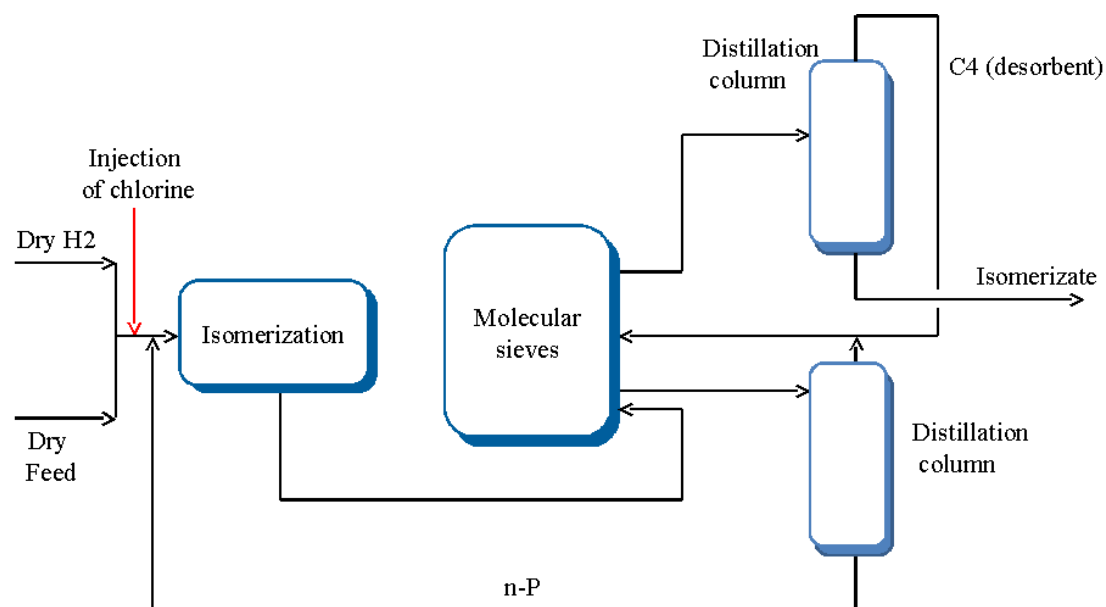


Figure 11. Block diagram of Penex/Molex process [12]

UOP offers patented isomerization processes on zeolite catalysts **Total Isomerization Process (TIP)** (Figure 12) [5, 7, 12], which also includes separation of n-paraffins on the molecular sieves.

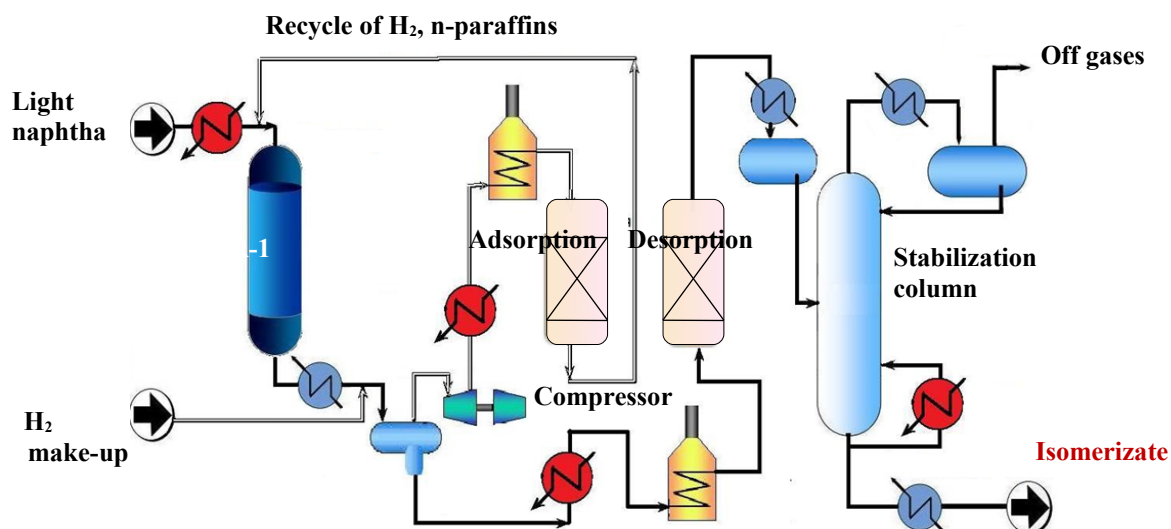


Figure 12 - Process flow diagram of TIP process [7]

Penex-Plus technology, which is for processing of the feed with high benzene content (from 7 up to 30 % vol. in the case of light straight-run gasoline fraction and light reformate blend), includes feed treatment section which is hydrogenation of benzene.

Performances of the process and isomerizate quality of UOP, Axens, S&D Chemie and JSC “NPP Neftehim” isomerization technologies on the different catalysts are represented in the table 1 [5-11, 14-20].

Performances of UOP, Axens, S&bd Chemie and JSC “NPP Neftehim” isomerization technologies (RON of the feed = 70-73)

Parameter	Pt/zeolite				Pt/chlorinated Al ₂ O ₃		Pt/ZrO ₂ -SO ₄	
	UOP Zeolitic Process	Axens	CKS Süd Chemie CKS ISOM	JSC “NPP Neftehim” Izomalk-1	UOP Penex	Axens	UOP Par-Isom	JSC “NPP Neftehim” Izomalk-2
	HS-10	IP-632	Hysopar	СИ-1	I-8 Plus, I-82, I-84	IS 614 A (ATIS-2L) ²	PI-242	СИ-2
Temperature, °C	260-280	250-270	240-280	250-270	120-180	120-180 (110-170)	140-190	120-160
Pressure, MPa	1,5-3,0	1,5-3,0	3-3,2	2,5	3,0 - 4,0	2	3,2	2,5 -2,8
LHSV, h ⁻¹	2	1-2	2	2	1,5	2	2,5	2,5- 3,5
Mole ratio H ₂ :CH	4:1	(3-4):1	1,6:1 ³	-	(0,3-0,5):1	< 1	2:1	(1,5-2,5):1
Compressor	Is necessary				Absent		Is necessary	
Chlorine compound injection and caustic soda washing	Absent				Is necessary		Absent	
Fire-heater	Is necessary				Absent		Absent	
Feed drying	Absent				Is necessary		Absent	
Impurities in the feed:								
- H ₂ O, ppm	50 (200) ¹	50 (200) ¹	≤ 200	10-20 мг/м3	0,1	0,1	≤ 20	≤ 20
- nitrogen, ppm	1	1	-	-	0,1	0,1	1	1-2
- sulfur, ppm	50 (100) ¹	50 (100) ¹	100 (200) ¹	≤ 1	0,1-0,5	0,1-0,5	1-5	2-5 (50) ¹
- benzene, % wt.	5 (15) ¹	5 (15) ¹	-	-	≤ 1	≤ 1	≤ 10	≤ 10
- C ₇₊ , % wt.	2-3	2-3	-	-	< 1	< 1	≤ 5	≤ 5
Service cycle (lifetime)	2-3 years (10 years)				-	IS 614 A is capable of regeneration	2-3 years with pretreatment (8-10 years)	
RON, points								
- «one-through»	78-80	80	78-80	80	83-86	83 (84-85)	81-83	82-84
-with DIP (DIP and DP) ⁴	-	82	80-83	-	-	84 (85-86)	-	85-86 ⁴
- with DIH	-	86	-	82-85	87-90 (Penex /DIH)	88 (89-90)	86-87 (Par-Isom /DIH)	87-89
-with DIP and DIH	-	-	-	-	90-93 (DIP-Penex /DIH)	-	-	89-90
-with DIP, DIH and DP	-	-	-	-	-	-	-	91-92
- with n-C ₅ , n-C ₆ recycle on the molecular sieves	87-90 (TIP)	88 Ipsorb 90 Hexorb ⁵	-	-	88-91 (Penex /Molex)	90 (90-91) Ipsorb 92 (92-93) Hexorb ⁵	-	91-92
Yield of isomerizate, % vol.	97-98	-	98,1	-	≥ 99	-	≥ 97	97-98
i-C ₅ /∑C ₅ , % wt	53-62				70-78		68-72	70-75
2,2-DMB/∑C ₆ , % wt	10-16				30-36		20-27	28-34

¹ - during short time;² - data for ATIS-2L catalyst are in brackets;³ - according to data of Angarsky Refinery;⁴ - data for scheme with C₅ recycle (DIP и DP);⁵ - process with C₅, C₆ and methylpentanes recycle.

6. THE DEVELOPMENT OF ISOMERIZATION PROCESS IN RUSSIA AND IN THE WORLD

UOP is the leader in licensing of isomerization technology; more than 220 units in the world are operating by its technology currently. More than 120 units of them are working by Penex process; more than 60 units are working on zeolite catalysts (TIP process is also referred to them) and more than 10 units are operating by Par-Isom technology. More than 30 units in the world are operating by Axens license, and more than 20 units are working on the base of CKS ISOM process of S&D-Chemie company. Izomalk-2 processes of JSC “NPP Neftehim” are operating not only in Russia; there is one unit in Ukraine and one unit in Rumania [6].

Let's refer to gasoline pool composition and to isomerizate contribution in it in Russia, Europe and USA, in order to understand the tendency of development of isomerization process in our country (Figure 13) [7,21].

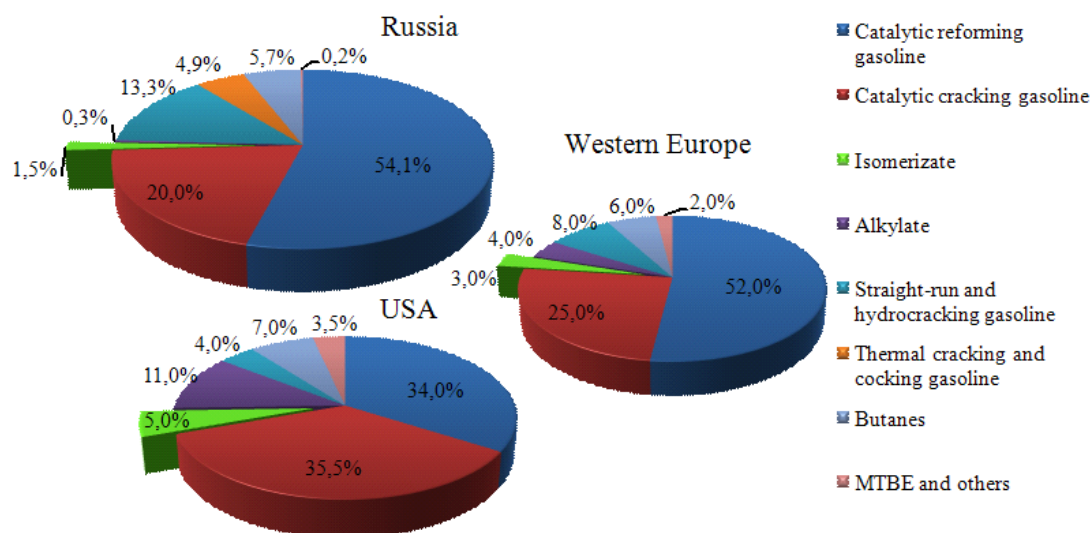


Figure 13. Structure of gasoline pool in Russia, Europe and USA

Considerable lagging from leading foreign countries, regarding the isomerizate contribution in gasoline pool (1,5 % against 5 % in USA and 3 % in Europe), is noted in Russia, where the base process for production of high-octane gasoline is catalytic reforming. Since 2002 the period of active starting-up of isomerization units is observed at Russian refineries because of approving of new technical regulation (Figure 14).

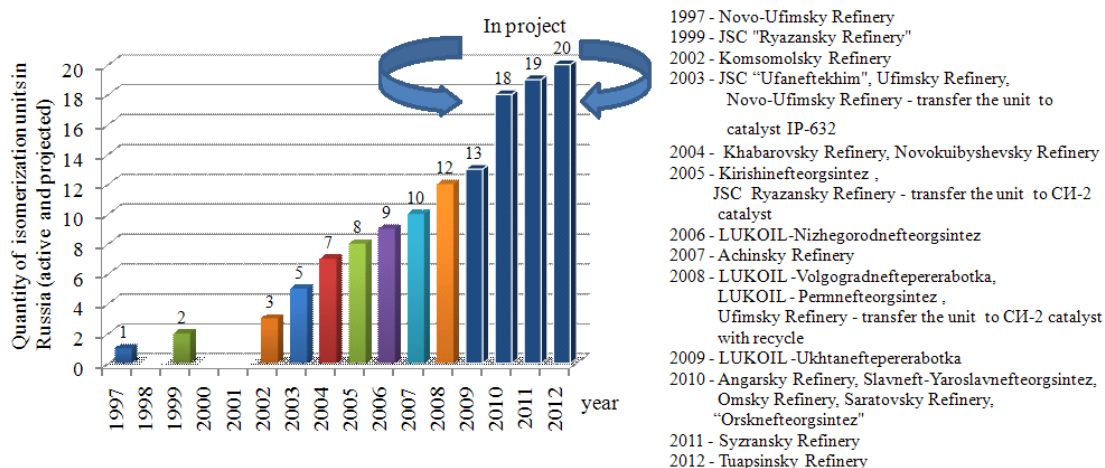


Figure 14. The development of isomerization process in Russia

According to data [5, 22] of 2008 year 12 Refineries in Russia are provided with isomerization process of light naphtha; 5 of them work on sulfated-zirconia catalysts (4 units work by Izomalk-2 process and 1 works by Par-Isom process), 4 units are operated on chlorinated-alumina catalysts and 3 units work on zeolite catalysts. Three units have been reconstructed and transferred to more effective catalysts (Table 2).

Realization of isomerization units construction projects are planned at 8 Russian Refineries more, up to 2012 year; 6 of them will work on sulfated-zirconia catalysts (4 units will work by Izomalk-2 process and 2 will work by Par-Isom process). Schemes of all project units include recycle of none converted low-octane components (Table 3).

Operating isomerization units at Russian Refineries [5-6, 8, 20, 22-25]

Refinery	Start-up (reconstruction) year	Capacity, kton/year	Process	Catalyst	Process parameters	RON of isomerizate	Isomerizate yield χ , IPI ¹ , IHI ² , % wt.	Remarks
Novo-Ufimsky Refinery	1997 (2003)	500	Axens	IP-632 Pt/zeolite	-	-	-	«One-through» scheme, providing with DIH section is planned, wide gasoline pretreatment section is available. Feed – straight-run and reformulated i.b.- 85 °C fraction.
JSC Ryazansky Refinery	1999 (2005)	450	Izomalk-2	СИ-2 Pt/ZrO ₂ -SO ₄	T = 130 °C P = 2,8-2,9 MPa H ₂ circ. ratio=560 nm ³ /m ³	83-84	χ = 98 IPI = 72-74 IHI = 30-32	«One-through» scheme. Unit worked with capacity 300 kton/year on СИ-1 catalyst before reconstruction.
Komsomolsky Refinery	2002	100	Axens	IS 614 A Pt/Cl Al ₂ O ₃	T = 130-140 °C P = 3-3,5 MPa	86-88	χ = 97,2 IPI = 69 IHI = 29	Scheme with DIP and DIH. Feed is i.b.- 85 °C fraction with moisture content < 1ppm, sulfur content < 0,5 ppm.
JSC “Ufaneftekhim”	2003	400	Izomalk-2	СИ-2 Pt/ZrO ₂ -SO ₄	T = 170-180 °C P = 3 MPa H ₂ circ. ratio=700-800 nm ³ /m ³	81-82	χ = 98 IPI = 69-70 IHI = 18-22	«One-through» scheme. Feed is i.b.- 70 °C fraction.
Ufimsky Refinery	2003 (2008)	380	Izomalk-2	СИ-2 Pt/ZrO ₂ -SO ₄	-	-	-	Scheme with DIH. Reconstruction consisted in changing medium-temperature catalyst ИИМ-02 to СИ-2 catalyst.
Khabarovsk Refinery	2004	108	CKS ISOM	Hysopar Pt/zeolite	-	-	-	-
Novokuibyshevsky Refinery	2004	200	CKS ISOM	Hysopar Pt/zeolite	-	-	-	-
Kirishinefteorgsintez	2005	450	Izomalk-2	СИ-2 Pt/ZrO ₂ -SO ₄	T = 127-130 °C P = 2,8-3,2 MPa H ₂ circ. ratio= 600-700 nm ³ /m ³	85	χ = 98 IPI = 72-75 IHI = 30-31	«One-through» scheme, catalyst is loaded into 3 reactors.
LUKOIL-Nizhegorodnefteorgsintez	2006	440	Par-Isom	LPI-100 Pt/ZrO ₂ -SO ₄	T = 165-175 °C H ₂ circ. ratio=1100-1200 nm ³ /m ³	80-82	-	«One-through» scheme. Feed is i.b.- 85 °C fraction.
LUKOIL - Permnefteorgsintez	2007	470	Penex-DIH	I-82 Pt/Cl Al ₂ O ₃	-	-	-	-
Achinsky Refinery	2007	300	Penex	I-82 Pt/Cl Al ₂ O ₃	T = 132-179 °C P = 2,9-3,2 MPa H ₂ circ. ratio = 300 nm ³ /m ³	86-87	χ = 99 IPI = 61-63 IHI = 36	The feed passes through hydrotreatment section, is not subjected to hydrogenation. RON of the feed = 70.
LUKOIL-Volgogradneftepererabotka	2008	385	Penex-DIH	I-82 Pt/Cl Al ₂ O ₃	-	-	χ = 92	Feed is light reformat fraction with RON = 78,9; benzene content in the feed is 16,3 %. The feed is subjected to benzene hydrogenation.

¹ IPI – intensity of pentanes isomerization, i-C₅/ΣC₅;² IHI – intensity of hexanes isomerization, 2,2-DMB/ΣC₆.

Table3

Isomerization unit's construction projects,
which are planned at Refineries of Russia [6, 20, 26]

Refinery	Start-up year	Capacity, kton/year	Process	Catalyst	RON of isomerizate	Scheme modification
LUKOIL-Ukhtaneftepererabotka	2009	120	Par-Isom	PI-242	86-87	with DIP
Angarsky Refinery	2010	280	CKS ISOM	Hysopar Pt/zeolite	86	with DIP
Slavneft-Yaroslavnefteorgsintez	2010	680	Izomalk-2	CH-2	90	with DIP and DIH
Omsky Refinery	2010	800	Izomalk-2	CH-2 Pt/ZrO ₂ -SO ₄	91-92	with DIP, DIH and DP
Saratovsky Refinery	2010	300	Izomalk-2	CH-2	91-92	with DIP, DIH and DP
"Orsknefteorgsintez"	2010	300	Izomalk-2	CH-2	80-82	«one-through»
Syzransky Refinery	2011	300	Axens	ATIS-2L	89-90	with DIP and DIH
Tuapsinsky Refinery	2012	800	Par-Isom	PI-242	-	-

CONCLUSIONS

Analysis of isomerization process development has shown its swiftly increasing of competitive ability compared with other processes, which are directed to gasoline components production. At that, the schemes of projected and reconstructed processes are provided predominately with recycle of low-octane pentanes and hexanes. It is connected with necessity of production of automotive gasoline, which corresponds to tougher standards.

It should be noted, that preference is given to the processes on sulfated zirconium oxides. In Russia the preference is essentially given to the process on CH-2 catalyst of domestic manufacturer. It is explained by operational characteristics of this type of catalyst, at which it isn't inferior to the foreign analogs.

REFERENCES

1. Специальный технический регламент «О требованиях к бензинам, дизельному топливу и отдельным горюче-смазочным материалам», федеральный закон, 2008.
2. Введение бензина Евро-3 в России отложено до 2011 г. // Информационное агентство Au92. URL: http://www.au92.ru/msg/20090113_9011311.html (review date 19.10.2009).
3. Palmer E.R., Kao, S.H., Tung C, Shipman D.R. Consider options to lower benzene levels in gasoline. New regulations further limit this aromatic from the refinery blending pool // Hydrocarbon Processing, June 2008. – pp. 55-66.
4. Танатаров М.А., Ахметов А.Ф., Шипикин В.В, Георгиевский В.Ю. Производство неэтилированных бензинов // Тематический обзор – М.: ЦНИИТЭнефтехим, 1981. – 76 с.
5. Хаимова Т.Г., Мхитарова Д.А. Изомеризация как эффективный путь производства высокооктановых компонентов бензина // Информационно-аналитический обзор. М.: ЦНИИТЭнефтехим, 2005. – 80 с.
6. Турукалов М. Полная изомеризация // Нефтегазовая вертикаль. – 2008. – № 16. – с. 22-28.
7. IFP Training. Isomerization of Light Gasoline // ENSPM Formation Industry, 2008.
8. ОАО "НПП Нефтехим". <http://www.nefthim.ru> .
9. Бруно Домерг, Лоран Ватрипон. Дальнейшее развитие технологии изомеризации парафинов // Нефтепереработка и нефтехимия – 2001.–№4.–с. 15-27.
10. Покровский С. Новые зарубежные технологии нефтепереработки // Нефтегазовая вертикаль. – 2002. – № 7. – с. 68-71.
11. Мартин Хантер ЮОП Лимитед. Процесс изомеризации и катализаторы – ключевое решение для удовлетворения спроса на бензин // 7-я Конференция и выставка по технологиям нефтепереработки России и стран СНГ.
12. UOP LLC, <http://www.uop.com> .
13. Бруно Домерг, Лоран Ватрипон. Передовые решения для процессов изомеризации парафинов // Нефтепереработка и нефтехимия – 2003.–№7.–с. 3-9.

14. Агабеков В.Е., Сеньков Г.М. Каталитическая изомеризация легких парафиновых углеводородов // Катализ в химической и нефтехимической промышленности – 2006. – № 5. – с. 31-41.
15. Буй Чонг Хан, Нгуен Ван Ты, Ахметов А.Ф. Сравнительный анализ различных схем изомеризации пентан-гексановой фракции // Нефтепереработка и нефтехимия – 2008. – № 2 – С. 22-25.
16. Воевода Н.В. Повышение октановых чисел бензинов // Информационно-аналитический обзор. М.: ЦНИИТЭнефтехим, 2001. – 114 с.
17. OGJ International refining-catalyst compilation – 1999 // Oil & Gas – 1999. – № 39 – р. 47-48.
18. Кузнецов П.Н., Кузнецова Л. И., Твердохлебов В.П., Санников А.Л. Сравнительный анализ эффективности катализаторов изомеризации n-алканов C₄-C₆ // Химическая технология. – 2005. – № 2. – с. 7-14.
19. Нгуен Ван Ты, Буй Чонг Хан, Ахметов А.Ф. Перспективные технологии производства моторных топлив с улучшенными экологическими свойствами в условиях Вьетнама // Нефтепереработка и нефтехимия – 2007. – № 5 – С. 31-34.
20. Шакун А.Н. Производство экологически чистых автобензинов. Новейшие сведения по проектированию и строительству установок изомеризации Анализ технологических схем // 8-я Конференция и выставка по технологиям нефтепереработки России и стран СНГ.
21. Ахметов С.А. Экологическая химмотология топлив и масел. – Уфа: УГНТУ, 2008.– 150 с.
22. Плюс изомеризация всей нефти // Нефть и капитал – 2008. – № 4 – с. 49-52.
23. Гаврилов Н.В., Дуров О.В., Сорокин Ю.Б., Сыркин А.М. Оптимизация температурного режима процесса изомеризации установки Л 35/5 ОАО «Лукойл-Нижегороднефтеоргсинтез» // Башкирский химический журнал – 2008. – Том 15 № 2. – с. 140-144.
24. Полункин Я.М., Анিকেев М.Н., Ромашкин В. А., Макеев С.А., Шакун А.Н. и др. Опыт эксплуатации новых катализаторов в производстве современных бензинов в Рязанской Нефтеперерабатывающей компании // Катализ в нефтеперерабатывающей промышленности – 2007. – № 5. – с. 19-22.

25. Ежов В.В., Мелехин В.В., Камалов К.Г., Боруцкий П.Н. и др. Интенсификация работы установки низкотемпературной изомеризации легкой бензиновой фракции ООО «РН-Комсомольский НПЗ» // Нефтепереработка – 2006. –№ 9. – с. 76-79.

26. Башинский А.И., Вихман А.Г., Мириманян А.А., Савватеев М.А., Киевский В.Я., Ямпольская М.Х., Карапетян И.Н., Енукова И.Ю., Данилян М.Ю., Елшин А.И., Кращук С.Г. Проектные решения по разработке комбинированной установки изомеризации с блоками подготовки сырья на НПЗ ОАО «Ангарская НХК» // Нефтепереработка и нефтехимия. -№9. -2006.

URL: <http://www.ect-service.ru/public/public3.php> (review date 16.10.2009).