ISSN 0036-0236, Russian Journal of Inorganic Chemistry, 2017, Vol. 62, No. 7, pp. 879–885. © Pleiades Publishing, Ltd., 2017.
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Praseodymium-Containing Catalysts for Oxidative Dehydrogenation of Organic Compounds

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Received October 27, 2016

Abstract—A method is developed for incorporating praseodymium into magnesium–aluminum hydrotalcites, which are precursors for oxide catalysts for oxidative dehydrogenation (ODH) of alkanes. Oxide catalyst samples that contain praseodymium and various combinations of magnesium, aluminum, chromium, vanadium, molybdenum, and niobium are prepared. The catalytic properties of the prepared catalysts in ethane, propane, and butane ODH reactions are studied. Into some of our studied multicomponent catalysts, the incorporation of praseodymium enhances the reaction selectivity and increases yields of desired products.

DOI: 10.1134/S0036023617070129

The work we report here is a continuation of the studies intended to elucidate the influence of the composition of multicomponent hydrotalcite-like hydroxo salts used as catalyst precursors on the catalytic properties of the catalysts for oxidative dehydrogenation (ODH) of organic compounds.

Earlier [1–13] we prepared a large set of complex hydroxo salts having the hydrotalcite layered structure where the metal–hydroxyl cationic layers contained magnesium, aluminum, nickel, chromium, iron, cobalt, copper, gallium, indium, samarium, and europium atoms in various combinations and the anionic interlayers contained nitrate, carbonate, decavanadate, paramolybdate, metatungstate, hexaoxoniobate, and pentaoxotantalate ions. Some of the oxide catalysts prepared from those salts had high selectivities and provided high yields of desired products in the ODH of lower alkanes and alcohols.

This study is targeted at developing a method to incorporate praseodymium(III) into catalysts and elucidate how it influences the properties of catalysts in the ODH of alkanes.

EXPERIMENTAL

The praseodymium-containing hydroxo salts to be used as catalyst precursors were prepared by the following protocol. To a solution containing aluminum, magnesium, praseodymium, and chromium nitrates in set amounts, a solution containing potassium hydroxide and potassium carbonate in the ratio 2 : 1 (mol/mol) was dropped at 60°C under stirring until pH changed from 1 to 10. The thus-obtained precipitate was washed with water from potassium ions according to the tetraphenyl borate test. Chemical analysis and X-ray powder diffraction showed that, depending on the initial solution composition, the precipitate was either the hydrotalcite-like aluminum–magnesium–praseodymium hydroxo salt $[Al_{0.8-0.83}Pr_{0.09-0.2}Mg_{1.67-1.92}(OH)_{5.34-5.84}][(CO_3)_{0.5} \cdot nH_2O]$, or the hydrotalcite-like aluminum–magnesium–praseodymium–chromium hydroxo salt $[Al_{0.83}Cr_{0.08}Pr_{0.09}Mg_{1.92}(OH)_{5.84}][(CO_3)_{0.5} \cdot nH_2O]$.

As probed by X-ray powder diffraction, these salts were isostructural to the hydrotalcite-type complex hydroxo salts we prepared earlier [1–13].

In order to accomplish anion exchange to replace carbonate ions in hydroxo salts by decavanadate ions $(V_{10}O_{28})^{6-}$ or paramolybdate ions $(Mo_7O_{24})^{6-}$, we diluted the paste obtained after precipitation and washing with water to S : L = 1 : 2, and then added a set amount of a solution of potassium decavanadate (0.15 M) and ammonium paramolybdate (0.15 M). The slurry was stirred for 10 min, and nitric acid (0.2 M) was then added to adjust pH to 4.5 in order to provide the necessary conditions for anion exchange to occur [14–16]. After the mixture was exposed for 10 min at pH of 4.5, the precipitate was filtered and washed with water from potassium and ammonium ions according to the tetraphenyl borate test.

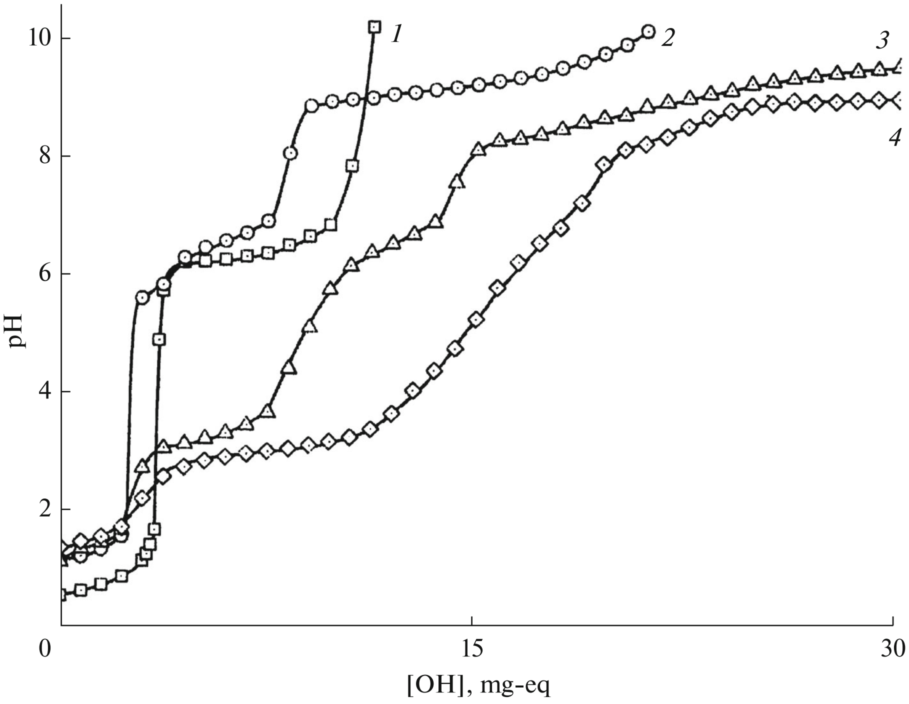

Fig. 1. Potentiometric titration curves for (*1*) praseodymium, (*2*) praseodymium—magnesium, (*3*) praseodymium—magnesium—aluminum, and (*4*) praseodymium—aluminum—chromium—magnesium nitrate solutions.

In order to introduce niobium into hydroxo salts, K_2CO_3 was alloyed with Nb_2O_5 in the ratio 10 : 1 (mol/mol) [16], the alloy was dissolved in water, and the resulting solution (pH 13) was used to accomplish the exchange of carbonate ions for polyoxoniobate ions $[Nb_6O_{19}]^{8-}$ [7, 16]. The anion exchange lasted 6 h; then, the precipitates were washed with water from potassium ions.

The phase and chemical compositions of the prepared hydroxo salts were determined by chemical analysis and X-ray powder diffraction (DRON-2.0 diffractometer, CuK_α radiation). The salt formation conditions were determined by potentiometric titration of solutions on a RADELKIS OR-208 precision digital pH meter. The determination methods for all elements, except for praseodymium, are found in [12]. The praseodymium was determined by titrating an aliquot with Trilon Bat at pH of 5.5–6.5 in the presence of pyridine with arsenazo as an indicator, with aluminum masked by 0.1 M sulfosalicylic acid.

RESULTS AND DISCUSSION

Figure 1 shows potentiometric titration curves for magnesium, praseodymium, chromium, aluminum nitrates and their mixtures with aqueous potassium hydroxide. Praseodymium was found to precipitate from metal nitrate solutions at pH 6–7 as amorphous praseodymium hydroxide $Pr(OH)_3$ (Fig. 1, curve *1*), which crystallized to $Pr(OH)_3$ with an admixture of the hydroxo salt in 2 weeks upon exposure to 50°C (Fig. 2); aluminum precipitated at pH 3–3.5 as a hydroxo salt of variable composition $Al(OH)_n(NO_3)_{3-n} \cdot mH_2O$, which is described in [1]; chromium precipitated in the form of chromium hydroxide at pH 4.5–5.0; and magnesium precipitated at pH 10–10.5 in the form of well-crystallized $MgOH(NO_3) \cdot mH_2O$, which we described earlier [1].

From a solution containing praseodymium and magnesium nitrates, amorphous praseodymium hydroxide first precipitated at pH 6–6.5, then crystalline $MgOH(NO_3) \cdot mH_2O$ precipitates at pH 9–10 (Fig. 1, curve *2*; Fig. 3, curve *1*) [1]. From a solution containing praseodymium, aluminum, and magnesium nitrates, amorphous aluminum hydroxonitrate first precipitated at pH 3–3.5, followed by the precipitation of amorphous praseodymium hydroxide at pH 6–7, and then well-crystallized hydrotalcite-like aluminum—praseodymium—magnesium hydroxonitrate of variable composition precipitated at pH 8–9 (Fig. 1, curve *3*; Fig. 3, curve *2*). We precipitated samples of two compositions: $[Al_{0.5}Pr_{0.5}Mg_3(OH)_8][(NO_3) \cdot nH_2O]$ and $[Al_{0.5}Pr_{0.5}Mg_2(OH)_6][(NO_3) \cdot nH_2O]$.

From a solution containing aluminum, praseodymium, chromium, and magnesium nitrates, amorphous aluminum hydroxonitrate first precipitated at pH 2.5–3, followed by the precipitation of amorphous chromium hydroxide and praseodymium hydroxide at pH 4–6, and then well-crystallized hydrotalcite-like aluminum—praseodymium—chromium—magnesium

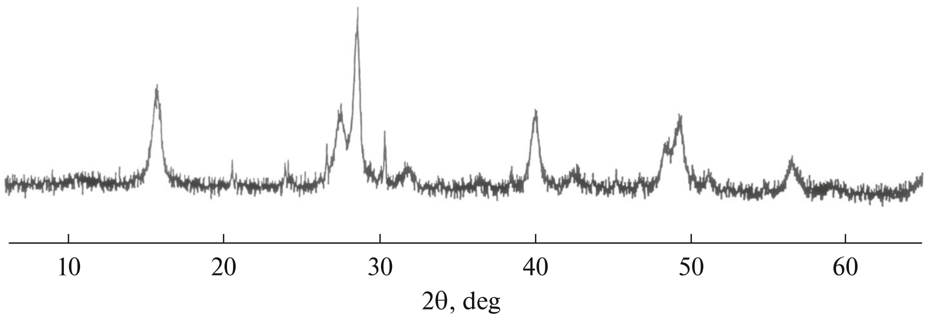

Fig. 2. X-ray diffraction pattern of crystalline $Pr(OH)_3$ with admixtures of a hydroxo salt and praseodymium.

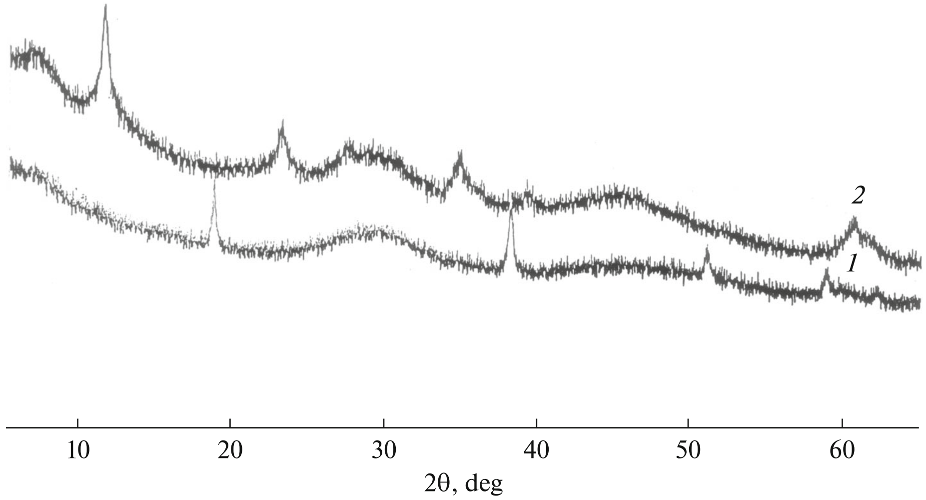

Fig. 3. X-ray diffraction patterns of (*1*) amorphous praseodymium hydroxide and crystalline $MgOH(NO_3) \cdot nH_2O$ and (*2*) hydrotalcite-like aluminum–praseodymium–magnesium hydroxonitrate $[Al_{0,5}Pr_{0,5}Mg_2(OH)_6][(NO_3) \cdot nH_2O$.

hydroxonitrate (isomorphous to aluminum–praseodymium–magnesium hydroxonitrate) precipitated at pH 8–8.5 (Fig. 1, curve *4*). We precipitated a sample of composition $[Al_{0.33}Cr_{0.33}Pr_{0.33}Mg_{2.5}(OH)_{6.97}][(NO_3) \cdot nH_2O]$.

In order to elucidate how praseodymium influences the catalytic properties of an oxide catalyst in alkane ODH reactions, we prepared samples of a praseodymium-containing catalyst precursor. For this purpose, we first prepared ternary and quaternary hydroxocarbonates and then introduced decavanadate and paramolybdate ions into them by anion exchange (Table 1, samples 2 and 3). In preparing precursors for ODH catalysts that contained hexaniobate ions together with decavanadate and paramolybdate ions, we had to use a mixture of two isomorphous phases for the reason that decavanadate and paramolybdate ions substitute for interlayer carbonate ions of hydrotalcite-like hydroxo salts at pH 4.5 and hexaniobate ions do it at pH 13. To prepare the precursor whose composition corresponds to sample 2 (Table 1), we used a mixture of aluminum–praseodymium–magnesium hexaniobate and aluminum–praseodymium–magnesium hydroxocarbonate that contained decavanadate and paramolybdate ions (Table 2, sample 1). To prepare sample 3 (Table 1), we used a mixture of aluminum–praseodymium–chromium–magnesium hexaniobate and aluminum–praseodymium–chromium–magnesium hydroxocarbonate that contained decavanadate and paramolybdate ions (Table 2, sample 2).

Those mixtures were prepared by stirring the two initial hydroxo salts in the weight ratio 1 : 1 in aqueous medium with S : L = 1 : 2 for 2 h (to attain homogeneity). The mixtures were sufficiently homogeneous, as verified by their sedimentation character and the chemical analysis of the slurry sampled from the upper and lower portions of the sedimentation column (the samples had the same ratios Al : Nb, Al : Mo, and Al : V). The compositions of the thus-prepared precursor samples are listed in Table 1.

Compounds 1–3 in Table 1 and compounds 1 and 2 in Table 2 were prepared by us for the first time.

Table 1. Praseodymium-containing hydrotalcite-like salts used as precursors for alkane ODH catalysts

Sample no.	Precursor
1	$[Al_{0.8}Pr_{0.2}Mg_{1.8}(OH)_{5.6}][CO_3)_{0.5} \cdot nH_2O]$
2	$[Al_{0.82}Pr_{0.18}Mg_{1.67}(OH)_{5.34}][(CO_3)_{0.412}(Mo_7O_{24})_{0.02}(V_{10}O_{28})_{0.004}(Nb_6O_{19})_{0.004} \cdot nH_2O]$
3	$[Al_{0.83}Cr_{0.08}Pr_{0.09}Mg_{1.92}(OH)_{5.84}][(CO_3)_{0.409}(Mo_7O_{24})_{0.02}(V_{10}O_{28})_{0.005}(Nb_6O_{19})_{0.004} \cdot nH_2O]$

Table 2. Isomorphous hydrotalcite-like hydroxo salts that were mixed in the weight ratio 1 : 1 to produce precursors for alkane ODH catalysts (see Table 1, samples 2 and 3)

Sample no.	Niobium-containing hydroxo salt	Molybdenum-and-vanadium-containing hydroxo salt
1	$[Al_{0.82}Pr_{0.18}Mg_{1.67}(OH)_{5.34}]$ $[(CO_3)_{0.468}(Nb_6O_{19})_{0.008} \cdot nH_2O]$	$[Al_{0.82}Pr_{0.18}Mg_{1.67}(OH)_{5.34}]$ $[(CO_3)_{0.356}(Mo_7O_{24})_{0.04}(V_{10}O_{28})_{0.008} \cdot nH_2O]$
2	$[Al_{0.83}Cr_{0.08}Pr_{0\cdot09}Mg_{1.92}(OH)_{5.84}]$ $[(CO_3)_{0.468}(Nb_6O_{19})_{0.008} \cdot nH_2O]$	$[Al_{0.83}Cr_{0.08}Pr_{0.09}Mg_{1.92}(OH)_{5.84}]$ $[(CO_3)_{0.35}(Mo_7O_{24})_{0.04}(V_{10}O_{28})_{0.01} \cdot nH_2O]$

To convert as-prepared precursor samples (Table 1) to oxide catalysts, we heat-treated them. Heat treatment consisted in drying a precipitate at 100–120°C to a water content of 40%, pelletizing, calcining in a muffle in flowing air with a constant rise of temperature to 500°C at 100 K/h, and then exposing to this temperature for 4–5 h.

The catalytic properties of the thus-produced materials were studied in a flow-through silica glass reactor charged with 1–2 mL of the catalyst. The oxidizing agents were atmospheric air and carbon dioxide. For maintaining isothermicity, the catalyst was mixed with an equal volume of ground silica. The reaction temperature, the hydrocarbon flow rate, and the hydrocarbon/oxygen/carbon dioxide ratio in the batch were varied widely. Reaction products were analyzed by liquid chromatography using a column filled with Porapak Q.

The contact gas was analyzed for the unreacted hydrocarbon (ethane, propane, or isobutane), dehydrogenation product (ethylene, propylene, or isobutylene), CO_2, and CO. The results of experiments were used to calculate the conversion of the initial compound, reaction selectivity, and the yield of desired products:

Conversion, % = [converted hydrocarbon/admitted hydrocarbon, mols × 100];
Selectivity, % = [produced hydrocarbon/converted hydrocarbon, mols × 100];
Yield, % = [produced hydrocarbon/admitted hydrocarbon, mols × 100].

The catalysts prepared from samples 1–3 (Table 1) were used in the oxidative dehydrogenation of ethane, propane, and isobutane.

An analysis of the results of catalytic studies shows that ethane-to-ethylene conversion over praseodymium-containing catalysts occurs at low temperatures (450°C).

Over the Pr-Al-Mg-O catalyst (Table 1, sample 1) ethane oxidation occurs with high selectivity (93.1%), but with low yield (17.6%) (Table 3). When molybdenum, vanadium, and niobium are entered into the catalyst (Table 1, sample 2), selectivity increases (97.6%) and the ethylene yield increases to 23.0%.

When the temperature rises to 650°C, the yields over samples 1 and 2 become higher (Table 3), increasing to 21.5 and 30.6%, respectively, but selectivities decline considerably (72.0 and 80.0% respectively). When chromium is introduced into the praseodymium-containing catalyst in addition to molybdenum, vanadium, and niobium (Table 1, sample 3), the yield at 450°C rises considerably (30.7%) with the high selectivity maintained (99.0%). At 650°C, the ethylene yield for this sample is 34.3% and the selectivity is 80.0%.

When oxygen is introduced into the reaction mixture in addition to carbon dioxide in the ratio 1/1/1, (we used a chromium-containing catalyst under these conditions; see Table 3, sample 3), the yield increases to become 35.2% at 450°C and 42.6% at 600°C.

We also studied the catalytic activity of a Pr-Cr-Al-Mg-Nb-Mo-V-O catalyst (Table 1, sample 3) in propane ODH reactions (Table 4).

Table 3. Results of ethane ODH over praseodymium-containing catalysts

Sample no. s	Catalyst	$C_2H_6/CO_2/O_2$ batch	Temperature, °C	C_2H_6 conversion, %	C_2H_4 yield, %	C_2H_4 selectivity, %
1	Pr-Al-Mg-O	1/0.3/0	450	18.9	17.6	93.1
		1/0.3/0	600	25.3	19.5	77.2
		1/0.3/0	650	29.9	21.5	72.0
2	Pr-Al-Mg-Nb-V-Mo-O	1/0.3/0	450	23.6	23.0	97.6
		1/0.3/0	600	25.4	22.6	89.0
		1/0.3/0	650	38.3	30.6	80.0
3	Pr-Cr-Al-Mg-Nb-V-Mo-O	1/0.3/0	450	31.0	30.7	99.0
		1/0.3/0	650	42.9	34.3	80.0
		1/1/1	450	36.8	35.2	95.7
		1/1/1	600	50.7	42.6	84.0

Table 4. Results of propane ODH over a Pr-Cr-Al-Mg-Nb-V-Mo-O catalyst (the batch: $C_3H_8/CO_2/O_2 = 1/1/0.5$)

Sample no.	Temperature, °C	C_3H_8 conversion, %	C_3H_6 yield, %	C_3H_6 selectivity, %
1	450	25.0	19.25	77
2	600	49.0	33.8	69

Propylene yields at temperatures in the range 450–600°C were 19.25–33.8% with 77–69% selectivities, respectively.

We also studied the catalytic activity of this catalyst in isobutane ODH (Table 5) at various temperatures and various batch compositions.

The isobutylene yield was found to increase as temperature rises and the amount of oxygen in the batch increases. At 450°C and *iso*-$C_4H_{10}/CO_2/O_2 = 1/1/0$, the isobutylene yield was 27.0% and the selectivity was 93.0%; for the same batch composition at 600°C, the yield was 39.5% and the selectivity was 76.0%. When the oxygen amount was increased to *iso*-$C_4H_{10}/CO_2/O_2 = 1/1/1$, the isobutylene yield at 450°C was 32.2% and the selectivity was 87.0%; at 600°C, the yield was 45.9% and the selectivity was 74.0%.

Comparing the catalytic activities of the chromium-containing catalyst (Table 1, sample 3) in ethane, propane, and isobutane ODH, we see the best results in ethane ODH (at 450°C, the yield was 30.7% and the selectivity was 99.0%). In isobutane ODH at 450°C, the yield was 27.0% and the selectivity was 93.0%; in propane ODH at 450°C, the yield was 19.25% and the selectivity was 77%.

Comparing the catalytic activities of catalysts that contained a rare-earth element (samarium, europium, or praseodymium) [12, 13] together with vanadium, molybdenum, and niobium, we found that chromium additions noticeably improved ethylene yields in the ethane ODH reaction: 24.3% for the samarium-containing catalyst, 26.2% for the europium-containing catalyst, and 30.7% for the praseodymium-containing catalyst with a high selectivity (93.7, 97.0, and 99.0%, respectively).

Table 6 shows a comparison of the catalytic properties of various catalyst compositions containing vanadium, molybdenum, niobium, and chromium in ethane ODH reactions. One can infer from Table 6 that

Table 5. Results of isobutane ODH over a Pr-Cr-Al-Mg-Nb-V-Mo-O catalyst at various temperatures and various batch compositions

Sample no.	Batch, *iso*-$C_4H_{10}/CO_2/O_2$	Temperature, °C	*iso*-C_4H_{10} conversion, %	*iso*-C_4H_8 yield, %	*iso*-C_4H_8 selectivity, %
1	1/1/0	450	29.0	27.0	93.0
2	1/1/0	600	52.0	39.5	76.0
3	1/1/0.5	450	32.0	29.4	92.0
4	1/1/0.5	600	60.0	45.0	75.0
5	1/1/1	450	37.0	32.2	87.0
6	1/1/1	600	62.0	45.9	74.0

Table 6. Comparison of the results of ethane ODH over various chromium-containing catalyst compositions

Sample no.	Catalyst	Temperature, °C	C_2H_6 conversion, %	C_2H_4 yield, %	C_2H_4 selectivity, %
1	In-Cr-Al-Mg-Nb-V-Mo-O	450 650	20.0 35.7	19.14 30.3	95.7 85.0
2	Ga-Cr-Al-Mg-Nb-V-Mo-O	450	20.4	19.5	95.7
3	Sm-Cr-Al-Mg-Nb-V-Mo-O	450 650	26.0 40.0	24.3 32.0	93.7 80.0
4	Eu-Cr-Al-Mg-Nb-V-Mo-O	450 650	27.0 41.0	26.2 33.2	97.0 81.0
5	Pr-Cr-Al-Mg- Nb-V-Mo-O	450 650	31.0 42.9	30.7 34.3	99.0 80.0

Table 7. Comparison of the results of ethane ODH over various catalyst compositions

Sample no.	Catalyst	Temperature, °C	C_2H_6 conversion, %	C_2H_4 yield, %	C_2H_4 selectivity, %
1	Pr-Al-Mg-Nb-V-Mo-O	450	23.6	23.0	97.6
2	Eu-Al-Mg-Nb-V-Mo-O	450	20.6	19.8	95.6
3	Sm-Al-Mg-Nb-V-Mo-O	450	20.0	19.14	95.7
4	In-Al-Mg-Nb-V-Mo-O	450	20.7	19.7	95.0
5	Ga-Al-Mg-Nb-V-Mo-O	450	20.4	19.5	95.7
6	Nb-Al-Mg-V-Mo-O	450	19.0	17.9	94.0
7	Ta-Al-Mg-V-Mo-O	500	17.5	15.95	91.15
8	Ni-Al-Mg-V-Mo-W-O	550	6.9	2.67	38.7
9	Fe-Al-Mg-V-Mo-W-O	550	7.45	3.32	44.6

Table 8. Comparison of the results of propane ODH over various catalyst compositions

Sample no.	Catalyst	Temperature, °C	C_3H_8 conversion, %	C_3H_6 yield, %	C_3H_6 selectivity, %
1	In-Cr-Al-Mg-Nb-V-Mo-O	450	26.6	23.9	90
2	Ga-Cr-Al-Mg-Nb-V-Mo-O	450	60.0	20.2	33.7
3	Sm-Cr-Al-Mg-Nb-V-Mo-O	450	20.0	19.14	95.7
4	Pr-Cr-Al-Mg-Nb-V-Mo-O	450	25.0	19.25	77.0
5	Eu-Cr-Al-Mg-Nb-V-Mo-O	450	25.0	17.5	70.0
6	Cu-Al-Mg-V-Mo-O	450	38.3	14.3	37.3
7	Bi-Al-Mg-V-Mo-O	450	21.1	8.0	37.9
8	Ni-Al-Mg-V-Mo-O	450	11.9	4.3	36.0

the praseodymium-containing catalyst gives the best results; ethylene yield increases noticeably over all catalysts as temperature rises from 450 to 650°C, but selectivity declines.

Table 7 shows a comparison of ethane ODH catalytic activities for various chromium-free catalysts. From Table 7, one can infer that the praseodymium-containing catalyst gives the best results (yield: 23.0%; selectivity: 97.6%). The europium-, samarium-, indium-, and gallium-containing catalysts perform almost equally given that they contain niobium, vanadium, and molybdenum: yields are 19.14–19.8% and selectivities are 95.0–95.7%. The Nb-Al-Mg-V-Mo-O catalyst shows slightly worse results: the yield is 17.9% and the selectivity is 94.0%. The Ta-Al-Mg-V-Mo-O catalyst shows even worse results: the yield is 15.95% and the selectivity is 91.15%.

Table 9. Comparison of the results of isobutane ODH over various catalyst compositions

Sample nos.	Catalyst	Temperature, °C	Isobutane conversion, %	Isobutylene yield, %	Isobutylene selectivity, %
1	Pr-Cr-Al-Mg-Nb-V-Mo-O	450	29.0	27.0	93.0
2	In-Cr-Al-Mg-Nb-V-Mo-O	450	26.6	23.94	90.0
3	Eu-Cr-Al-Mg-Nb-V-Mo-O	450	26.0	23.9	92.0
4	Ga-Cr-Al-Mg-Nb –V-Mo-O	450	60.0	20.2	33.7
5	Sm-Cr-Al-Mg-Nb-V-Mo-O	450	24.1	17.4	72.2

Over Ni-Al-Mg-V-Mo-W-O and Fe-Al-Mg-V-Mo-W-O catalysts, ethane ODH virtually does not occur (Table 7, samples 8 and 9): yields are 2.7–3.3%, and selectivities are 39–45%.

Table 8 shows a comparison of the propane OHD catalytic properties of various catalyst compositions. One can infer from Table 8 that the indium-containing catalyst gives the best results: the yield is 23.9%, and selectivity is 90%. The yield further systematically drops from the gallium-containing catalyst to the europium-containing one, from 20.2 to 17.5%, respectively. For the praseodymium-containing catalyst, the yield is 19.25% and the selectivity is 77.0%. The other catalysts show lower yields and selectivities (yields are 14.3–4.3%; selectivities are 36–38%).

Table 9 shows a comparison of the performances of various catalyst compositions in isobutane ODH reactions. The praseodymium-containing catalyst gives the best results: the yield is 23.9% and selectivity is 93.0% at 450°C. For europium- and indium-containing catalysts, the yield is 23.9% and the selectivity is 92.0 and 90.0%, respectively. For gallium- and samarium-containing catalysts, the ODH results are noticeably worse: yields are 20.2 and 17.4%, and selectivities are 33.7 and 72.2%, respectively.

In summary, we have developed a method to introduce praseodymium to catalysts that contain Mg, Al, Cr, V, Mo, and Nb in various proportions. We have prepared new hydroxo salts having hydrotalcite-type layered structure, namely, $[Al_{1-n}Pr_nMg_m(OH)_{3+2m-1}][A \cdot qH_2O]$ and $[Al_{1-(n+m)}Pr_nCr_mMg_p(OH)_{3+2p-1}][A \cdot qH_2O]$ where A = (NO_3) or $(CO_3)_{0.5}$. Similar hydroxocarbonates were subjected to a partial anion exchange of (CO_3) for $(Mo_7O_{24})^{6-}$, $(V_{10}O_{28})^{6-}$, and $(Nb_6O_{19})^{8-}$ to be subsequently used as precursors for alkane ODH catalysts.

We studied the catalytic properties of the prepared catalysts in ethane, propane, and isobutane ODH reactions. Praseodymium when introduced into catalysts enhances the selectivity and final product yields in ethane and isobutane ODH reactions. The praseodymium-containing catalyst gives the best results in ethane and isobutane ODH among the M-Cr-Al-Mg-Nb-V-Mo-O catalysts where M = Pr, Eu, Sm, In, or Ga.

ACKNOWLEDGMENTS

This study was supported by the Presidium of the Russian Academy of Sciences through the fundamental research program of "Development of Methods for Preparing Chemical Materials and Materials Design" and "Targeted Synthesis of Inorganic Compounds Having Tailored Properties and Design of Functional Materials on Their Base" (project no. 8P6).

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Translated by O. Fedorova