APPLICATION OF CALCINED LAYERED DOUBLE HYDROXIDES AS CATALYSTS FOR ABATEMENT OF N_2O EMISSIONS

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The results of catalytic decomposition of N_2O over mixed oxide catalysts obtained by calcination of layered double hydroxides (LDHs) are summarized. Mixed oxides were prepared by thermal treatment (500 °C) of coprecipitated LDH precursors with general chemical composition of $M^{II}_{1-x}M^{III}_x(OH)_2(CO_3)_{x/2}\cdot yH_2O$, where M^{II} was Ni, Co, Cu and/or Mg, M^{III} was Mn, Fe and/or Al, and the M^{II}/M^{III} molar ratio was adjusted to 2. The influence of chemical composition of the M^{II}-M^{III} mixed oxide catalysts on their activity and stability in N_2O decomposition was examined. The highest N_2O conversion was reached over Ni-Al (4:2) and Co-Mn-Al (4:1:1) catalysts. Their suitability for practical application was proved in simulated process stream in the presence of O_2, NO, NO_2 and H_2O. It was found that N_2O conversion decreased with increasing amount of oxygen in the feed. The presence of NO in the feed caused a slight decrease in N_2O conversion. A strong decrease in the reaction rate was observed over the Ni-Al catalyst in the presence of NO_2 while no N_2O conversion decrease was observed over the Co-Mn-Al catalyst. Water vapor inhibited the N_2O decomposition over all tested catalysts. The obtained kinetic data for N_2O decomposition in a simulated process stream over the Co-Mn-Al catalyst were used for a preliminary reactor design. The packed bed volume necessary for N_2O emission abatement in a HNO_3 production plant was calculated as 35 m^3 for waste gas flow rate of 30 000 m^3 h^{-1}.

Keywords: Nitrous oxide; Catalytic decomposition; Mixed oxides; Layered double hydroxides; Inhibition.

Nitrous oxide (N_2O) belongs to a group of compounds depleting stratospheric ozone layer and also strongly contributes to the greenhouse effect. Nitric acid plants are indicated as the biggest industrial source of anthropogenic N_2O emissions (worldwide 400 kt N_2O per year)[1]. Nitrous oxide to-

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gether with nitrogen arises from non-selective oxidation of ammonia during high-temperature NH_3 oxidation over Pt-Rh sieves, possibly by consecutive reactions of NO and nonreacted ammonia[1–3].

One of the possible methods for N_2O emission lowering is direct N_2O decomposition according to Eq. (*1*).

$$N_2O \rightarrow N_2 + 0.5\ O_2 \qquad (1)$$

Reaction (*1*) represents a spin-forbidden reaction with high activation energy (250–270 kJ mol^{-1}); a measurable N_2O conversion could be obtained only above 620 °C. On the other hand, 100% N_2O conversion could be obtained already at 320 °C in the presence of a suitable catalyst, depending on the composition of inlet gas. It is known that water vapour, oxygen and possibly other components characteristic of off-gases containing N_2O have inhibition effect over some of the catalysts[4–7].

The reaction rate of N_2O decomposition according to Eq. (*1*) could be further increased in the presence of a reducing agent (such as hydrocarbons, ammonia or carbon monoxide)[8–22]. A reducing agent added into the inlet gas decreases the temperature necessary for full N_2O conversion; however, it increases operating costs of the process and undesirable reaction products can be formed. Therefore, the catalysts should exhibit also a satisfactory selectivity.

A sufficiently active and stable catalyst is still the object of the research despite the fact that many catalysts have been tested for N_2O decomposition or reduction[4,23]. The present work deals with the N_2O catalytic decomposition over mixed oxides prepared by thermal decomposition of layered double hydroxides.

Layered double hydroxides (LDHs), known also as hydrotalcite-like compounds or anionic clays, are layered materials consisting of positively charged hydroxide layers separated by interlayers composed of anions and water molecules. The chemical composition of LDHs can be represented by the general formula $[M^{II}_{1-x}M^{III}_{x}(OH)_2]^{x+}[A^{n-}_{x/n}\cdot yH_2O]^{x-}$ where M^{II} and M^{III} are divalent and trivalent metal cations, A^{n-} is an *n*-valent anion, and *x* has usually values between 0.20 and 0.33. A wide variety of LDHs can be prepared modifying both the composition of hydroxide layers and interlayer species. After heating at moderate temperatures, LDHs give finely dispersed mixed oxides of M^{II} and M^{III} metals with a large surface area and good thermal stability[24–29]. Therefore, the LDHs are often used as precursors for preparation of mixed oxide catalysts. Some of them were also tested in the catalytic decomposition of nitrous oxide[30–41].

The effect of chemical composition of mixed-oxide catalysts on their catalytic activity for N_2O decomposition was studied in the present work. The catalyst testing in inert gas was carried out in order to compare the activity of catalysts containing various M^{II} and M^{III} metals. The tests in a simulated process stream (in the presence of O_2, NO, NO_2 and H_2O) were performed in order to elucidate a practical application of selected catalysts, over which a high N_2O conversion was obtained. Based on the results, some parameters of a catalytic reactor for N_2O emission abatement from nitric acid production plant were estimated.

EXPERIMENTAL

The LDH precursors with chemical composition represented by general formula $[M^{II}_{1-x}M^{III}_x(OH)_2(CO_3)_{x/2}\cdot yH_2O$, where M^{II} = Ni, Co, Cu and/or Mg, and M^{III} = Mn, Fe and/or Al were prepared by coprecipitation. An aqueous solution (450 ml) of appropriate nitrates, i.e., $Ni(NO_3)_2\cdot 6H_2O$, $Co(NO_3)_2\cdot 6H_2O$, $Cu(NO_3)_2\cdot 3H_2O$, $Mg(NO_3)_2\cdot 6H_2O$, $Mn(NO_3)_2\cdot 4H_2O$, $Fe(NO_3)_3\cdot 9H_2O$ and $Al(NO_3)_3\cdot 9H_2O$, with a M^{II}/M^{III} molar ratio of 2 and total metal ion concentration 1.0 mol l^{-1} was added with flow rate of 7.5 ml min^{-1} into 1000 ml reactor containing 200 ml of distilled water. The flow rate of simultaneously added alkaline solution of 0.5 M Na_2CO_3 and 3 M NaOH was controlled to maintain reaction pH at 10.0 ± 0.1. The coprecipitation was carried out under vigorous stirring at 30 °C. The resulting suspension was stirred at 30 °C for 1 h, the obtained product was then filtered off, washed thoroughly with distilled water, and dried overnight at 60 °C in air. The dried precursors were formed into extrudates and calcined in air at 500 °C for 4 h. The calcined extrudates were crushed and sieved to obtain the fraction with particle size 0.160–0.315 mm. The prepared catalysts were denoted by acronyms with elemental composition and the molar ratios of the constituents. For example, Co_4MnAl sample contained Co, Mn and Al in molar ratio of 4:1:1.

The prepared precursors and mixed oxide catalysts were characterized by chemical analysis, powder X-ray diffraction (XRD), infrared (IR), photoelectron (XPS) and Raman spectroscopy and by surface area measurements. Details of the used methods are described in our previous reports[42–44].

The N_2O catalytic reaction was performed in a fixed-bed reactor (i.d. 5 mm) in the temperature range 300–450 °C with the total flow rate 50–330 ml min^{-1} NTP (273 K, 101.325 kPa), 0.1–0.33 g of catalyst and a space velocity of 30–60 l $h^{-1}g^{-1}$. Inlet concentration was varied according to the type of experiment in the following range: 0–0.1 mole % N_2O, 0–20 mole % O_2, 0–0.17 mole % NO_2, 0–0.17 mole % NO and 0–3 mole % H_2O balanced by helium. All the measurements were carried out at a steady state.

A gas chromatograph Agilent Technologies 6890 N with TCD detector was used to measure N_2O, O_2 and N_2 concentrations. The valve system made it possible to switch the columns Porapot Q 30 m × 0.53 mm × 40 μm for separation of N_2O and Molsieve 5A 30 m × 0.53 mm × 25 μm for separation of N_2 and O_2. NO and NO_2 were determined by an IR analyzer Ultramat 6 (Siemens) supplemented by a catalytic NO_2/NO converter (TESO). Water vapor was added via a saturator with a Nafion® (Perma Pure Inc.) membrane. The moisture content was controlled by measuring relative humidity and temperature (Thermo).

RESULTS AND DISCUSSION

Catalyst Characterization

Physico-chemical properties of the selected catalysts are summarized in Table I. In all cases, the LDH precursors were transformed into mixed oxides by calcination at 500 °C. Release of interlayer water, dehydroxylation of hydroxide layers and decomposition of interlayer carbonate resulted in evolution of a large amount of volatile components (H_2O and CO_2) and destruction of the layered LDH structure. The formation of oxide phases was confirmed by XRD and Raman spectroscopy. The FTIR spectroscopy revealed a slight amount of residual carbonate in some calcined samples.

Simple $M^{II}O$ oxides were found by XRD in the calcined M^{II}-Al samples (Ni_4Al_2 and Cu_4Al_2); no individual Al-containing crystalline phase was detected in these catalysts. A mixed oxide with spinel structure, which could be considered as a solid solution of Co_3O_4 and $CoAl_2O_4$ spinels, was identified in the powder XRD pattern of the Co_4Al_2 sample. Non-stoichiometric

TABLE I
Catalyst characterization

Catalyst	Crystalline phase (XRD)	S_{BET} m^2g^{-1}	M^{II}/M^{III} molar ratio[a]	
			Bulk (AAS)	Surface (XPS)
Mg_4Mn_2	Mg_6MnO_8	52	2.00	2.20
Mg_4Fe_2	MgO, Fe_3O_4/Fe_2O_3	98	2.00	n.d.[b]
Co_4Al_2	Co_3O_4, $CoAl_2O_4$	86	1.92	0.64
Co_4MnAl	Co_3O_4,Co-Al-Mn spinel	93	Co/Mn 4.12 Co/Al 3.85	Co/Mn 2.38 Co/Al 1.97
Co_4Mn_2	Co_3O_4,Co-Mn spinel	76	2.00	0.9–1.2
Co_4Fe_2	Co-Fe spinel	44	2.00	n.d.
Ni_4Al_2	NiO	188	1.96	2.06
Ni_4Mn_2	Ni_6MnO_8, $NiMnO_3$	72	1.92	n.d.
Ni_4Fe_2	Ni-Fe spinel	69	2.00	n.d.
Cu_4Al_2	CuO	47	2.08	0.70
Cu_4Mn_2	CuO, Cu-Mn spinel	48	2.02	n.d.

[a] M^{II} = Co, Ni, Cu, Mg; M^{III} = Al, Mn, Fe. [b] n.d., not determined.

oxides with spinel structure were found also in other samples containing cobalt[45]. Only spinel-type mixed oxides were found also in the Fe-containing samples (Ni_4Fe_2 and Co_4Fe_2); iron oxides Fe_3O_4 and/or Fe_2O_3 together with MgO were detected in the Mg_4Fe_2 sample. The Mn-containing catalysts exhibited very different phase compositions. As it was mentioned above, in the Co-containing samples (Co_4Mn_2 and Co_4MnAl) only spinel-type oxides were found. In the Cu_4Mn_2 sample, Cu-Mn spinel together with CuO was detected. Murdochite-like mixed oxides containing Mn^{IV}, Mg_6MnO_8 and Ni_6MnO_8 were identified in the Mg_4Mn_2 and Ni_4Mn_2 samples, respectively. In the Ni_4Mn_2 catalyst, the $NiMnO_3$ oxide with ilmenite structure was detected together with Ni_6MnO_8 [46]. A certain content of amorphous part was found together with crystalline phases in all examined catalysts.

A surface area ranging from 44 to 188 $m^2\ g^{-1}$ was measured with the examined catalysts, which can be explained by evolution of volatile components and formation of porous structure during calcination of LDH precursors. Surface composition of some catalysts determined by photoelectron spectroscopy was different from the bulk one. An enrichment of the catalyst surface in Al and/or Mn was observed. An exception to this trend was observed with Ni_4Al_2 sample, in which no difference between the surface and bulk composition was found.

Catalytic Decomposition of N_2O in Inert Gas

The temperature dependence of N_2O conversion in an inert gas was used in order to compare the catalytic activity of catalysts with different chemical composition (Fig. 1). Nitrous oxide decomposition over some catalysts (Ni_4Al_2, Co_4Al_2, Cu_4Al_2) has been already reported by other authors[47,48] and the obtained results were comparable with the published data. The other examined catalysts contained two transition metal cations or transition metal cations in combination with Mg^{2+}. These mixed oxides have not been tested in N_2O decomposition so far. A combination of two transition metals in Co_4Mn_2, Cu_4Mn_2 and Co_4Fe_2 catalysts enhanced the N_2O decomposition in comparison with analogous M^{II}-Al catalysts. On the other hand, a decrease in catalytic activity was observed with Ni_4Mn_2 and Ni_4Fe_2 samples. Out of the group of mixed oxide catalysts containing three-cation components[42–44], only the most active Co_4MnAl sample is mentioned in this study.

The XPS and TPR results published recently[44–46] indicate that optimization of physico-chemical properties of the mixed oxides can give catalysts

active in N_2O decomposition. As it implies from published mechanisms of N_2O decomposition, an optimum oxygen bond strength is supposedly a prerequisite for a very active N_2O decomposition catalyst[4]. The oxygen bond strength can be determined from TPR experiment as a shift of reduction peak maximum to lower temperatures. The H_2 consumption in the temperature range from 350 to 450 °C was chosen as the parameter of oxygen bond strength on the catalyst surface. The optimal value of H_2 consumption in the selected interval corresponding to the highest catalytic activity was found. It was also found that such catalysts contain an optimum amount of metal components in suitable oxidation state[44].

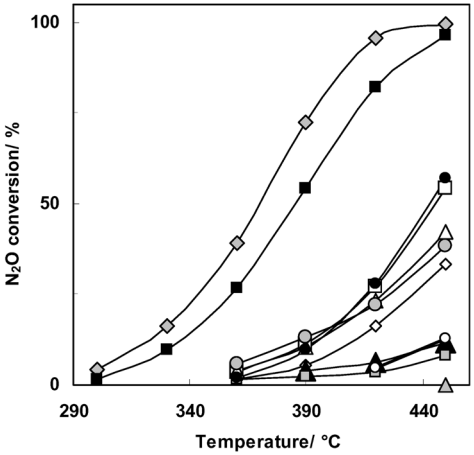

FIG. 1
Temperature dependence of N_2O conversion over Ni_4Al_2 (◆), Cu_4Al_2 (◇), Co_4MnAl (■), Co_4Mn_2 (□), Ni_4Mn_2 (■), Cu_4Mn_2 (▲), Co_4Al_2 (△), Mg_4Fe_2 (▲), Co_4Fe_2 (●), Ni_4Fe_2 (○) and Mg_4Mn_2 (●) catalysts. Conditions: 0.1 mole % N_2O, 0.1 g, 100 ml min^{-1}

Catalytic Decomposition of N_2O in Simulated Process Stream

The Ni_4Al_2 and Co_4MnAl catalysts, exhibiting the highest activity in the preliminary tests performed in an inert gas, were chosen for testing N_2O decomposition in the presence of other gaseous components, which could simulate a real off-gas in industrial plants. A mixture containing oxygen, water vapor, NO and NO_2 together with N_2O (~1000 ppm) was used as a model gas for catalyst testing; the chosen composition corresponded to the waste gas from nitric acid production plant.

The effect of O_2 and NO_2 addition on the N_2O conversion obtained over the Ni_4Al_2 and Co_4MnAl catalysts is shown in Figs 2 and 3. The N_2O conversion decreased with increasing amount of oxygen in the inlet: a sharp

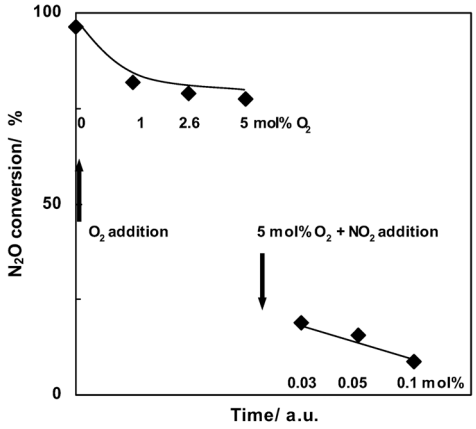

FIG. 2
Effect of O_2 and NO_2 addition on the N_2O conversion over Ni_4Al_2 at 450 °C. Conditions: 0.1 mole % N_2O, 0.2 g, 50 ml min^{-1}, 450 °C

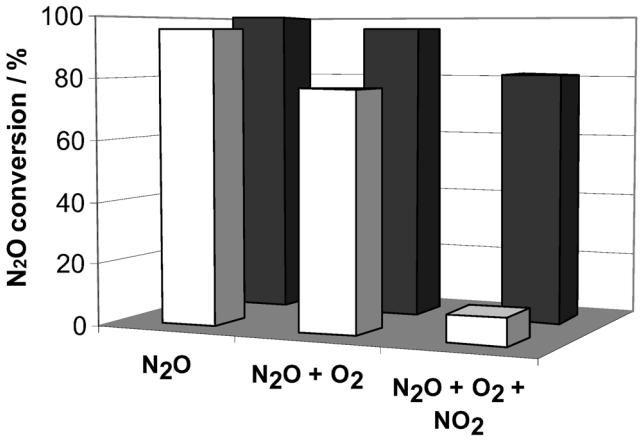

FIG. 3
Effect of O_2 and NO_2 addition on N_2O conversion at 450 °C over Co_4MnAl (■) and Ni_4Al_2 (□) catalysts. Conditions: 0.1 mole % N_2O, 5 mole % O_2, 0.1 mole % NO_2. Ni_4Al_2: 0.2 g, 50 ml min^{-1}; Co_4MnAl: 0.3 g, 100 ml min^{-1}

decrease was observed up to 2 mole % O_2 over the Ni_4Al_2 catalyst, while further addition of oxygen did not cause any other conversion decrease – the conversion remained nearly constant (Fig. 2). Comparison of N_2O conversion over the examined catalysts measured in the presence of 5 mole % O_2 is shown in Fig. 3. In spite of the different space velocity applied, it is evident that the Co_4MnAl catalysts exhibited a lower decrease in N_2O conversion in comparison with Ni_4Al_2.

The examined catalysts exhibited a different change in N_2O conversion after NO_2 addition. A considerable decrease in N_2O conversion was observed over the Ni_4Al_2 catalyst (see Fig. 2), the N_2O conversion being further decreased with increasing NO_2 concentration. The decrease in N_2O conversion can be likely caused by NO_2 competitive adsorption on the active sites. Over the Co_4MnAl catalyst, a much lower inhibition effect of NO_2 addition was found (see Fig. 3).

The effect of water vapor addition on the N_2O conversion was tested over the Ni_4Al_2, Co_4Al_2, Co_4MnAl and Co_4Mn_2 catalysts with the aim to elucidate the reversibility of the water vapor inhibition effect (Figs 4 and 5).

As the N_2O conversion was irreversibly decreased in the presence of water vapor over the Ni_4Al_2 catalyst, the attention was focused on the catalysts containing Co, Mn and Al [43,44]. Over all examined catalysts water vapor in

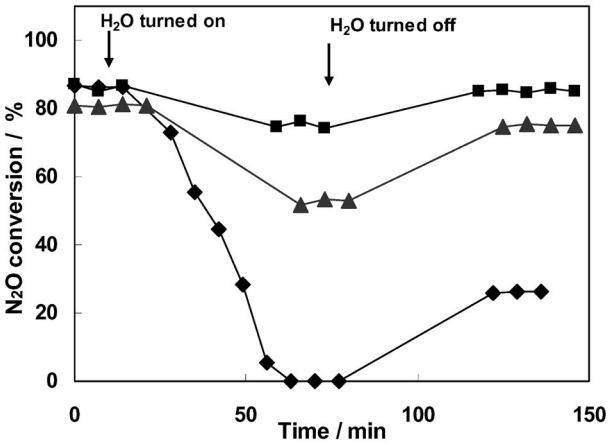

FIG. 4
Effect of water vapor addition on the N_2O conversion over Ni_4Al_2 (◆), Co_4Mn_2 (■) and Co_4Al_2 (▲) catalyst. Conditions: 0.1 mole % N_2O + 0.5 mole % H_2O, 0.3 g, 100 ml min^{-1}, 450 °C

the feed gas decreased the N_2O conversion (see Fig. 5), which further decreased with increasing concentration of water vapor (not shown here). However, a different drop in N_2O conversion was observed for individual catalysts. The highest N_2O conversion in the presence of water vapor was measured with the Co_4MnAl catalyst.

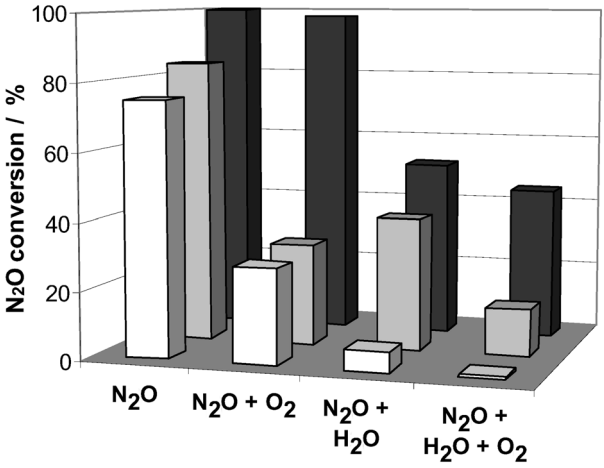

FIG. 5
Effect of water vapor and O_2 addition on the N_2O conversion over Co_4MnAl (■), Co_4Mn_2 (▒) and Co_4Al_2 (□) catalysts. Conditions: 0.1 mole % N_2O + 0.5 mole % H_2O, 0.3 g, 100 ml min^{-1}, 450 °C

The effect of NO addition on the N_2O catalytic decomposition over the Co_4MnAl catalyst is shown in Fig. 6. The presence of NO in the feed caused a slight decrease in N_2O conversion and the conversion drop increased with increasing amount of NO in the gas inlet. The simultaneous presence of NO and O_2 in the gas inlet resulted in a further very slight decrease in N_2O conversion, probably caused by formation of surface nitrates and nitrites and/or by consecutive reactions.

Stability of the Catalysts

Gradual deactivation of the Ni_4Al_2, Co_4Al_2, $Ni_2Mg_2Al_2$, Co_4Mn_2 and Co_4MnAl catalysts was observed during long-term stability tests (Figs 7 and 8), while a slight gradual increase in N_2O conversion was observed over the Mg_4Mn_2 catalyst during the testing period (see Fig. 7).

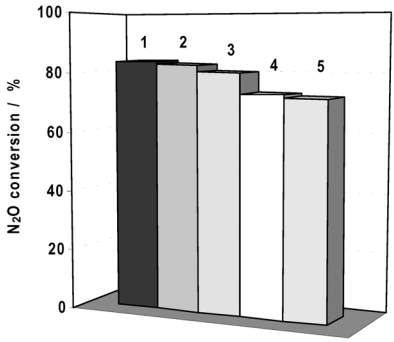

FIG. 6

Effect of NO and O_2 addition on the N_2O catalytic decomposition over the Co_4MnAl catalyst. Conditions: 1000 ppm N_2O, 0.33 g, 330 ml min^{-1}, 450 °C. Inlet mixture: N_2O (1), N_2O + 0.02 mole % NO (2), N_2O + 0.06 mole % NO (3), N_2O + 0.02 mole % NO + 4 mole % O_2 (4), N_2O + 0.06 mole % NO + 4 mole % O_2 (5)

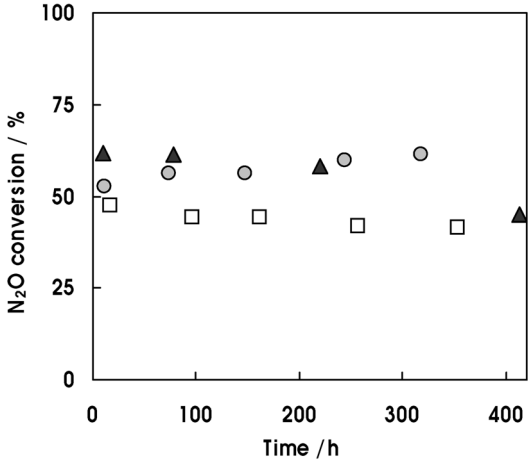

FIG. 7

Time dependence of N_2O conversion over Co_4Al_2 (□), Co_4Fe_2 (▲) and Mg_4Mn_2 (●) catalysts. Conditions: 0.1 mole % N_2O, 450 °C. Co_4Al_2: 0.1 g, 100 ml min^{-1}; Mg_4Mn_2: 0.2 g, 100 ml min^{-1}; Co_4Fe_2: 0.33 g, 330 ml min^{-1}

The most noticeable decrease in N_2O conversion was observed over the Co_4MnAl catalyst (see Fig. 8). The N_2O conversion decreased by 30 % during the first 300 h, but remained relatively constant in the course of the next 1200 h. The initial decrease in N_2O conversion can be likely caused by testing the catalyst under "the most aggressive" conditions – the sample was frequently cooled and heated and also exposed to various combinations of compounds such as O_2, CO, NO, CO_2 and NH_3.

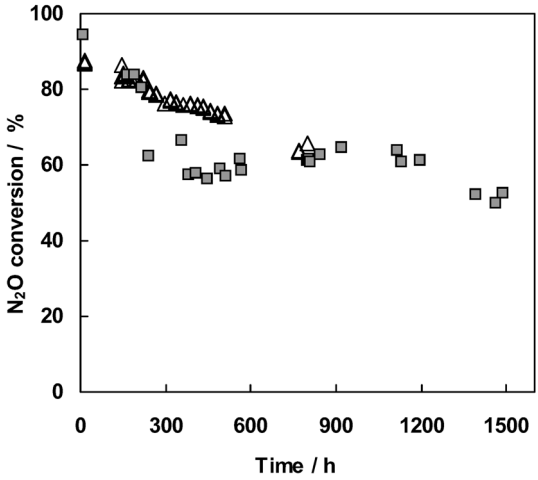

FIG. 8
Time dependence of N_2O conversion over Co_4Mn_2 (△) and Co_4MnAl (■) catalysts. Conditions: 0.1 mole % N_2O, 450 °C. Co_4MnAl: 0.33 g, 330 ml min^{-1}; Co_4Mn_2: 0.1 g, 100 ml min^{-1}

The changes in catalyst activity reflect changes in both porous structure and surface concentration of active species (Table II). The lower thermal stability could be explained also by only a slight difference between the temperature, at which long-term catalytic measurements were performed (450 °C), and the temperature used for preparation of catalysts (the LDH precursors were calcined at 500 °C).

Estimation of Parameters of Industrial Catalytic Unit for N_2O Emission Abatement

Based on the laboratory results obtained with the Co_4MnAl catalyst in simulated process stream conditions, dimensions of a catalytic unit for abate-

ment of N_2O emissions from the nitric acid plant were calculated. Suitable position for the catalytic unit is at such a place[49] where NH_3 is not present in the gas stream in order to exclude a non-selective oxidation of ammonia to N_2O, NO and NO_2.

TABLE II
Catalyst characterization of fresh catalysts and catalysts used in N_2O decomposition

Catalyst	S_{BET}, m^2g^{-1}		Surface composition, XPS	
	fresh	used	fresh	used
Mg_4Mn_2	52	36	$Mn_1Mg_{2.00}Na_{0.35}O_{5.06}$	$Mn_1Mg_{2.40}Na_{0.52}O_{4.47}$
Co_4Mn_2	76	62	$Mn_1Co_{0.9\text{-}1.2}O_{4.80}$	$Mn_1Co_{0.9\text{-}1.2}O_{4.90}$
Co_4MnAl	93	n.d.	$Mn_1Co_{2.57}Al_{1.35}O_{9.59}$	$Mn_1Co_{1.89}Al_{1.32}O_{7.93}$

The reactor is proposed as a fixed-bed reactor with an ideal plug flow. The influence of internal and external diffusion was described by the overall effectiveness factor. The influence of external heat transfer on the reaction rate was neglected; under the given conditions, the catalyst particle is assumed as isothermal. The isothermal regime of the reactor was considered because of a low N_2O concentration and consequently, a low amount of released heat.

Only a slight decrease of N_2O conversion was observed after the addition of NO_x (0.35 mole %) to the gas mixture containing 0.1 mole % N_2O, 5 mole % O_2 and 2 mole % H_2O in N_2O decomposition over Co_4MnAl catalyst. For that reason, the simulated process stream contained only 0.1 mole % N_2O, 5 mole % O_2 and 2 mole % H_2O balanced by N_2 was used for calculation. The first-order rate law was applied to the kinetics of N_2O decomposition at atmospheric pressure in this simulated stream over the cylinder extrudates (3 × 3 mm) from fresh Co_4MnAl [50]. The model of reactor consist of equations described below[51,52].

Material balance of component A (A = N_2O) in differential dimension dz of plug flow reactor operating in steady state:

$$\dot{n}_A^o \frac{dX_A}{dz} = -r_A A \rho_b \ . \qquad (2)$$

Kinetic equation for first-order rate law including the internal and external mass transfer limitations described by effectiveness factor Ω:

$$r = -r_A = \Omega\, 89859\, e^{\frac{-137181}{RT}} c_A . \qquad (3)$$

Concentration of component A using conversion X_A and neglecting the change of volumetric flow along the reactor:

$$c_A = c_{A0}(1 - X_A)\frac{p}{p_0} . \qquad (4)$$

TABLE III
Parameters of the model operating reactor unit

Input parameter	Value	Calculated parameter	Value[a]
Inlet pressure	130 000 Pa	Bed height	2.8 m
Inlet temperature	450 °C	Catalyst bed volume	35 m^3
Flow rate	30 000 $m^3\ h^{-1}$ (NTP)	Catalyst weight	28 t
Reactor diameter	4 m	Pressure drop	2.7×10^4 Pa
Specific surface area of catalyst	93 $m^2\ g^{-1}$	Effective diffusion of N_2O	$1.77 \times 10^{-7}\ m^2\ s^{-1}$
Catalyst bed density	1290 kg m^{-3}	Mass transfer coefficient	0.03 m s^{-1}
Equivalent particle diameter (cylinder 3 × 3 mm)	0.0037 m	Internal effectiveness factor	0.15
Pore diameter, (average)	9×10^{-9} m	Overall effectiveness factor	0.14
Catalyst bed porosity	0.38		
Rate constant (1st rate)	$1.102 \times 10^{-5}\ m^3\ s^{-1}\ g^{-1}$		
Density of waste gas at the inlet	0.512 kg m^{-3}		
Dynamic viscosity of waste gas	0.295×10^{-4} Pa s		

[a] Calculated for 90% N_2O conversion.

Pressure lost in the fixed bed:

$$\frac{\mathrm{d}p}{\mathrm{d}z} = \frac{2c_{\mathrm{D}}\rho v^2}{\mathrm{d}p} \,. \tag{5}$$

Where c_{D} is resistance coefficient according to Ergun equation:

$$c_{\mathrm{D}} = \frac{1-\varepsilon}{\varepsilon}\left[\frac{150(1-\varepsilon)}{Re} + 1.75\right]. \tag{6}$$

Inlet and calculated parameters of the operating reactor unit are given in Table III.

The estimated volume of the catalytic bed necessary for 90% N_2O conversion is quite high. Thus, further research will be focused on an increase in catalyst activity, especially in the presence of water vapor as well as on experimental ascertainment of the pressure effect on the kinetics of N_2O decomposition. The reaction is hindered by internal diffusion in catalyst pores, as it is evident from the value of the internal effectiveness factor. That is why attention will be also focused on optimization of the size and shape of catalyst particles with the aim to decrease the effect of internal mass transport at acceptable pressure drop.

LIST OF SYMBOLS

A	cross-section of reactor, m^2
c_{A}	concentration of compound A, mol m^{-3}
c_{A0}	inlet concentration of compound A, mol m^{-3}
c_{D}	resistance coefficient
$\dot{n}_{\mathrm{A}}^{\mathrm{o}}$	inlet molar flow of compound A, mol s^{-1}
p	total pressure, Pa
p_0	inlet total pressure, Pa
R	universal gas constant, J mol^{-1} K^{-1}
r	reaction rate, mol s^{-1} g^{-1}
$-r_{\mathrm{A}}$	rate of increment of compound A, mol s^{-1} g^{-1}
Re	Reynolds number
T	thermodynamic temperature, K
X_{A}	conversion of compound A
ε	porosity of the catalyst bed
ρ	gas density, kg m^{-3}
ρ_{b}	density of the catalyst bed, kg m^{-3}
Ω	overall effectiveness factor
ν	kinematic viscosity, m^2 s^{-1}

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