

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  $\theta$ -Al<sub>2</sub>O<sub>3</sub> ( $S = 100 \text{ m}^2 \text{ g}^{-1}$ , particle size between 40 and 50  $\mu\text{m}$ ) modified by Ce, which forms resistant surface CeAlO<sub>3</sub> 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 N<sub>2</sub> 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 (H<sub>2</sub>) 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 H<sub>2</sub> (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/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> catalyst, and the greatest 98.5% degree was observed on the three-component 9% Ni-Cu-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> catalyst. The following series by activity in the reaction of deep oxidation of toluene was determined: Ni-Cu-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> (98.5%) > Ni-Cu-Cr/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> (92.0%) > Ni-Cu/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> (84.0%) > Ni-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> (75.0%) > Ni/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> (57.0%). The largest conversion of toluene is observed on three-component Ni-Cu-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> 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/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> and Cu-Cr/2% Ce/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> 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/ $\theta$ -Al<sub>2</sub>O<sub>3</sub> catalyst was the most stable.