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NITROGEN OXIDES REMOVAL BY SCR PROCESS –
STATE OF THE ART

INTRODUCTION

Air pollution is one of the most important environmental concerns. Due to the increasing awareness in global environmental protection, the government and consumer demands for cleaner emissions and lower fuel consumption grow worldwide. The major primary source of air pollution is combustion of fossil fuels used in power plants, vehicles and other incineration processes. Basic air contaminants are sulfur oxides (especially SO$_2$), particulate matter, carbon monoxide (CO), unburned hydrocarbons (HC) and nitrogen oxides (NO$_x$). Among them NO$_x$ are considered as the primary pollutants of the atmosphere$^1$.

Various technologies can be applied for the NO$_x$ emissions abatement. NO$_x$ storage/reduction (NSR) process is a promising technology for the elimination of NO$_x$ from diesel exhausts. This technology is based in the sequential lean-rich changes of the diesel engines, i.e. when the engine is operating in an oxygen excess (lean conditions) NO$_x$ is stored on the NSR catalysts in the form of surface nitrates, and then after changing from lean to rich conditions (excess of fuel) the nitrates are catalytically reduced and/or decomposed to N$_2$. Another alternative is the use of the three way catalysts for the removal of NO$_x$, CO and unburned hydrocarbons in spark-ignition engine exhausts; however, it cannot be applied for diesel engines. One promising technology for the elimination of NO$_x$ used in electric power stations is a process that is based on the selective catalytic

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reduction of NO\textsubscript{x} with ammonia (NH\textsubscript{3}-SCR). Recently, this commercial method, in a modified version, was also applied for the elimination of NO\textsubscript{x} from diesel exhausts\textsuperscript{2}.

The aim of this paper is to review the sources of the formation of nitrogen oxides and its influence on the environment and human life as well as different catalytic technologies used for removal of NO. The main point in this short review will be the discussion of SCR technology used for the reduction of NO by utilizing ammonia. The catalysts for this process, including commercial catalysts based on titania, are discussed. Another goal of this review is to present the mixed metal oxides derived from hydrotalcite-like materials as potential catalyst-applicants for the NH\textsubscript{3}-SCR process in vehicles. In addition, general conclusions and some research directions are given.

**NITROGEN OXIDES POLLUTION PROBLEM**

Numerous types of nitrogen oxides, such as N\textsubscript{2}O, NO, NO\textsubscript{2}, N\textsubscript{2}O\textsubscript{3}, N\textsubscript{2}O\textsubscript{4}, NO\textsubscript{3}, and N\textsubscript{2}O\textsubscript{5} exist in the environment. The abbreviation NO\textsubscript{x} refers to the cumulative emissions, mainly of nitric oxide (NO) and nitrogen dioxide (NO\textsubscript{2})\textsuperscript{3}. NO\textsubscript{x} emitted in incineration processes typically consist of a mixture of 95% of NO and 5% of NO\textsubscript{2} due to the thermodynamics of the combustion process\textsuperscript{4}. NO\textsubscript{x} are one of the primary pollutants formed during the combustion of fossil fuels and biomasses in three basic, interdependent processes of the NO\textsubscript{x} formation\textsuperscript{5}:

(i) thermal NO\textsubscript{x} (the Zeldovich mechanism) – direct reaction between air N\textsubscript{2} and O\textsubscript{2} at high (flame) temperature, (ii) fuel NO\textsubscript{x} – oxidation of N-containing compounds present in fuel or biomass, and (iii) prompt NO\textsubscript{x} – formation of volatile-N (an intermediate gaseous compound) species via the reaction of N\textsubscript{2} and hydrocarbon radicals in the rich zone of the flame as a primary process, followed by oxidation of HCN to NO, or reduced back to N\textsubscript{2}.

The contribution of thermal NO\textsubscript{x} increases with increasing the flame temperature and in the aftermath at high temperatures, thermal NO\textsubscript{x} usually represents

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\textsuperscript{3} K. Skalska, J. S. Miller, S. Ledakowicz, op. cit., s. 3976–3989.


most of the total NO\textsubscript{x} formed. The formation of fuel NO\textsubscript{x} is independent of the combustion temperature and depends on the nature of N-containing compounds. The formation of prompt NO\textsubscript{x} has a slight temperature dependence and a short lifetime, and in principle it is only significant in very fuel-rich flames. Accordingly, at high temperatures, thermal NO\textsubscript{x} usually represents most of the total NO\textsubscript{x} formed\textsuperscript{6}.

NO\textsubscript{x} are blamed for the formation of acid rain, photochemical smog\textsuperscript{7}, tropospheric ozone, ozone layer depletion\textsuperscript{8}, as well as global warming caused by N\textsubscript{2}O\textsuperscript{9}. Further, NO\textsubscript{x} cause many health problems in humans exposed to high concentrations of these gases (e.g. lowering the body’s resistance to bacterial infections, eye and respiratory system irritation, problems with breathing, and allergic diseases\textsuperscript{10}). Their negative impact both on the environment and on human health led to the legislations that limit NO\textsubscript{x} emissions from stationary and mobile sources. Limits on emission in most countries have been established by setting standards of NO\textsubscript{x} concentration emitted in flue gas, in ppm related to 3\% O\textsubscript{2} (reference oxygen concentration on dry basis).

Until now, to control NO\textsubscript{x} emission several technologies – such as the above-mentioned catalytic reduction of NO in the presence of CO, H\textsubscript{2} or hydrocarbons as well as decomposition of NO – have been developed to meet the standards\textsuperscript{11}. In this work, some technologies for the selective catalytic reduction of NO with ammonia are reviewed.

**SELECTIVE CATALYTIC REDUCTION OF NO\textsubscript{x} WITH AMMONIA**

Among flue gas treatment methods, the selective catalytic reduction (SCR) of NO\textsubscript{x} by ammonia is a well-developed and widespread technology for removing NO\textsubscript{x} at moderate temperatures (250-500\degree C) due to its efficiency, selectivity and economics\textsuperscript{12}. Generally, the NH\textsubscript{3}-SCR process is based on the reaction between

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\textsuperscript{6} S. Matsumoto, Y. Ikeda, H. Suzuki, M. Ogai, N. Miyoshi, op. cit., s. 115–124.
\textsuperscript{11} X. Tang, S. Madronich, T. Wallington, D. Calamari, op. cit., s. 83–95.
\textsuperscript{12} F. Nakahjima, I. Hamada, *The state-of-the-art technology of NO\textsubscript{x} control*, „Catalysis Today” 1996, nr 29 (1–4), s. 109–115.
NO\textsubscript{x} (including NO, NO\textsubscript{2}) and ammonia (NH\textsubscript{3}) or urea (CO(NH\textsubscript{2})\textsubscript{2}), injected into the flue gas stream, to produce N\textsubscript{2} and H\textsubscript{2}O\textsuperscript{13}.

Selective noncatalytic reduction (SNCR) has also been applied to control the emission of nitrogen oxides. NO\textsubscript{x} is selectively reduced in the gas phase by ammonia (or urea, cyanuric acid), which is introduced into the upper part of the boiler\textsuperscript{14}. NO\textsubscript{x} can be reduced into N\textsubscript{2} and H\textsubscript{2}O rapidly and effectively at rather high temperatures (800-1100ºC)\textsuperscript{15}, which is the major drawback of the SNCR process. In comparison, in the presence of catalysts, the temperature of the reaction depends on the catalysts nature and can be below 250ºC for the most active catalysts\textsuperscript{16}.

The SCR process is based on the reduction of NO\textsubscript{x} (NO, NO\textsubscript{2}) with ammonia into N\textsubscript{2} and H\textsubscript{2}O according to the following main reactions (equations 1-3)\textsuperscript{17}:

\begin{align*}
4\text{NO} + 4\text{NH}_3 + \text{O}_2 &\rightarrow 4\text{N}_2 + 6\text{H}_2\text{O} \quad \text{standard SCR} \\
\text{NO} + \text{NO}_2 + 2\text{NH}_3 &\rightarrow 2\text{N}_2 + 3\text{H}_2\text{O} \quad \text{fast SCR} \\
6\text{NO}_2 + 8\text{NH}_3 &\rightarrow 7\text{N}_2 + 12\text{H}_2\text{O} \quad \text{NO}_2\text{-SCR}
\end{align*}

The standard SCR reaction (equation 1) is the most desirable and it proceeds rapidly at temperatures between 250 and 450ºC in excess of oxygen\textsuperscript{18}. The fast SCR process (equation 2) was reported to be much faster than standard SCR and can be used in the lower temperature range (180-300ºC)\textsuperscript{19}. Both fast SCR and NO\textsubscript{2}-SCR (equations 2-3) play less significant role in technologies of NO\textsubscript{x} cont-
version, since NO₂ accounts only for 5% of the total NOₓ in the engine exhaust²⁰.

Numerous undesirable oxidation reactions, which can take place alongside the desired ones in the presence of NH₃-SCR catalysts, can also lead to the emission of unwanted products and a decrease in NOₓ conversion²¹. For example, ammonia oxidation reactions (equations 4-6) are undesirable because they imply the consumption of NH₃, thus limiting the NOₓ conversion and partially leading to the formation of NO and N₂O as by-products²²:

\[
\begin{align*}
4\text{NH}_3 + 3\text{O}_2 & \rightarrow 2\text{N}_2 + 6\text{H}_2\text{O} \quad (4) \\
4\text{NH}_3 + 5\text{O}_2 & \rightarrow 4\text{NO} + 6\text{H}_2\text{O} \quad (5) \\
2\text{NH}_3 + 2\text{O}_2 & \rightarrow \text{N}_2\text{O} + 3\text{H}_2\text{O} \quad (6) \\
2\text{SO}_2 + \text{O}_2 & \rightarrow 2\text{SO}_3 \quad (7)
\end{align*}
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In the presence of NOₓ, these reactions (equations 4-6) become negligible due to the ability of the catalysts and the reducing agent (ammonia) to favor reduction of nitrogen oxides (equation 1)²³.

In case of sulfur-containing fossil fuels (e.g. coal, oil), SOₓ (SO₂ with a minor percentages of SO₃) is generated during combustion in boilers. Further oxidation of SO₂, which takes place over the catalysts (equation 7), is highly undesirable. SO₃ is known to react with water and unreacted ammonia (NH₃ slip) present in flue gas to form sulfuric acid and ammonium sulfates according to the following reactions (equations 8–12)²⁴:

\[
\begin{align*}
\text{SO}_3 + \text{H}_2\text{O} & \rightarrow \text{H}_2\text{SO}_4 \quad (8) \\
\text{NH}_3 + \text{SO}_3 + \text{H}_2\text{O} & \rightarrow \text{NH}_4\text{HSO}_4 \quad (9) \\
2\text{NH}_3 + \text{SO}_3 + \text{H}_2\text{O} & \rightarrow (\text{NH}_4)_2\text{SO}_4 \quad (10) \\
2\text{NH}_4\text{HSO}_4 & \rightarrow (\text{NH}_4)_2\text{SO}_4 + \text{H}_2\text{SO}_4 \quad (11) \\
\text{NH}_4\text{HSO}_4 + \text{NH}_3 & \rightarrow (\text{NH}_4)_2\text{SO}_4 \quad (12)
\end{align*}
\]

Ammonium sulphates are deposited and accumulated on the catalyst surface, especially if it is working at a low temperature (<300ºC), and therefore lead to its deactivation. The deposition of ammonium sulphates on the catalyst’s surface

²³ Ibidem.
can be inhibited upon heating. Apart from the sulfuric acid and ammonium sulfates formation, two additional unselective reactions may occur, namely the formation of ammonium nitrate and N₂O²⁵. The ammonium nitrate prevails at temperatures below 200ºC, and – similarly to ammonium sulfates – leads to reversible catalyst deactivation²⁶. Decomposition of NH₄NO₃ leads to NH₃ and HNO₃²⁷.

SELECTIVE CATALYTIC REDUCTION SYSTEM

The catalytic converter is the most important part of SCR system, and its location – together with a system used for ammonia injection – are the critical design parameters²⁸. Ammonia is injected into the flue gas stream through a distribution grid. The source of ammonia is usually 32.5 wt.% urea solution (also referred to as AdBlue)²⁹. The SCR systems are designed to produce gaseous mixture of ammonia and carbon dioxide by the hydrolysis reaction of the urea solution (equation 15)³⁰:

$$\text{NH}_2\text{CONH}_2 + \text{H}_2\text{O} \rightarrow 2\text{NH}_3 + \text{CO}_2$$

(15)

The hydrolysis reaction is endothermic, and thus requires heat input (it proceeds rapidly at temperature above 130ºC³¹, temperature flash vaporization³² or

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²⁵ Ibidem.
²⁶ Ibidem.
catalysts\textsuperscript{33}. The primary issue is the safety of transportation, storage, and handling of the required bulk reagent.

The required injection molar ratio of ammonia to NO, according to stoichiometry, is 1 (equation 1), although it is generally kept below 1 to avoid ammonia slip at very low values under less than 5 ppm\textsuperscript{34}. Besides the NH\textsubscript{3} slip control system, the installation should be equipped with: (i) an effective SCR catalyst, (ii) advanced process control instrumentation, (iii) optimal operating conditions (reaction temperature and the NH\textsubscript{3}/NO feed ratio), and (iv) NH\textsubscript{3} distributor. For the scheme of the commercial SCR process, the reaction kinetics forecasting NH\textsubscript{3} slip must be involved in the model of SCR reactor\textsuperscript{35}.

The SCR reactor operating in thermal power plants can be placed according to four different configurations: (i) immediately behind the boiler (high dust arrangement, HD), (ii) upstream of the air preheater unit (low dust arrangement, LD), and (iii) behind the sulfur dioxide removal by a flue gas desulfurization unit (tail end arrangement, TE). More information about the SCR location configuration is available in paper of Forzatti\textsuperscript{36} and Heck\textsuperscript{37}.

\textbf{NITROGEN OXIDE REDUCTION CATALYSTS}

Different types of catalytic materials have been considered for use in the selective catalytic reduction of NO with ammonia reaction stationary applications. These catalysts can be divided into three main groups: (i) noble metals, (ii) metal oxides, and (iii) transition metal–modified zeolites. Among these categories, metal oxides based catalysts are the most widely utilized SCR systems nowadays.

Supported noble-metal (mainly Pt, Rh, Pd) catalysts are very active in the SCR reaction in the low temperature region (170–300\degree C)\textsuperscript{38}. Unfortunately, they

\textsuperscript{33} M. Casapu, A. Bernhard, D. Peitz, M. Mehring, M. Elsener, O. Kröcher, \textit{A niobia-ceria based multi-purpose catalyst for selective catalytic reduction of NO\textsubscript{x}, urea hydrolysis and soot oxidation in diesel exhaust}, „Applied Catalysis B” 2011, nr 103 (1–2), s. 79–84.

\textsuperscript{34} J. B. Lefers, P. Lodders, G. D. Gerd, \textit{Modeling of selective catalytic DeNO\textsubscript{x} reactors – strategy for replacing deactivated catalyst elements}, „Chemical Engineering & Technology” 1991, nr 14 (3), s. 192–200.


\textsuperscript{36} P. Forzatti, I. Nova, E. Tronconi, op. cit., s. 8516–8518.

\textsuperscript{37} R. M. Heck, op. cit., s. 519–523.

also effectively oxidize both NH₃ and SO₂° and are not sulfur tolerant°. For these reasons, and also because of the high cost of this type of materials, noble metal-based catalysts were soon replaced by the second group of catalysts, consisting of transition metal oxides.

Single- and multi-metal oxide catalysts, based on Co, Cr, Cu, Fe, Mn, V, and other oxides, either unsupported or supported on Al₂O₃, SiO₂, TiO₂, ZrO₂, and carbon materials, were investigated as potential candidates for NO₃ reduction by ammonia. Among the various studied oxide compositions, V₂O₅ supported on TiO₂ (in the form of anatase) and additionally promoted with WO₃ or MoO₃ showed superior catalytic properties in the selective NO reduction with ammonia. These catalysts operate at temperatures significantly higher than noble metals (260-425°C) and additionally present high sulfur tolerance.

Zeolites (e.g. ZSM-5, faujasite – both of X and Y types, mordenite, beta) modified with transition metal ions such as Co, Cu, Fe, Mn, Ce, Ni are another group of materials intensively tested as potential catalysts for stationary SCR applications, mainly in gas-fired cogeneration plants. The studies of zeolite materials as catalysts for the SCR process have resulted in very high NOx conversion, selectivity towards the desired products (N₂ and H₂O) even at temperatures as high as 600°C and sulfur tolerance.

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40 R. M. Heck, op. cit., s. 519–523
42 J. Li, H. Chang, L. Ma, J. Hao, R. T. Yang, Low-temperature selective catalytic reduction of NO, with NH₃ over metal oxide and zeolite catalysts – A review, „Catalysis Today” 2011, nr 175 (1), s. 147–156.
43 R. M. Heck, op. cit., s. 519–523.
More detail and comprehensive review of SCR catalysts was given by Bosch and Janssen 46 (and references herein), Janssen and Meijer 47, Brandenberger et al. 48, and Li et al. 49

COMMERCIAL METAL OXIDE SCR CATALYSTS

The widely used commercial catalysts for the SCR process in power plants are based on V₂O₅-WO₃/TiO₂ and V₂O₅-MoO₃/TiO₂ oxide systems. Titania in form of anatase is used as high surface area carrier to support the active components (vanadium pentoxide, tungsten trioxide or molybdenum trioxide) 50. Anatase shows activating properties in the supported V₂O₅, which makes for a very active catalyst, more active than those obtained with other supports. This type of support is only weakly and reversibly sulfated under conditions of SCR reaction, and this sulfation even enhances the SCR catalytic activity 51. V₂O₅ is an active phase and is responsible for high activity and selectivity to N₂ 52 and for undesired oxidation of SO₂ to SO₃ in case of sulfur-containing fuels. The content of vanadium oxide is usually below 1 wt.% in high sulfur applications. WO₃ or MoO₃ are introduced into the V₂O₅/TiO₂ catalyst structure in larger amounts (ca. 10 and 6 wt.%, respectively) 53. It is proposed that WO₃ is added to improve stability of the catalysts. The V₂O₅-MoO₃/TiO₂ catalyst was found to be more resistant to thermal deactivation and poisoning by metal oxides (e.g. As₂O₃) in comparison to V₂O₅/TiO₂. Additionally, the V₂O₅-MoO₃/TiO₂ catalyst is less

47 F. Janssen, R. Meijer, Quality control of DeNOₓ catalysts: Performance testing, surface analysis and characterization of DeNOₓ catalysts, „Catalysis Today” 1993, nr 16 (2), s. 157–185.
49 J. Li, H. Chang, L. Ma, J. Hao, R. T. Yang, op. cit., s. 147–156
50 S. Brandenberger, O. Kroecher, A. Tissler, R. Althoff, op. cit., s. 492–531.
52 M. Takagi, T. Kawai, M. Soma, T. Onishi, K. Tamaru, The mechanism of the reaction between NOₓ and NH₃ on V₂O₅ in the presence of oxygen, „Journal of Catalysis” 1977, nr 50 (3), s. 441–446.
active in undesired oxidation of NH$_3$ and SO$_2$. The introduction of MoO$_3$ prevents the catalyst’s deactivation in the presence of As-containing compounds in flue gases, even as the mechanics of the process is not fully understood. Finally, other inert compounds (e.g. aluminosilicates, fiberglass) are used in commercial catalysts as additives to improve its mechanical resistance.

The NO conversion obtained over the V$_2$O$_5$-TiO$_2$ commercial catalysts depends on the vanadium pentoxide loading: e.g. for high V$_2$O$_5$ loading, the temperatures about 327ºC is needed for total removal of NO. At higher temperatures, the NO conversion slowly decreases due to the side process of ammonia oxidation.

The SCR catalyst forms are represented mainly by honeycomb monoliths, plates and coated metal monoliths. These catalyst forms are preferred because of: (i) lower pressure drop, (ii) higher geometric surface areas, (iii) abrasion resistance, and (iv) lower tendency to fly ash plugging. Many studies are focused on design and modeling of the honeycomb-type monolith reactor for the SCR process.

If we consider the applications of the SCR technology to vehicles, there is a clear trend in the automobile industry to replace V-based SCR catalysts with zeolite or other catalytic materials, mainly due to narrow operating temperature range.

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window of the V$_2$O$_5$/TiO$_2$ catalysts$^{60}$, anatase to rutile phase transformation under reaction conditions$^{61}$, and vanadium pentoxide toxicity$^{62}$.

**LAYERED DOUBLE HYDROXIDES AS SCR CATALYSTS**

One group of the potential catalysts for SCR application in vehicles suggested by research is the layered double hydroxides (LDHs) referred also as hydrotalcite-like materials (HTs). They are either natural or synthetic minerals described with the general formula [M$^{II}_{1-x}$M$^{III}_x$(OH)$_2$]$^{n-x/n}$·zH$_2$O, where M$^{II}$ is a divalent cation (e.g. Mg$^{2+}$, Ni$^{2+}$, Zn$^{2+}$ etc.), M$^{III}$ is a trivalent cation (e.g. Al$^{3+}$, Fe$^{3+}$, Cr$^{3+}$ etc.), A$^{n-}$ can be organic or inorganic anion (e.g. CO$_3^{2-}$, Cr$_2$O$_7^{2-}$, Mo$_7$O$_{24}^{6-}$ etc.), x can generally have values between 0.2 < x < 0.4 and z is normally 4-5. Hydrotalcite-like compounds are very interesting materials due to highly developed surface area (>200 m$^2$/g), homogeneous dispersion of components, and high thermal stability$^{63}$. Different composition of mixed metal oxides obtained from hydrotalcite-like material such as Mg-Cu-Al$^{64}$, Mg-Co-Al, Mg-Cu-Co-Al$^{65}$, Mg-Cu-Fe$^{66}$ have been studied. Among them, the highest catalytic activity in the SCR process was observed for the series of Mg-Cu-Al mixed oxides.

In order to improve the catalytic activity and selectivity of the Cu-containing materials (Mg/Cu/Al=66/5/29), further modifications of the catalysts composition with small amounts of: (i) noble metals (0.2 wt.% of Pd, Rh, Pt), and (ii) alkaline metal (2 wt.% of K) were carried out. According to research data

$^{60}$ R. M. Heck, op. cit., s. 519–523.
$^{62}$ F. Liu, H. He, Ch. Zhang, Novel iron titanate catalyst for the selective catalytic reduction of NO with NH$_3$ in the medium temperature range, „Chemical Communications” 2008, nr 17, s. 2043–2045.
$^{65}$ Ibidem.
$^{66}$ L. Chmielarz, A. Węgrzyn, M. Wojciechowska, S. Witkowski, M. Michalik, Selective catalytic oxidation (SCO) of ammonia to nitrogen over hydrotalcite originated Mg-Cu-Fe mixed metal oxides, „Catalysis Letters” 2011, nr 141 (9), s. 1345–1354.
such selected metals are the most often used to increase activity and selectivity of the catalysts in the SCR process. The influence of the composition modifications on the catalytic activity and selectivity to N₂ over prepared catalysts has been examined. Examples of the catalytic results are presented in Fig. 1. More results of the catalytic studies of the SCR process for a series of the Cu-containing samples doped with noble metals were presented in a paper given by Chmielarz et al.\textsuperscript{67} The deposition of noble metals enhanced the activity of the catalysts in the low temperature range; however, such modification of the Mg-Cu-Al oxide system decreased selectivity to N₂. On the contrary, the deposition of potassium promoter decreased both activity and selectivity of the Mg-Cu-Al oxide catalysts, which could be related to the changes in the redox properties of copper oxide species\textsuperscript{68}. At higher temperatures for all the catalysts, the NO conversion decreased due to the side process of ammonia oxidation.

Fig. 1. Selective catalytic reduction of NO with ammonia performed for Mg-Cu-Al oxides and its modifications with Pd/K. Conditions: mass of catalysts = 100 mg, [NH₃] = [NO] = 0.25%, [O₂] = 2.5%, [He] = 97%, total flow rate = 40 cm³/min, linear heating of 10°C/min.


The results revealed that Mg-Cu-Al oxides derived from hydrotalcite-like material could be considered as potential SCR catalysts in the vehicle application. Further studies and longer tests in the presence of typical exhaust gases (H₂O, CO₂, SO₂) are still required. The reaction mechanism over this type of catalysts should be determined to specify the role of the individual components in the process and to identify the key properties of the catalytic systems that determine their activity. Moreover, the comparison with the vanadium-containing reference catalyst should be carried out.

SUMMARY AND CONCLUDING REMARKS

Nowadays, NOₓ reduction has become one of the major issues in environmental protection. Looking for an active and selective catalyst is one of the challenges. Up to now, tungsten and molybdenum promoted V₂O₅/TiO₂ catalysts exhibit the best performance in the NOₓ reduction process, and these catalysts have already been industrialized. For the vehicle applications there is a trend for considering other catalysts due to some drawbacks of titania-supported catalysts. Application of Cu-containing mixed metal oxides obtained from hydrotalcite-like materials as catalysts for this process could be a potential solution; however, further research in real operating conditions is needed.

USUWANIE TLENKÓW AZOTU METODĄ SCR – PRACA PRZEGLĄDOWA

W pracy omówiono źródła powstawania tlenków azotu, wpływ NOₓ na środowisko i życie człowieka, jak również katalityczne reakcje ich usuwania. W szczególności omówiono technologię procesu selektywnej katalitycznej redukcji NO amoniakiem (proces NH₃-SCR), w tym stosowane w procesie komercyjne katalizatory oparte na tlenu tytanu oraz mieszane tlenki pochodzenia hydrotalkitowego. Uzyskane wyniki jednoznacznie wskazują na duży potencjał materiałów hydrotalkitowych jako katalizatorów technologii SCR.

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