

ISSN 2518-1491 (Online),  
ISSN 2224-5286 (Print)

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ  
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫНЫҢ

Д.В. Сокольский атындағы «Жанармай,  
катализ және электрохимия институты» АҚ

# Х А Б А Р Л А Р Ы

## ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК  
РЕСПУБЛИКИ КАЗАХСТАН  
АО «Институт топлива, катализа и  
электрохимии им. Д.В. Сокольского»

## NEWS

OF THE ACADEMY OF SCIENCES  
OF THE REPUBLIC OF KAZAKHSTAN  
JSC «D.V. Sokolsky institute of fuel, catalysis  
and electrochemistry»

**SERIES**  
**CHEMISTRY AND TECHNOLOGY**

**3 (441)**

**MAY – JUNE 2020**

PUBLISHED SINCE JANUARY 1947

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

---

*NAS RK is pleased to announce that News of NAS RK. Series of chemistry and technologies scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of chemistry and technologies in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of chemical sciences to our community.*

*Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Химия және технология сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Web of Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Химия және технология сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді химиялық ғылымдар бойынша контентке адалдығымызды білдіреді.*

*НАН РК сообщает, что научный журнал «Известия НАН РК. Серия химии и технологий» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по химическим наукам для нашего сообщества.*

Б а с р е д а к т о р ы  
х.ғ.д., проф., ҚР ҰҒА академигі  
**М.Ж. Жұрынов**

Р е д а к ц и я а л қ а с ы:

**Ағабеков В.Е.** проф., академик (Белорус)  
**Волков С.В.** проф., академик (Украина)  
**Воротынцев М.А.** проф., академик (Ресей)  
**Газалиев А.М.** проф., академик (Қазақстан)  
**Ергожин Е.Е.** проф., академик (Қазақстан)  
**Жармағамбетова А.К.** проф. (Қазақстан), бас ред. орынбасары  
**Жоробекова Ш.Ж.** проф., академик (Қырғыстан)  
**Иткулова Ш.С.** проф. (Қазақстан)  
**Манташян А.А.** проф., академик (Армения)  
**Пралиев К.Д.** проф., академик (Қазақстан)  
**Баешов А.Б.** проф., академик (Қазақстан)  
**Бүркітбаев М.М.** проф., академик (Қазақстан)  
**Джусипбеков У.Ж.** проф., корр.-мүшесі (Қазақстан)  
**Молдахметов М.З.** проф., академик (Қазақстан)  
**Мансуров З.А.** проф. (Қазақстан)  
**Наурызбаев М.К.** проф. (Қазақстан)  
**Рудик В.** проф., академик (Молдова)  
**Рахимов К.Д.** проф., академик (Қазақстан)  
**Стрельцов Е.** проф. (Белорус)  
**Тәшімов Л.Т.** проф., академик (Қазақстан)  
**Тодераш И.** проф., академик (Молдова)  
**Халиков Д.Х.** проф., академик (Тәжікстан)  
**Фарзалиев В.** проф., академик (Әзірбайжан)

«ҚР ҰҒА Хабарлары. Химия және технология сериясы».

ISSN 2518-1491 (Online),

ISSN 2224-5286 (Print)

Меншіктенуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» Республикалық қоғамдық бірлестігі (Алматы қ.).

Қазақстан республикасының Мәдениет пен ақпарат министрлігінің Ақпарат және мұрағат комитетінде 30.04.2010 ж. берілген №1089-Ж мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Мерзімділігі: жылына 6 рет.

Тиражы: 300 дана.

Редакцияның мекенжайы: 050010, Алматы қ., Шевченко көш., 28; 219, 220 бөл.; тел.: 272-13-19; 272-13-18,  
<http://chemistry-technology.kz/index.php/en/arhiv>

© Қазақстан Республикасының Ұлттық ғылым академиясы, 2020

Редакцияның мекенжайы: 050100, Алматы қ., Қонаев к-сі, 142, «Д. В. Сокольский атындағы отын, катализ және электрохимия институты» АҚ, каб. 310, тел. 291-62-80, факс 291-57-22, e-mail:orgcat@nursat.kz

Типографияның мекенжайы: «NurNaz GRACE», Алматы қ., Рысқұлов көш., 103.

Главный редактор  
д.х.н., проф., академик НАН РК  
**М.Ж. Журинов**

Редакционная коллегия:

**Агабеков В.Е.** проф., академик (Беларусь)  
**Волков С.В.** проф., академик (Украина)  
**Воротынцев М.А.** проф., академик (Россия)  
**Газалиев А.М.** проф., академик (Казахстан)  
**Ергожин Е.Е.** проф., академик (Казахстан)  
**Жармагамбетова А.К.** проф. (Казахстан), зам. гл. ред.  
**Жоробекова Ш.Ж.** проф., академик (Кыргызстан)  
**Иткулова Ш.С.** проф. (Казахстан)  
**Манташян А.А.** проф., академик (Армения)  
**Пралиев К.Д.** проф., академик (Казахстан)  
**Баешов А.Б.** проф., академик (Казахстан)  
**Буркитбаев М.М.** проф., академик (Казахстан)  
**Джусипбеков У.Ж.** проф., чл.-корр. (Казахстан)  
**Мулдахметов М.З.** проф., академик (Казахстан)  
**Мансуров З.А.** проф. (Казахстан)  
**Наурызбаев М.К.** проф. (Казахстан)  
**Рудик В.** проф., академик (Молдова)  
**Рахимов К.Д.** проф., академик (Казахстан)  
**Стрельцов Е.** проф. (Беларусь)  
**Ташимов Л.Т.** проф., академик (Казахстан)  
**Тодераш И.** проф., академик (Молдова)  
**Халиков Д.Х.** проф., академик (Таджикистан)  
**Фарзалиев В.** проф., академик (Азербайджан)

«Известия НАН РК. Серия химии и технологии».

ISSN 2518-1491 (Online),

ISSN 2224-5286 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации и архивов Министерства культуры и информации Республики Казахстан №10893-Ж, выданное 30.04.2010 г.

Периодичность: 6 раз в год.

Тираж: 300 экземпляров.

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28; ком. 219, 220; тел. 272-13-19; 272-13-18,

<http://chemistry-technology.kz/index.php/en/arhiv>

© Национальная академия наук Республики Казахстан, 2020

---

Адрес редакции: 050100, г. Алматы, ул. Кунаева, 142, АО «Институт топлива, катализа и электрохимии им. Д.В. Сокольского», каб. 310, тел. 291-62-80, факс 291-57-22, e-mail: orgcat@nursat.kz

Адрес типографии: «NurNaz GRACE», г. Алматы, ул. Рыскулова, 103.

Editor in chief

doctor of chemistry, professor, academician of NAS RK

**M.Zh. Zhurinov**

Editorial board:

**Agabekov V.Ye.** prof., academician (Belarus)  
**Volkov S.V.** prof., academician (Ukraine)  
**Vorotyntsev M.A.** prof., academician (Russia)  
**Gazaliyev A.M.** prof., academician (Kazakhstan)  
**Yergozhin Ye.Ye.** prof., academician (Kazakhstan)  
**Zharmagambetova A.K.** prof. (Kazakhstan), deputy editor in chief  
**Zhorobekova Sh.Zh.** prof., academician (Kyrgyzstan)  
**Itkulova Sh.S.** prof. (Kazakhstan)  
**Mantashyan A.A.** prof., academician (Armenia)  
**Praliyev K.D.** prof., academician (Kazakhstan)  
**Bayeshov A.B.** prof., academician (Kazakhstan)  
**Burkitbayev M.M.** prof., academician (Kazakhstan)  
**Dzhusipbekov U.Zh.** prof., corr. member (Kazakhstan)  
**Muldakhmetov M.Z.** prof., academician (Kazakhstan)  
**Mansurov Z.A.** prof. (Kazakhstan)  
**Nauryzbayev M.K.** prof. (Kazakhstan)  
**Rudik V.** prof., academician (Moldova)  
**Rakhimov K.D.** prof., academician (Kazakhstan)  
**Streltsov Ye.** prof. (Belarus)  
**Tashimov L.T.** prof., academician (Kazakhstan)  
**Toderash I.** prof., academician (Moldova)  
**Khalikov D.Kh.** prof., academician (Tadjikistan)  
**Farzaliyev V.** prof., academician (Azerbaijan)

**News of the National Academy of Sciences of the Republic of Kazakhstan. Series of chemistry and technology.**

ISSN 2518-1491 (Online),

ISSN 2224-5286 (Print)

Owner: RPA "National Academy of Sciences of the Republic of Kazakhstan" (Almaty).

The certificate of registration of a periodic printed publication in the Committee of Information and Archives of the Ministry of Culture and Information of the Republic of Kazakhstan N 10893-Ж, issued 30.04.2010.

Periodicity: 6 times a year.

Circulation: 300 copies.

Editorial address: 28, Shevchenko str., of. 219, 220, Almaty, 050010, tel. 272-13-19; 272-13-18,

<http://chemistry-technology.kz/index.php/en/arhiv>

© National Academy of Sciences of the Republic of Kazakhstan, 2020

---

Editorial address: JSC «D.V. Sokolsky institute of fuel, catalysis and electrochemistry», 142, Kunayev str., of. 310, Almaty, 050100, tel. 291-62-80, fax 291-57-22, e-mail: [orgcat@nursat.kz](mailto:orgcat@nursat.kz)

Address of printing house: «NurNaz GRACE», 103, Ryskulov str, Almaty.

**NEWS**

OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN

**SERIES CHEMISTRY AND TECHNOLOGY**

ISSN 2224-5286

<https://doi.org/10.32014/2020.2518-1491.55>

Volume 3, Number 441 (2020), 142 – 150

UDK 546.74:542.973.7; 66.074.3

**Z.T. Zheksenbaeva<sup>1,2</sup>, R.O. Sarsenova<sup>1,3</sup>, S.A. Tungatarova<sup>1,2</sup>,  
T.S. Baizhumanova<sup>1,2</sup>, S.I. Zhevnikitskiy<sup>4</sup>, S.V. Romanenko<sup>5</sup>**

<sup>1</sup>D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry, Almaty, Kazakhstan;

<sup>2</sup>Al-Farabi Kazakh National University, Almaty, Kazakhstan;

<sup>3</sup>Abai Kazakh National Pedagogical University, Almaty, Kazakhstan;

<sup>4</sup>M.Kh. Dulaty Taraz State University, Taraz, Kazakhstan;

<sup>5</sup>Tomsk Polytechnic University, Tomsk, Russia.

E-mail: [tungatarova58@mail.ru](mailto:tungatarova58@mail.ru)

## **INVESTIGATION OF Ni-CONTAINING CATALYSTS FOR THE PURIFICATION OF EXHAUST GASES**

**Abstract.** Results of the development of multicomponent oxide catalysts for the purification of exhaust gases based on Ni, Cu, and Cr supported on 2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> by varying the concentration of the active phase of catalyst are presented in paper. It was found that the highest degree of toluene conversion (up to 98.8 %) is observed on the three-component Ni-Cu-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> catalyst with optimal metal ratio Ni : Cu : Cr = 1.0 : 3.0 : 0.1 at GHSV = 5410<sup>3</sup> h<sup>-1</sup> and a temperature of 723 - 773 K. The presence of CeO<sub>2</sub> crystals, X-ray amorphous clusters (d = 20 – 100 E) of variable valence metal oxides NiO and CuO as well as solid metal solutions CuO (NiO) and aluminates was detected on the surface of optimum catalyst calcined at 873 K using XRD and transition electron microscopy methods. Preparation of polyoxide supported catalysts as well as study the influence of catalyst composition and modified additives on deep oxidation of toluene - a major component of toxic organic gaseous industry emissions, is the goal of research.

**Key words:** catalytic oxidation, toluene, purification, nickel, copper.

**Introduction.** The problem of chemical safety and sanitary air protection is particularly relevant due to the increase of harmful emissions of industrial enterprises, which have a strong toxic effect. Many chemical compounds (toluene, xylene, styrene, phenol, tricresol, mineral spirits, CO, etc.), which negatively affect the living organisms and flora are harmful toxic emissions from industrial plants. Under the Paris agreement, adopted on December 12, 2015 and signed on April 22, 2016, in addition to the United Nations Framework Convention on Climate Change (UNFCCC), developed countries and countries with economies in transition have to reduce or stabilize greenhouse gas emissions [1]. The content of harmful emissions above the MPC in industrial workshops and atmospheric air in the cities cause a negative impact on living organisms and lead to various diseases thereby creates a threat to the safety of the environment [2]. Toluene, xylene and ethyl-benzene are major part of the solvents used in various industries, which are present in gaseous emissions [3]. Toxic and adverse effect of harmful emissions on a living organism can be traced on the example of toluene - a major component of toxic organic gaseous emissions that are present in the emissions of furniture, paint, cable, printing and other industries. For example, the inhalation of toluene with a concentration of 250 mg m<sup>-3</sup> for 2 h leads to a decrease in heart rate, disturbance of speech, movement coordination [4]. Prolonged inhalation of toluene, which is present in the composition of glue, varnishes, paints, etc., causes neurotoxic deviations that lead to clinical consequences - hallucinations, somnolence, suicide attempts, visual disturbances and seizures.

From the literature data [5] on the methods and apparatuses for neutralization of toxic emissions follows that deep catalytic oxidation is the most economical way for cleaning of gases from the emissions of complex composition [6]. Typically, the catalysts based on noble metals (Pt, Pd) [7], which have high

activity (95-100 %) in complete oxidation of organic substances [8], are used mainly for cleaning of waste gas of industrial enterprises [9]. Catalysts based on Pt group metals have high activity at low temperatures, durability, heat resistance and ability to operate stably at high space velocities. Conditions of deficit and high cost of platinum group metals lead to the need to develop new approaches to the creation of highly effective polyoxide catalysts that do not contain noble metals capable exhibit a high thermal stability and poison-resistance and sustainable in the long term operation [10-15]. Creation of catalysts for gas purification, which do not contain noble metals or contain them in small amounts [16], is an important goal. In this context, the development of high-performance polyoxide catalysts, which do not contain precious metals, and technology for deep oxidation of toxic organic gaseous emissions from industry are relevant.

**Experimental.** Purification of exhaust gases from harmful organic impurities, in particular from toluene, was carried out on a flow installation, the implementation conditions of which are close to real conditions.

The granulated  $\theta$ - $\text{Al}_2\text{O}_3$  ( $S = 100 \text{ m}^2 \text{ g}^{-1}$ , particle size between 40 and 50  $\mu\text{m}$ ) modified by Ce, which forms resistant surface  $\text{CeAlO}_3$  perovskite up to 1,373 K was used as a carrier. Polyoxide catalysts were prepared by capillary impregnation of alumina modified with cerium by mixed aqueous solution of Ni, Cu and Cr nitrates by incipient wetness, followed by drying at 453 - 473 K (4 - 5 h) and calcination at 873 K (1 - 1.5 h) in air. The prepared oxide catalysts have been promoted with Pt and Pd (0.05%) to improve the activity and thermal stability.

Deep oxidation of toluene was carried out on the flow type PKU-2VD catalytic installation intended for testing of catalysts at pressures from atmospheric pressure up to 3.4 MPa in tubular reactor with fixed catalyst bed. Catalytic activity of catalysts was determined in flow installation at deep oxidation of toluene in air at various temperatures (523 – 773 K), space velocities ( $5 - 15410^3 \text{ h}^{-1}$ ) and toluene concentration ( $320 \text{ mg m}^{-3}$ ) in the initial mixture.

Analysis of the initial mixture and reaction products were carried out using CHROMOS GC-1000 chromatograph. The rate of carrier gas (Ar) -  $10 \text{ ml min}^{-1}$ .

The phase composition of catalysts was determined by X-ray diffractometer DRON-4.7, Co – anode, 25 kV, 25 mA,  $2\theta - 5 - 80^\circ$  (XRD). The morphology, particle size and chemical composition of the Ni-Cu-Cr catalysts were investigated using transmission electron microscope EM-125K at 80,000 times magnification by the replica method with extraction using microdiffraction (TEM). The surface of catalysts was determined by the BET method on the low temperature  $\text{N}_2$  adsorption using the Accusorb apparatus (Micromeritics, USA).

Determination of the amount of adsorbed oxygen by catalysts, its characteristics, as well as the ability to interact with a reducing agent ( $\text{H}_2$ ) were carried out by methods of temperature-programmed desorption of oxygen (TPD) and temperature-programmed reduction (TPR). Temperature-programmed reduction of catalysts after the formation in air at 873 K were carried out by passing a mixture of  $\text{H}_2$  (10%) and He (90%) at  $20 \text{ ml min}^{-1}$  and the temperature rises at speeds of  $8 \text{ K min}^{-1}$  from 293 to 1,173 K (at 1,173 K temperature was stabilized).

**Results and discussion.** Investigation of the activity of polyoxide catalysts in the reaction of deep oxidation of toluene at 723 K and space velocity  $5410^3 \text{ h}^{-1}$  is presented. The conversion of toluene increased with the complexity of the composition of catalysts. The lowest 57.0 % degree of toluene oxidation was observed on the 5% Ni/2% Ce/ $\theta$ - $\text{Al}_2\text{O}_3$  catalyst, and the greatest 98.5% degree was observed on the three-component 9% Ni-Cu-Cr/2% Ce/ $\theta$ - $\text{Al}_2\text{O}_3$  catalyst. The following series by activity in the reaction of deep oxidation of toluene was determined: Ni-Cu-Cr/2% Ce/ $\theta$ - $\text{Al}_2\text{O}_3$  (98.5%) > Ni-Cu-Cr/ $\theta$ - $\text{Al}_2\text{O}_3$  (92.0%) > Ni-Cu/2% Ce/ $\theta$ - $\text{Al}_2\text{O}_3$  (84.0%) > Ni-Cr/2% Ce/ $\theta$ - $\text{Al}_2\text{O}_3$  (75.0%) > Ni/2% Ce/ $\theta$ - $\text{Al}_2\text{O}_3$  (57.0%). The largest conversion of toluene is observed on three-component Ni-Cu-Cr/2% Ce/ $\theta$ - $\text{Al}_2\text{O}_3$  catalyst with an optimal ratio of metals Ni: Cu : Cr = 1.0 : 3.0 : 0.1 at  $T = 723 \text{ K}$ . The degree of toluene oxidation reduces from 98.5 to 89.3% with the increase of space velocity from  $5410^3$  to  $15410^3 \text{ h}^{-1}$ , respectively.

Increasing the concentration of toluene from 100 to  $320 \text{ mg m}^{-3}$  in the initial mixture with air leads to a slight decrease in the degree of conversion of toluene on the two component Ni-Cu/2% Ce/ $\theta$ - $\text{Al}_2\text{O}_3$  and Cu-Cr/2% Ce/ $\theta$ - $\text{Al}_2\text{O}_3$  catalysts. A noticeable decrease in activity between two component oxide catalysts was found on the Ni-Cr-containing catalyst from 76.6 to 73.0%. Ni-Cu-Cr/2% Cr/ $\theta$ - $\text{Al}_2\text{O}_3$  catalyst was the most stable.

Thus, the optimal conditions of deep oxidation of toluene on oxide Ni-, Cu- and Cr-containing catalysts over 2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> were determined. Degree of conversion of toluene reaches 98.5 – 98.8% on the Ni-Cu-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> catalyst at temperatures of 723 - 773 K, GHSV - 5410<sup>3</sup> h<sup>-1</sup> and the concentration of toluene in the initial mixture with air – 100 - 320 mg m<sup>-3</sup>.

The intensive reflections from CuO and less intensive from NiO, CeO<sub>2</sub>, and  $\theta$ -Al<sub>2</sub>O<sub>3</sub> are observed in roentgenograms of the Ni-Cu-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> catalyst heated at 873 K. Not only CeO<sub>2</sub> crystallization, but a sharp increase in the content of  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> starting from 1,273 K is a result of heating of the Ni-Cu-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> catalyst. Significant reduction of the total surface area of catalysts is due to heating. CeO<sub>2</sub> crystallization occurs to a lesser extent due to the small (2%) of Ce content (in carrier only). According to XRD the presence of CeO<sub>2</sub> crystals and X-ray amorphous clusters with diameters from 20 to 100 E, metal oxides of variable valence NiO, CuO, and solid solutions of metals CuO (NiO) is fixed on the surface of carrier in the process of catalyst synthesis after heating at 873 K. Phase transformations occur in the Ni-Cu-Cr catalyst upon heating in air above 1,273 K. Metal oxides react with alumina to form the Me-Al<sub>2</sub>O<sub>4</sub> type aluminates with diameter from 200 to 1,000 E and the surface decreases sharply to 2 - 5 m<sup>2</sup>. Reflexes from the  $\theta$ -Al<sub>2</sub>O<sub>3</sub>,  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>, and CeO<sub>2</sub> are presented in the 2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub>, as well as in the carrier (quantification was performed by reflections 2.31 E, 1.74 E, 1.91 E, respectively). The intensity of CeO<sub>2</sub> reflexes increases slightly with increasing the Ce content in catalyst, and especially after the heating consistently at 873, 1,073, 1,273, 1,373 and 1,473 K. This indicates that crystallization of the amorphous cerium oxides happens as a result of heating. The same process is characteristic for supported on the 2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> catalysts, but to different degrees.

Thus, the use of X-ray diffraction analysis to study of polyoxide catalysts supported on 2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> showed that the active components are mainly in amorphous state in the initial catalysts; part of Ni and Cu is represented by Ni and Cu oxides [17].

The morphology and particle size of the developed catalysts were examined by transmission electron microscope on the EM-125K at magnification 80,000 times by the replica method with extraction using electron microdiffraction. It was found that single, double and triple metal oxides, the particle size of which are decreased from 50-80 E (Ce/Al<sub>2</sub>O<sub>3</sub>) to 20-30 E (Ni-Cu-Cr) are formed at complication the composition of three-component catalyst. The nanoparticles of metal oxides or their mixtures are formed after decomposition of nitrates of initial oxide Ni-Cu-Cr catalyst at 873 K according to electron microscopy and microdiffraction. Interaction of elements with  $\theta$ -Al<sub>2</sub>O<sub>3</sub> carrier with formation of larger copper and nickel aluminates of the AB<sub>2</sub>O<sub>4</sub> and ABO<sub>3</sub> type occurs when the temperature rises [18].

Figure 1 shows the spectra of thermal desorption of oxygen from the oxide Ni-Cu-Cr/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> after oxygen adsorption at 873 K. It is seen that the amount of oxygen released upon heating to 1,173 K (stabilizing temperature) increases with the complexity of the composition of mixed catalyst. Desorption curve has bends at 773 K and 923 K as well as maximum at 1,023 K, which is caused by desorption of the adsorbed oxygen (673 – 873 K) and decomposition (873-1,073 K) of copper and nickel oxides (up to Cu<sub>2</sub>O, Ni<sub>2</sub>O) and then mixed oxides (> 1,070 K).

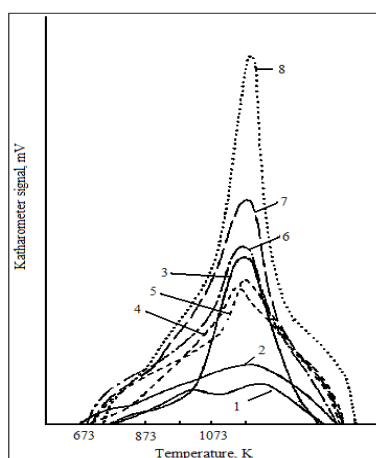


Figure 1 – Thermal desorption of oxygen from the catalysts on Al<sub>2</sub>O<sub>3</sub> after heating in air:  
 1-5% Ni, 2-5% Cu, 3-5% Cr, 4-5% (Ni + Cr), 5-5% (Cu + Cr), 6-8-10% Ni-Cu-Cr at varying the deposition methods of catalysts:  
 6 - NH<sub>4</sub>HCO<sub>3</sub>, 7 - Al(NO<sub>3</sub>)<sub>3</sub>, 8 - NH<sub>4</sub>HCO<sub>3</sub> + Al(NO<sub>3</sub>)<sub>3</sub>, T – 873 K, 1 h



The total amount of released oxygen (9.7 mmol from the 1.0 g of active phase) exceeds the probable sorption at each of oxides. This is obviously connected with the dissolving of oxides of superstoichiometric oxygen in formed solid solutions, which are released at lower temperatures [19]. The total amount of released oxygen (mainly due to weak adsorbed oxygen) from the Ni-Cu-Cr catalyst depends on the conditions of preparation of mixed carbonates and their decomposition. It is increased by 2 times when using  $\text{NH}_4\text{HCO}_3 + \text{Al}(\text{NO}_3)_3$  in the precipitation of mixture.

Calculation of activation energy release of oxygen from the catalyst showed that it is 88 - 89 kJ/mol. Desorption energy from single copper oxides is 128 kJ/mol; from nickel oxides - 120 kJ/mol and from mixed oxides - 140 - 144 kJ/mol.

Heating of Ni-Cu-Cr/2% Ce/ $\theta$ - $\text{Al}_2\text{O}_3$  catalyst at 1,473 K sharply reduces the release of oxygen in the area of decomposition of metal oxides for the initial and promoted contacts (Figure 2). The area of adsorbed oxygen completely disappears in the spectrum of Ni-Cu-Cr and Ni-Cu-Cr + Pt catalysts. The observed phenomenon can be explained by the fact that most of the metal oxides reacts with the carrier to form large (200 – 1,000 Å) Ni(Cu) $\text{Al}_2\text{O}_4$  aluminates (XRD and TEM), because of which the total surface area of contacts is reduced from 60 to 5 m<sup>2</sup> g<sup>-1</sup> [20].

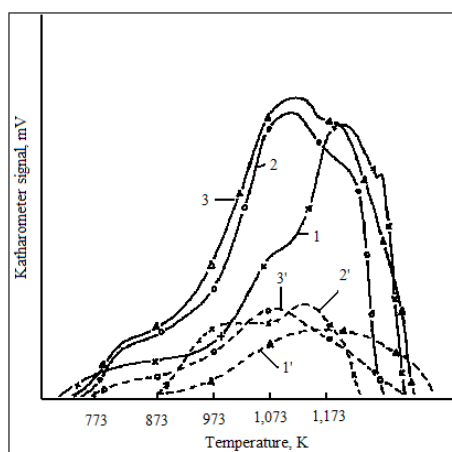


Figure 2 – Thermal desorption of oxygen from the Ni-Cu-Cr/2 % Ce/ $\text{Al}_2\text{O}_3$  catalyst heated in oxygen and promoted with Pd and Pt: 1 - Ni-Cu-Cr/2 % Ce/ $\text{Al}_2\text{O}_3$ , 2 - Ni-Cu-Cr/2 % Ce/ $\text{Al}_2\text{O}_3$  + Pd, 3 - Ni-Cu-Cr/2 % Ce/ $\text{Al}_2\text{O}_3$  + Pt. 1<sup>1</sup>, 2<sup>1</sup>, 3<sup>1</sup> - catalysts after heating at 1,473 K, T – 873 K

The study of temperature-programmed reduction of Ni-Cu-Cr/2% Ce/ $\theta$ - $\text{Al}_2\text{O}_3$  catalysts allowed to make one more step in understanding of reduction mechanism and elimination of oxygen from oxides, and to assess the ability of catalyst to absorb oxygen from gas phase.

Figure 3a shows that the TPR curve has four hydrogen absorption peaks:  $T_1 = 523$  K,  $T_2 = 573$  K,  $T_3 = 673$  K and  $T_4 = 1,073$  K corresponding to reduction of CuO ( $T_1$ ), mixed oxides CuO-NiO ( $T_2$ ), NiO ( $T_3$ ) and formed partially Ni or Cu aluminates.

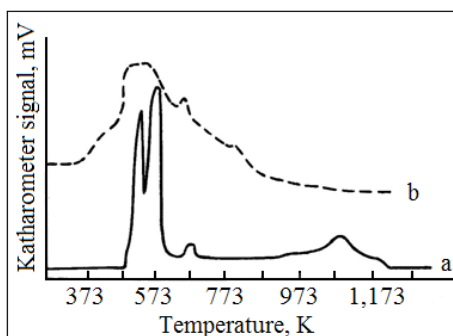


Figure 3 – TPR and TPO spectra of the initial Ni-Cu-Cr/Ce/ $\theta$ - $\text{Al}_2\text{O}_3$  catalyst: a - TPR of the initial catalyst, b - TPO after TPR up to 1,225 K

Temperature-programmed oxidation (TPO) of catalyst after its reduction up to 1,225 K (figure 3b) showed that oxygen is adsorbed easily, starting from 357 – 373 K, as a broad peak with  $T_m^1 = 523$  K,  $T_m^2 = 673$  K and  $T_m^3 = 800 - 810$  K, which corresponds to adsorption of it on surface ( $T_m^1$ ) and formation of Ni and Cu oxides. Ni-Cu-Cr/Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> catalyst has undergone profound changes in the phase composition after heat treatment at 1,473 K 5 h (Figure 4a).

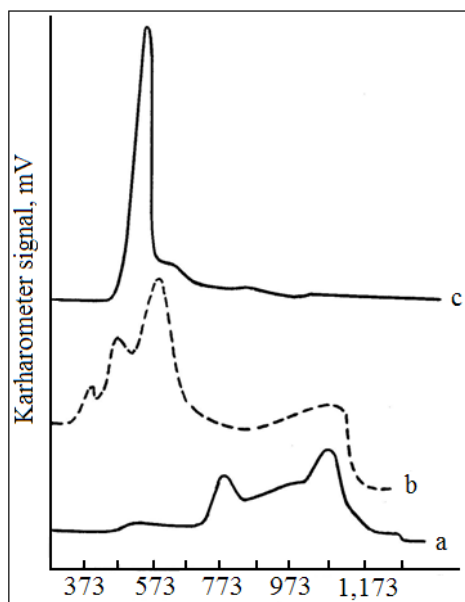


Figure 4 - TPR and TPO spectra of the Ni-Cu-Cr/Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> catalyst:  
 a - TPR of the initial catalyst, b - TPO of catalyst reduced up to 1,223 K,  
 c - TPR of catalyst after treatment in oxygen to 973 K, T - 1,473 K, 5 h

Weak bending of curve at 473 K is available in TPR spectrum. The main absorption of H<sub>2</sub> occurs at  $T_m = 773$  and 1,073 K when Cu (Ni) aluminates are reduced. Cu(Ni)Al<sub>2</sub>O<sub>4</sub> crystals (2,42 reflex) is also fixed according to XRD. If the reduction temperature of catalyst reaches 1,223 K, the adsorption of oxygen in the initial Ni-Cu-Cr catalyst is carried out at a temperature above than 373 K (figure 4b).

Subsequent temperature-programmed reduction of catalyst indicates on absorption of H<sub>2</sub> only as a single peak (Figure 4c). This indicates that a mixture of Ni(Cu) oxides, which are reduced at 523 K, is synthesized from aluminates.

Thus, Ni-Cu-Cr catalyst is a solid solution of copper and nickel oxides with chromium, included in it, according to the TPD and TPR results. Superstoichiometric surface oxygen with  $E_{des} = 88 - 89$  kJ mol<sup>-1</sup>, which reacts easily with reducing agents is adsorbed onto its surface. TPD curves and TPO data indicate on its presence in catalyst. Besides mixed oxides the less active Ni and Co aluminates are formed in the oxidation process at high temperatures in catalyst in an oxidizing atmosphere.

**Conclusion.** As a result of studies, it was found that the highest degree of toluene conversion (to 98.8 %) is observed on three-component Ni-Cu-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> catalyst with optimal ratio Ni : Cu : Cr = 1.0 : 3.0 : 0.1 at space velocity of 5410<sup>3</sup> h<sup>-1</sup> and temperature 723 - 773 K. The binding energy of oxygen with surface and its reactivity on polyoxide catalysts were determined by the TPD, TPO and TPR methods. It was shown that formed Ni and Cu aluminates can be reduced to the initial oxides or their mixtures under the influence of H<sub>2</sub> at 973 - 1,223 K. Again, oxygen adsorption on Ni-Cu-Cr catalysts after decomposition of oxides occurs at low temperature (325 K). This point to high reactivity of adsorbed O<sub>2</sub><sup>-</sup>, O<sup>-</sup>, and lattice oxygen of dispersed oxides, as well as mixtures thereof, and its ability to easy reactivation.

**Acknowledgments.** The work was supported by the Ministry of Education and Science of the Republic of Kazakhstan (AP05132348).

**З.Т. Жексенбаева<sup>1,2</sup>, Р.О. Сарсенова<sup>1,3</sup>, С.А. Тунгатарова<sup>1,2</sup>,  
Т.С. Байжуманова<sup>1,2</sup>, С.И. Жевнитский<sup>4</sup>, С.В. Романенко<sup>5</sup>**

<sup>1</sup>Д.В.Сокольский атындағы жанармай, катализ және электрохимия институты АҚ, Алматы, Қазақстан;

<sup>2</sup>әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан;

<sup>3</sup>Абай атындағы Қазақ ұлттық педагогикалық университеті, Алматы, Қазақстан;

<sup>4</sup>М.Х. Дулати атындағы Тараз мемлекеттік университеті, Тараз, Қазақстан;

<sup>5</sup>Томск политехникалық университеті, Томск, Ресей

### **ШЫҒАРЫЛҒАН ГАЗДАРДЫ ТАЗARTУ ҮШІН Ni-ҚҰРАМДЫ КАТАЛИЗАТОРЛАРДЫ ЗЕРТТЕУ**

**Аннотация.** Химиялық қауіпсіздік және ауаны санитарлық қорғауда қатты уытты әсер ететін өнеркәсіптік кәсіпорындардан шығарылатын зиянды қалдықтың артуы өзекті мәселе болып саналады. Өндірістік кәсіпорындардан шығатын зиянды улы қалдықтар, яғни көптеген химиялық қосылыстар (толуол, ксилол, стирол, фенол, трикрезол, минералды спирттер, СО және т.б.) тірі организмдер мен флораға теріс әсер тигізеді. Климаттың өзгеруі жөніндегі 2015 жылы 12 желтоқсанда қабылданған Париж келісіміне және 2016 жылы 22 сәуірде қол қойылған Біріккен Ұлттар Ұйымының конвенциясына сәйкес дамыған және экономикасы дамушы елдерде парниктік газдардың шығындысын азайтып, тұрақтандыру қажет. Өнеркәсіптік цехтардан шығарылған зиянды газдардың құрамы қаладағы атмосфералық ауада шекті рұқсат етілген концентрациядан жоғары болса, ол қоршаған ортаның қауіпсіздігіне, сондай-ақ тірі организмге теріс әсерін тигізеді және түрлі ауруларға әкеледі. Өртүрлі өндірістік салалардан шығарылған газдағы толуол, ксилол және этилбензол негізгі еріткіштертердің бөлігі болып саналады.

Өндірістік өнеркәсіптерден, мысалы жиһаз, бояу, лак, кабель, полиграфия салаларынан шығарылатын улы газ қалдықтары тірі ағзаларға теріс әсер тигізеді. Осындай органиканың негізгі компоненті – толуол. Мысалы, 2 сағат ішінде  $250 \text{ мг м}^{-3}$  концентрациясы бар толуолды жұтқанда жүрек жиілігі төмендейді, сөйлеу бұзылып, қозғалыс баяулайды.

Желім, лак, бояудың және т.б. құрамында болатын толуолмен ұзақ дем алатын болса, нейротоксикалық ауытқу клиникалық салдарға, яғни галлюцинация, ұйқышылдық, өз-өзіне қол жұмсау мен көру қабілетінің бұзылуына және құрысуға әкеледі.

Органикалық заттардың толық тотығуы кезінде жоғары белсенділікке ие (95 - 100%) бағалы металдар негізіндегі (Pt, Pd) катализаторлар өнеркәсіптік өндірістерден шығарылған газдарды тазарту үшін қолданылады. Платина тобы металдарының қолжетімділігі мен бағасының жоғары болуы құрамында асыл металдары болмайтын, термотұрақтылығы жоғары, улануға қарсы және ұзақ уақыт аралығында эксплуатациялануға тұрақты, тиімділігі жоғары полиоксидті катализаторларды жасауға деген қажеттілік тудырады. Шығарылған газдарды тазалауға бағалы металдарсыз және құрамында бағалы металдар аз катализаторларды жасау басты мақсат болып саналады.

Өндірістік өнеркәсіптерден шығарылған улы органикалық газдарды толық тотығу технологияларын дамытуда құрамында бағалы металдары жоқ жоғары тиімді полиоксидті катализаторларды жасау да өзекті.

Көлемдік жылдамдығы  $5 \cdot 10^3 \text{ с}^{-1}$  мен температурасы 723 К-де толуолдың толық тотығу реакциясында полиоксидті катализаторлардың белсенділігін зерттеу жолдары көрсетілген. Катализаторлар құрамының көбеюі арқылы толуолдың конверсиясы жоғарылады.  $5 \text{ Ni}/2\% \text{ Ce}/\theta\text{-Al}_2\text{O}_3$  катализаторында толуолдың ең төменгі тотығу көрсеткіші 57.0% болса, ал керісінше үш компонентті  $9\% \text{ Ni-Cu-Cr}/2\% \text{ Ce}/\theta\text{-Al}_2\text{O}_3$  катализаторда 98.5% ең жоғары тотығу дәрежесі байқалды.

Бастапқы қоспадағы ауа мен толуолдың концентрациясын 100-ден  $320 \text{ мг}^{-3}$ -ке дейін жоғарылатқанда екі компонентті  $\text{Ni-Cu}/2\% \text{ Ce}/\theta\text{-Al}_2\text{O}_3$  және  $\text{Cu-Cr}/2\% \text{ Ce}/\theta\text{-Al}_2\text{O}_3$  катализаторда толуол конверсиясының дәрежесі төмендейді.

Зерттеу нәтижесі барысында үш компонентті  $\text{Ni-Cu-Cr}/2\% \text{ Ce}/\theta\text{-Al}_2\text{O}_3$  катализаторда оңтайлы  $\text{Ni} : \text{Cu} : \text{Cr} = 1,0 : 3,0 : 0,1$  қатынасында,  $5 \cdot 10^3 \text{ сағ}^{-1}$  көлемдік жылдамдықта және 723 - 773 К температурада толудың айналым дәрежесі анағұрлым (98.8%- дейін) жоғарылайды. Оттектің беттік қабатпен байланыс энергиясы және полиоксидті катализатордағы реакциялық қабілеттілігі ТБД, ТБТ және ТБТ әдістері арқылы анықталды. Түзілген Ni және Cu алюминаттары 973-1223 К аралығында  $\text{H}_2$  әсерінен оксидтерге немесе олардың қоспаларына дейін тотықсызданатындығы анықталды.

Ni-Cu-Cr катализаторларында оттегінің адсорбциясы оксидтердің ыдырауынан кейін ең төменгі (325 К) температурада жүреді. Бұл дисперсті оксидтердің адсорбцияланған  $\text{O}_2^-$ , O және оттегі торларының жоғары қайта белсенділігін, сондай-ақ олардың қоспаларын оның жеңіл жолмен қайта қосылуға қабілеттілігін көрсетеді.

**Түйін сөздер:** каталитикалық тотығу, толуол, тазалау, никель, мыс.

З.Т. Жексенбаева<sup>1,2</sup>, Р.О. Сарсенова<sup>1,3</sup>, С.А. Тунгатарова<sup>1,2</sup>,  
Т.С. Байжуманова<sup>1,2</sup>, С.И. Жевнитский<sup>4</sup>, С.В. Романенко<sup>5</sup>

<sup>1</sup>Институт топлива, катализа и электрохимии им. Д.В. Сокольского, Алматы, Казакстан;

<sup>2</sup>Казахский национальный университет им. аль-Фараби, Алматы, Казакстан;

<sup>3</sup>Казахский национальный педагогический университет им. Абая, Алматы, Казакстан;

<sup>4</sup>Таразский государственный университет имени М.Х. Дулати, Тараз, Казакстан;

<sup>5</sup>Томский политехнический университет, Томск, Россия

## ИССЛЕДОВАНИЕ Ni-СОДЕРЖАЩИХ КАТАЛИЗАТОРОВ ДЛЯ ОЧИСТКИ ОТХОДЯЩИХ ГАЗОВ

**Аннотация.** Проблема химической безопасности и санитарной защиты воздуха особенно актуальна в связи с увеличением вредных выбросов промышленных предприятий, которые оказывают сильное токсическое воздействие. Многие химические соединения (толуол, ксилол, стирол, фенол, трикрезол, минеральные спирты, СО и т.д.), которые негативно влияют на живые организмы и флору, являются вредными токсичными выбросами от промышленных предприятий. В соответствии с Парижским соглашением, принятым 12 декабря 2015 года и подписанным 22 апреля 2016 года в дополнение к Рамочной конвенции Организации Объединенных Наций об изменении климата, развитые страны и страны с переходной экономикой должны сократить или стабилизировать выбросы парниковых газов. Содержание вредных выбросов выше ПДК в промышленных цехах и атмосферном воздухе в городах оказывает негативное воздействие на живые организмы и приводит к различным заболеваниям, тем самым создает угрозу безопасности окружающей среды. Толуол, ксилол и этилбензол являются основной частью растворителей, используемых в различных отраслях промышленности, которые присутствуют в газообразных выбросах. Токсичное и вредное воздействие вредных выбросов на живые организмы можно проследить на примере толуола - основного компонента токсичных органических газообразных выбросов, которые присутствуют в выбросах мебельной, лакокрасочной, кабельной, полиграфической и других отраслей промышленности. Например, вдыхание толуола с концентрацией  $250 \text{ мг м}^{-3}$  в течение 2 ч приводит к снижению частоты сердечных сокращений, нарушению речи, координации движений. Длительное вдыхание толуола, который присутствует в составе клея, лаков, красок и т.д., вызывает нейротоксические отклонения, которые приводят к клиническим последствиям - галлюцинациям, сонливости, попыткам самоубийства, нарушениям зрения и судорогам.

Как правило, катализаторы на основе благородных металлов (Pt, Pd), которые обладают высокой активностью (95 - 100%) при полном окислении органических веществ, используются в основном для очистки отходящих газов промышленных предприятий. Условия дефицита и высокая стоимость металлов платиновой группы приводят к необходимости разработки новых подходов к созданию высокоэффективных полиоксидных катализаторов, не содержащих благородных металлов, способных проявлять высокую термостойкость и стойкость к отравлению и устойчивых в течение длительного срока эксплуатации. Создание катализаторов для очистки газов, которые не содержат благородных металлов или содержат их в небольших количествах, является важной целью. В этом контексте актуальны разработки высокоэффективных полиоксидных катализаторов, которые не содержат драгоценных металлов, а также технологии глубокого окисления токсичных органических газообразных выбросов промышленности.

Представлено исследование активности полиоксидных катализаторов в реакции глубокого окисления толуола при 723 К и объемной скорости  $5 \text{ ч}10^3 \text{ ч}^{-1}$ . Конверсия толуола возрастала с усложнением состава катализаторов. Самая низкая степень окисления толуола 57.0% наблюдалась на катализаторе 5% Ni/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub>, а наибольшая степень 98.5% наблюдалась на трехкомпонентном 9% Ni-Cu-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> катализаторе. Увеличение концентрации толуола от 100 до 320 мг м<sup>-3</sup> в исходной смеси с воздухом приводит к незначительному снижению степени превращения толуола на двухкомпонентных Ni-Cu/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> и Cu-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> катализаторах.

В результате исследований было установлено, что наибольшая степень превращения толуола (до 98.8%) наблюдается на трехкомпонентном катализаторе Ni-Cu-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> с оптимальным соотношением Ni : Cu : Cr = 1,0 : 3,0 : 0,1 при объемной скорости  $5 \text{ ч}10^3 \text{ ч}^{-1}$  и температуре 723 - 773 К. Энергию связи кислорода с поверхностью и его реакционную способность на полиоксидных катализаторах определяли методами ТПД, ТПО и ТПВ. Было показано, что образующиеся алюминаты Ni и Cu могут восстанавливаться до исходных оксидов или их смесей под воздействием H<sub>2</sub> при 973 - 1223 К. Адсорбция кислорода на катализаторах Ni-Cu-Cr после разложения оксидов происходит при низкой температуре (325 К). Это указывает на высокую реакционную способность адсорбированного O<sub>2</sub>, O и кислорода решетки дисперсных оксидов, а также их смесей и его способность к легкой реактивации.

**Ключевые слова:** каталитическое окисление, толуол, очистка, никель, медь.

**Information about authors:**

Zheksenbaeva Z.T., Leading Researcher, Candidate of Chemical Sciences, Laboratory of Organic Catalysis, JSC “D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry”, Al-Farabi Kazakh National University, Almaty, Kazakhstan. [zheksenbaeva07@mail.ru](mailto:zheksenbaeva07@mail.ru), <https://orcid.org/0000-0001-8227-5750>;

Sarsenova R.O., PhD student, Abai Kazakh National Pedagogical University; Junior Researcher of the Laboratory of Oxidative Catalysis, JSC “D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry”, Almaty, Kazakhstan. [rabinur@mail.ru](mailto:rabinur@mail.ru), <https://orcid.org/0000-0001-5669-8178>;

Tungatarova S.A., Professor, Chief Researcher, Doctor of Chemical Sciences, Laboratory of Organic Catalysis, JSC “D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry”, Al-Farabi Kazakh National University, Almaty, Kazakhstan. [tungatarova58@mail.ru](mailto:tungatarova58@mail.ru), <https://orcid.org/0000-0001-6005-747X>;

Baizhumanova T.S., Leading Researcher, Candidate of Chemical Sciences, Laboratory of Organic Catalysis, JSC “D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry”, Al-Farabi Kazakh National University, Almaty, Kazakhstan. [baizhuma@mail.ru](mailto:baizhuma@mail.ru), <https://orcid.org/0000-0001-9851-264>;

Zhevniitskiy S.I., PhD student, Taraz State University named after M.Kh. Dulaty, Taraz, Kazakhstan, [zhevniitskii@gmail.com](mailto:zhevniitskii@gmail.com), <https://orcid.org/0000-0002-2923-7234>;

Romanenko S.V., Professor, Doctor of Chemical Sciences, Head of the Department of Ecology and Life Safety, Tomsk Polytechnic University, Russia. [svr@tpu.ru](mailto:svr@tpu.ru), <https://orcid.org/0000-0002-2021-2321>

**REFERENCES**

[1] Reckien D, Salvia M, Heidrich O, Church JM, Pietrapertosa F, Gregorio-Hurtado SD, D'Alonzo V, Foley A, Simoes SG, Lorencova EK, Orru H, Orru K, Wejs A, Flacke J, Olazabal M, Geneletti D, Feliu E, Vasilie S, Nador C, Krook-Riekkola A, Matosovic M, Fokaides PA, Ioannou BI, Flamos A, Spyridaki NA, Balzan MV, Fьльор O, Paspaldzhiev I, Grafakos S, Dawson R. (2018) How are cities planning to respond to climate change? Assessment of local climate plans from 885 cities in the EU-28, *J Clean Prod*, 191:207-219. <https://doi.org/10.1016/j.jclepro.2018.03.220> (in Eng.).

[2] Jecha D, Martinec J, Brummer V, Stehlík P, Ležtinský P. (2013) Modernization of unit for elimination of VOCs by catalytic oxidation, *Chem Eng Trans*, 35:745-750. DOI: 10.3303/CET1335124 (in Eng.).

[3] Brattoli M, Cisternino E, Gennaro G, Giungato P, Mazzone A, Palmisani J, Tutino M. (2014) Gas chromatography analysis with olfactometric detection (GC-O): an innovative approach for chemical characterization of odor active volatile organic compounds (VOCs) emitted from a consumer product, *Chem Eng Trans*, 40:121-126. DOI:10.3303/CET1440021 (in Eng.).

[4] Zheksenbaeva ZT, Omarova NO. (2012) Development of technology for the oxidative purification of exhaust gases of petrochemical plants. Proceedings of the All-Russian scientific and practical conference actual problems of engineering, chemical and petrochemical industries and solutions, Nizhnekamsk, Russian Federation. P. 21-22. (in Russian).

[5] Popova NM, Dosumov K, Zheksenbaeva ZT, Komashko LV, Grigor'eva VP, Sass AS, Salakhova RKh. (2006) Thermally stable multicomponent manganese catalyst for the deep oxidation of methane to CO<sub>2</sub>, *Kinet Catal*, 47:907-916. (in Eng.).

[6] Duplančić M, Tomašić V, Kurajica S, Minga I, Valkaj KM. (2017) A Comparative study of toluene oxidation on different metal oxides, *Chem Eng Trans*, 57:889-894. DOI:10.3303/CET1757149 (in Eng.).

[7] Tidahy HL, Siffert S, Wyrwalski F, Lamonier JF, Aboukais A. (2007) Catalytic activity of copper and palladium based catalysts for toluene total oxidation, *Catal Today*, 119:317-320. <https://doi.org/10.1016/j.cattod.2006.08.023> (in Eng.).

[8] Kim MY, Kamata T, Masui T, Imanaka N. (2013) Complete toluene oxidation on Pt/CeO<sub>2</sub>-ZrO<sub>2</sub>-ZnO catalysts, *Catalysts*, 3:646-655. <https://doi.org/10.3390/catal3030646> (in Eng.).

[9] Tong R, Zhang L, Yang X, Liu J, Zhou P, Li J. (2019) Emission characteristics and probabilistic health risk of volatile organic compounds from solvents in wooden furniture manufacturing, *J Clean Prod*, 208:1096-1108. <https://doi.org/10.1016/j.jclepro.2018.10.195> (in Eng.).

[10] Tungatarova SA, Zheksenbaeva ZT, Abdukhalykov DB, Baizhumanova TS. (2014) Thermostable polyoxide catalysts of complete combustion of methane or biogas in the catalytic heat generators, *Chem Eng Trans*, 39:1279-1284. DOI: 10.3303/CET1439214 (in Eng.).

[11] Tungatarova S, Xanthopoulou G, Baizhumanova T, Zhumabek M, Kaumenova G, Massalimova B, Shorayeva K. (2019) Catalytic methane reforming into synthesis-gas over developed composite materials prepared by combustion synthesis, *React Kinet Mech Catal*, 126:645-661. DOI 10.1007/s11144-019-01541-9 (in Eng.).

[12] Tungatarova S, Xanthopoulou G, Karanasios K, Baizhumanova T, Zhumabek M, Kaumenova G (2017) New composite materials prepared by solution combustion synthesis for catalytic reforming of methane, *Chem Eng Transactions*, 61:1921-1926. DOI: 10.3303/CET1761318 (in Eng.).

[13] Tungatarova SA, Xanthopoulou G, Kaumenova GN, Zhumabek M, Baizhumanova TS, Grigorieva VP, Komashko LV, Begimova GU. (2018) Development of composite materials by combustion synthesis method for catalytic reforming of methane

to synthesis gas, *News of the National Academy of Sciences of the Republic of Kazakhstan. Series Chemistry and Technology*, 6:6-15. <https://doi.org/10.32014/2018.2518-1491.20> (in Eng.).

[14] Tungatarova SA, Xanthopoulou G, Baizhumanova TS, Zhumabek M, Kaumenova GN, Amrenova NA, Salimanova AK, Raiyssov A. (2018) Dry reforming and oxidative conversion of methane to synthesis gas in the presence of Ni-Co-Mg-Ce catalysts, *News of the National Academy of Sciences of the Republic of Kazakhstan. Series Chemistry and Technology*, 3:13-19. (in Eng.).

[15] Talasbayeva N, Kazhdembek B, Zhang X, Kaumenova GN, Xanthopoulou G, Tungatarova SA, Baizhumanova TS. (2019) Catalytic conversion of methane into syngas and ethylene, *News of the National Academy of Sciences of the Republic of Kazakhstan. Series Chemistry and Technology*, 3:6-12. <https://doi.org/10.32014/2019.2518-1491.22> (in Eng.).

[16] Zhang B, Zhao R, Sun D, Li Y, Wu T. (2019) Sustainable fabrication of graphene oxide/manganese oxide composites for removing phenolic compounds by adsorption-oxidation process, *J Clean Prod*, 215:165-174. <https://doi.org/10.1016/j.jclepro.2019.01.055> (in Eng.).

[17] Grigoriyeva VP, Popova NM, Zheksenbaeva ZT, Sass AS, Salakhova RH, Dosumov K. (2002) Study of polyoxide methane combustion catalysts based on Mn, Cu, Ni, REE, AEE by XRD method, *Bulletin of the National Academy of Sciences of Kazakhstan, Ser Chem*, 5:63-69. (in Russian).

[18] Komashko LV, Zheksenbaeva ZT. (2002) Study of multicomponent oxide catalysts of methane combustion on Ce/Al<sub>2</sub>O<sub>3</sub> by electron microscopy, *Bulletin of the National Academy of Sciences of Kazakhstan, Ser Chem*, 6:68-72. (in Russian).

[19] Dadakhodzhaev AT. (1985) Study of the ability to poisoning of low-interest palladium-containing catalyst of complete oxidation. *Proceedings of the IV All-Union Conference Catalytic purification of gases, Alma-Ata, Kazakhstan*. P. 155-159. (in Russian)

[20] Kvasov AA, Mikheeva TJa, Abaseev VK, Frontinski AA, Abramova IV. (1985) On the experience of applying the method of catalytic afterburning of organic impurities of industrial off-gases. *Proceedings of the IV All-Union Conference Catalytic purification of gases, Alma-Ata, Kazakhstan*. P. 96-100. (in Russian).

## **Publication Ethics and Publication Malpractice in the journals of the National Academy of Sciences of the Republic of Kazakhstan**

For information on Ethics in publishing and Ethical guidelines for journal publication see <http://www.elsevier.com/publishingethics> and <http://www.elsevier.com/journal-authors/ethics>.

Submission of an article to the National Academy of Sciences of the Republic of Kazakhstan implies that the described work has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see <http://www.elsevier.com/postingpolicy>), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. In particular, translations into English of papers already published in another language are not accepted.

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The National Academy of Sciences of the Republic of Kazakhstan follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct ([http://publicationethics.org/files/u2/New\\_Code.pdf](http://publicationethics.org/files/u2/New_Code.pdf)). To verify originality, your article may be checked by the Cross Check originality detection service <http://www.elsevier.com/editors/plagdetect>.

The authors are obliged to participate in peer review process and be ready to provide corrections, clarifications, retractions and apologies when needed. All authors of a paper should have significantly contributed to the research.

The reviewers should provide objective judgments and should point out relevant published works which are not yet cited. Reviewed articles should be treated confidentially. The reviewers will be chosen in such a way that there is no conflict of interests with respect to the research, the authors and/or the research funders.

The editors have complete responsibility and authority to reject or accept a paper, and they will only accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the National Academy of Sciences of the Republic of Kazakhstan.

The Editorial Board of the National Academy of Sciences of the Republic of Kazakhstan will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации  
в журнале смотреть на сайте:

[www.nauka-nanrk.kz](http://www.nauka-nanrk.kz)

<http://chemistry-technology.kz/index.php/en/arhiv>

ISSN 2518-1491 (Online), ISSN 2224-5286 (Print)

Редакторы: *М. С. Ахметова, Г. Б. Халидуллаева, Д. С. Аленов*  
Верстка на компьютере *А.М. Кульгинбаевой*

Подписано в печать 08.06.2020.

Формат 60x88<sup>1</sup>/<sub>8</sub>. Бумага офсетная. Печать – ризограф.  
10,8 п.л. Тираж 300. Заказ 3.