De la Découverte d’une Méthode de Caractérisation des Oxydes Divisés à des Correlations Structure-Activité en Catalyse Environnementale pour la Réduction des NO_x par le Propène

Cyril THOMAS

Laboratoire de Réactivité de Surface,
Sorbonne Université, UMR CNRS 7197,
Paris, France

Environmental context of NO_x atmospheric pollutants

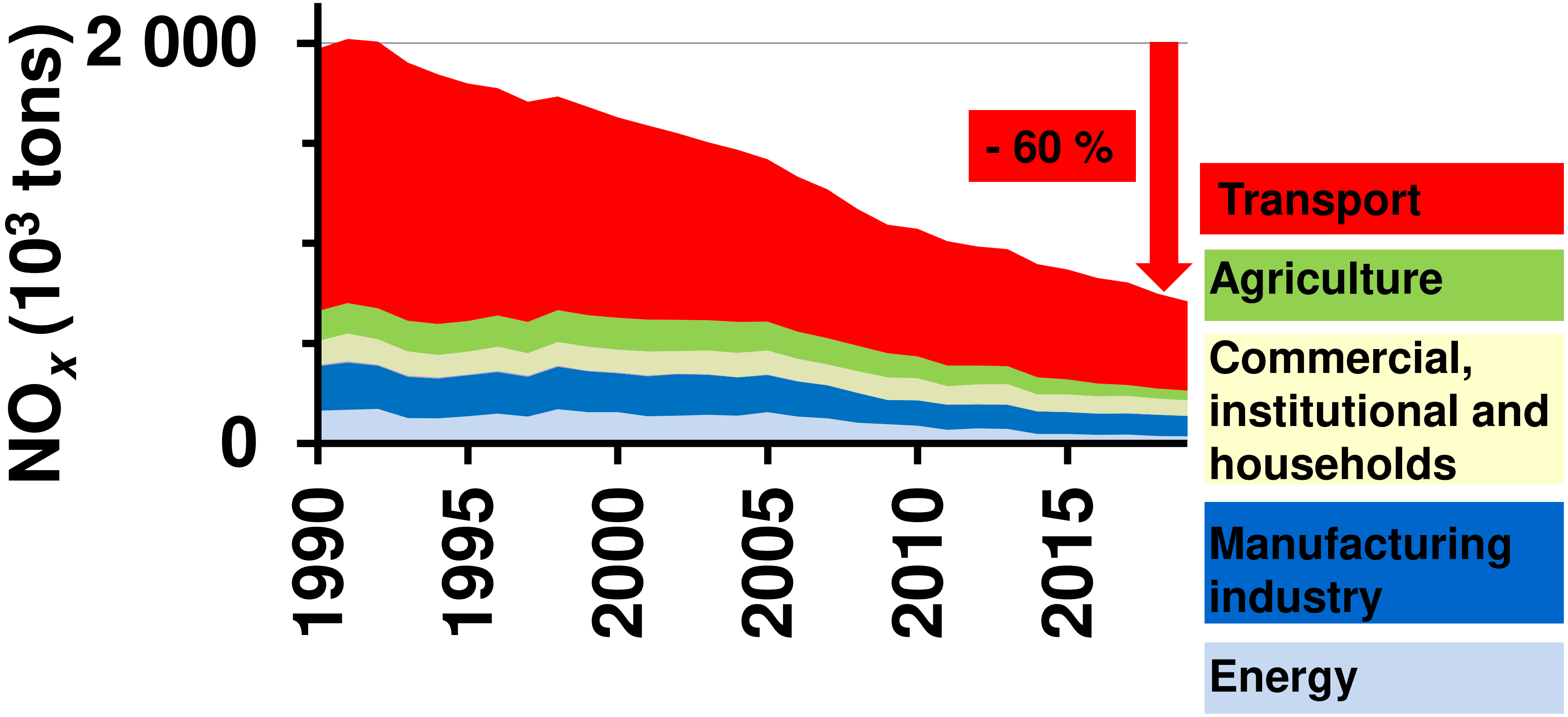
NO_x ($NO + NO_2$) contributes to acid deposition and eutrophication of soil and water. The subsequent impacts of acid deposition can be significant, including adverse effects on aquatic ecosystems in rivers and lakes and damage to forests, crops and other vegetation. Eutrophication can lead to severe reductions in water quality with subsequent impacts including decreased biodiversity, changes in species composition and dominance, and toxicity effects.

NO_2 is associated with adverse effects on human health, as at high concentrations it can cause inflammation of the airways and reduced lung function, increasing susceptibility to respiratory infection. It also contributes to the formation of secondary particulate aerosols and tropospheric ozone in the atmosphere, both of which are important air pollutants due to their adverse impacts on human health and other climate effects.

European Environment Agency (EEA):
https://www.eea.europa.eu/data-and-maps/indicators/eea-32-nitrogen-oxides-nox-emissions-1/assessment.2010-08-19.0140149032-3

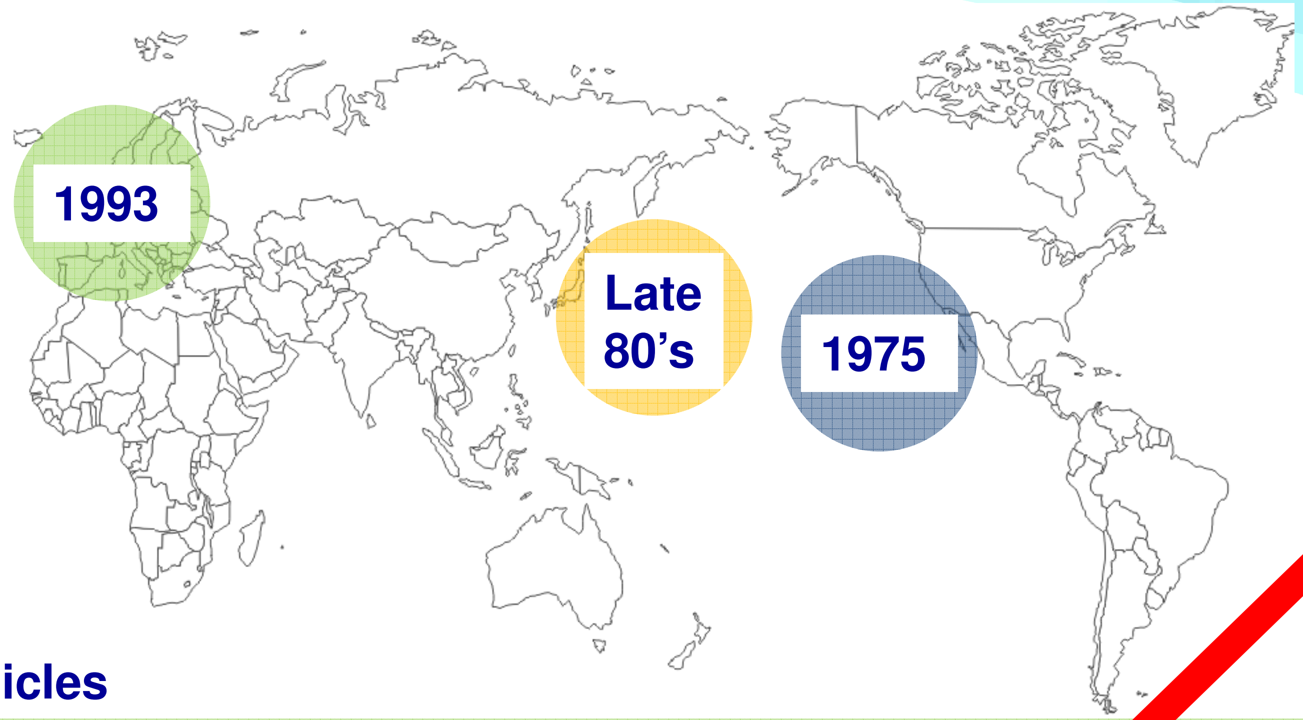
Origins of the NO_x emissions in France

NO_x are essentially produced at high temperatures in the combustion processes (engines, burners) due to the recombination of O_2 and N_2 from air.



Citepa:
https://www.citepa.org/fr/secten/#download-secten

Light-duty emission regulations: catalytic converters



VW Dieselgate

Diesel Vehicles

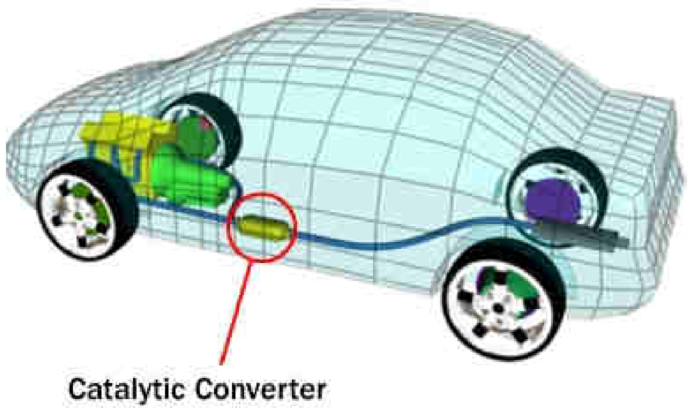
mg/km (NEDC)

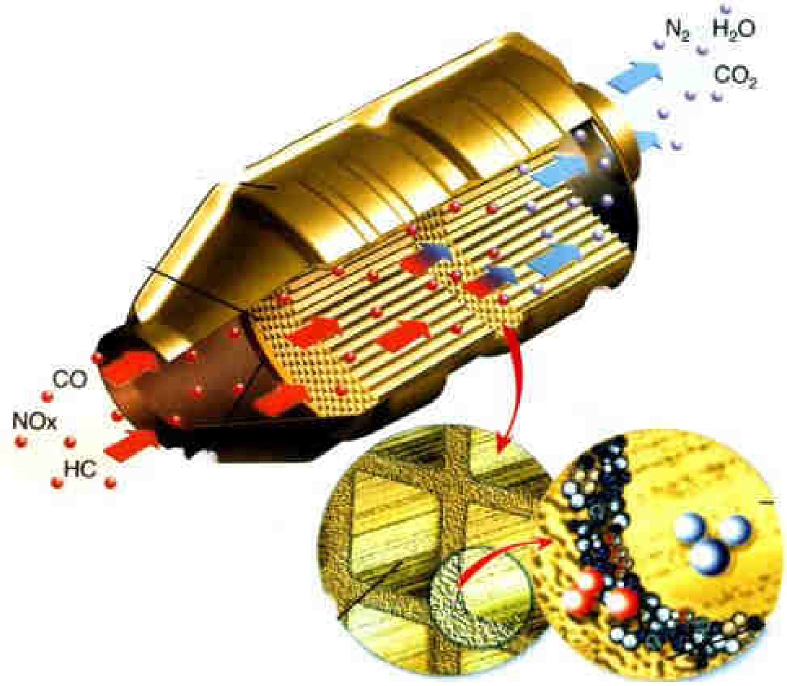
Euro	1	2	3	4	5a	5b	6b	6c	$6d_{TEMP}$	6d
	1993	1997	2001	2006	2011	2013	2015	2018	2019	2021
NO_x	-	-	500	250	180	180	80	80	80	80
CO	2720	1000	640	500	500	500	500	500	500	500
HC + NO_x	970	700	560	300	230	230	170	170	170	170
Real Driving Emissions (RDE): NO_x									168	120

Catalytic converters

First patent on catalytic converters: 1930, Eugene Houdry (French mechanical engineer, US emigrant)

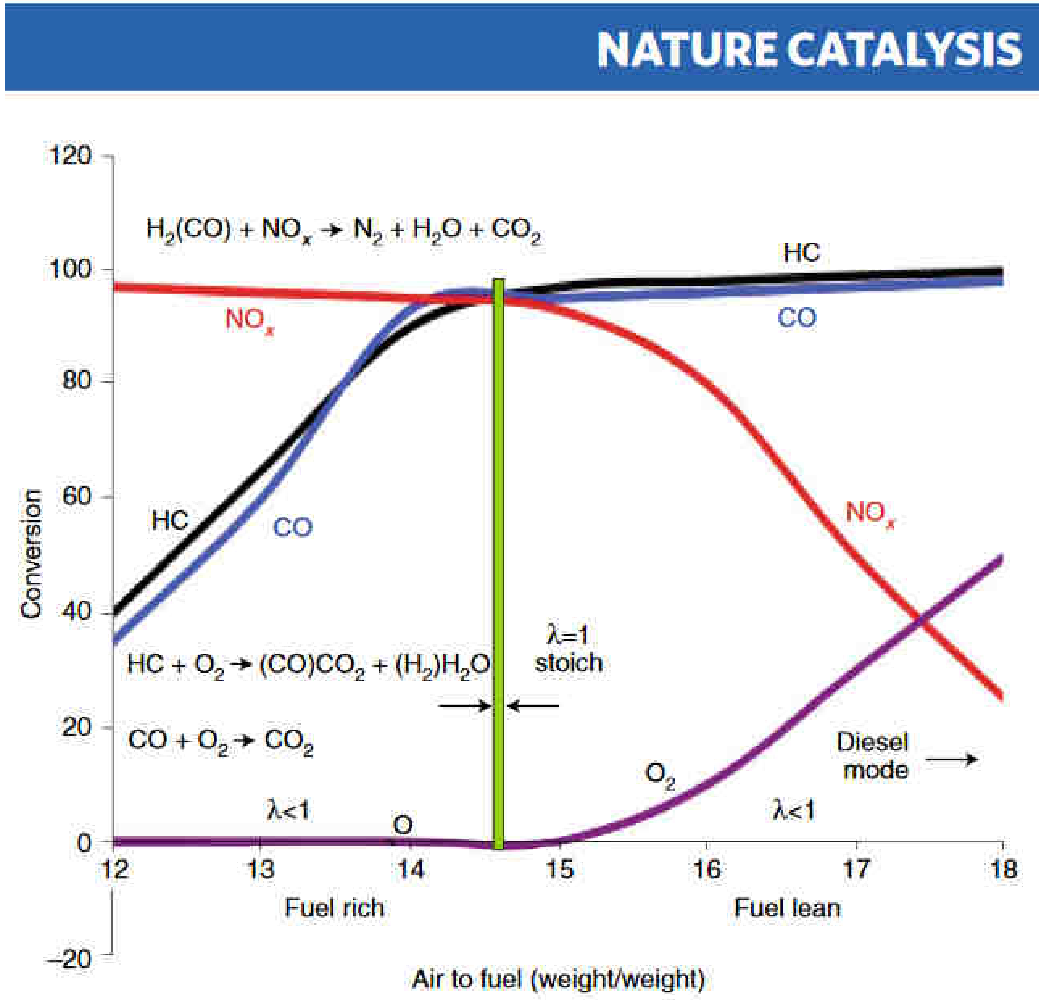
Dey and Mehta,
Resources, Environment and Sustainability
(2020) doi.org/10.1016/j.resenv.2020.100006





Catalytic converters: Gasoline versus Diesel vehicles

1980-present: Three-Way Catalysts (TWC)



$Pd(Pt)$-Rh/CeO_2-ZrO_2-Al_2O_3

Farrauto, Deeba, Alerasool
Nature Catal. (2019) 603-613

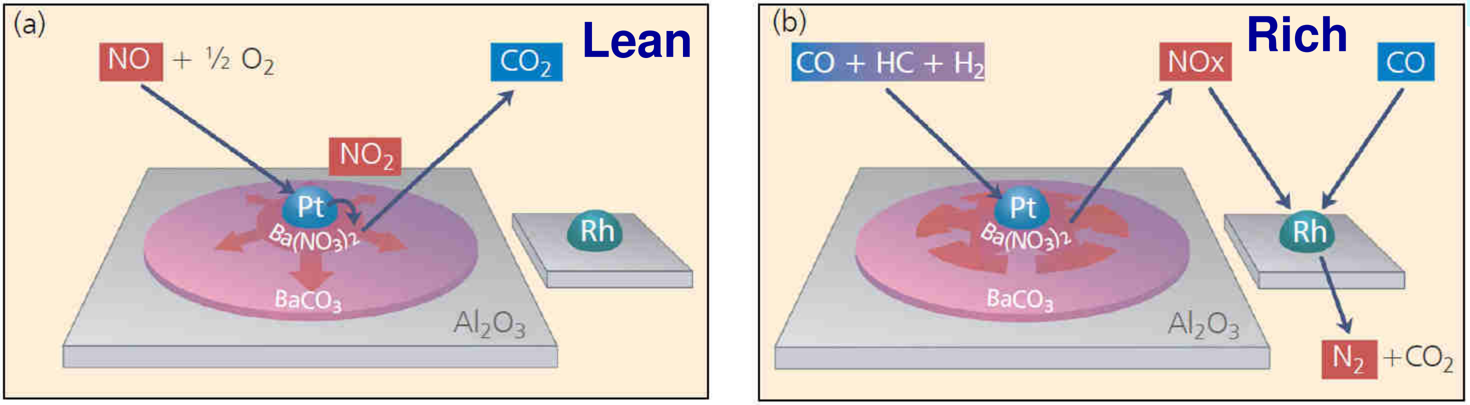
Decrease in CO_2 emissions
(Global warming)

Lean mixtures (excess O_2, $\lambda>1$)

TWC useless for NO_x remediation

Catalytic converters for lean engines (Diesel + GDI)

1- Lean NO_x Trap (LNT) catalysts patented by Toyota: Pt-Rh/Ba(CO_3)-Al_2O_3



Johnson Matthey Catalysts, "Catalyst Handbook: The right chemistry for Tier 4", Royston, UK, 2007, p. 8

CO_2 emission and engine control

2- NH_3 Selective Catalytic Reduction of NO_x (NH_3-SCR) catalysts: Cu/Chabazite

$$2\ NH_3 + NO + NO_2 = 2\ N_2 + 3\ H_2O$$

Kwak, Tonkyn, Szanyi, Peden
J. Catal. 275 (2010) 187-190

CO_2 emission as urea is used as NH_3 precursor

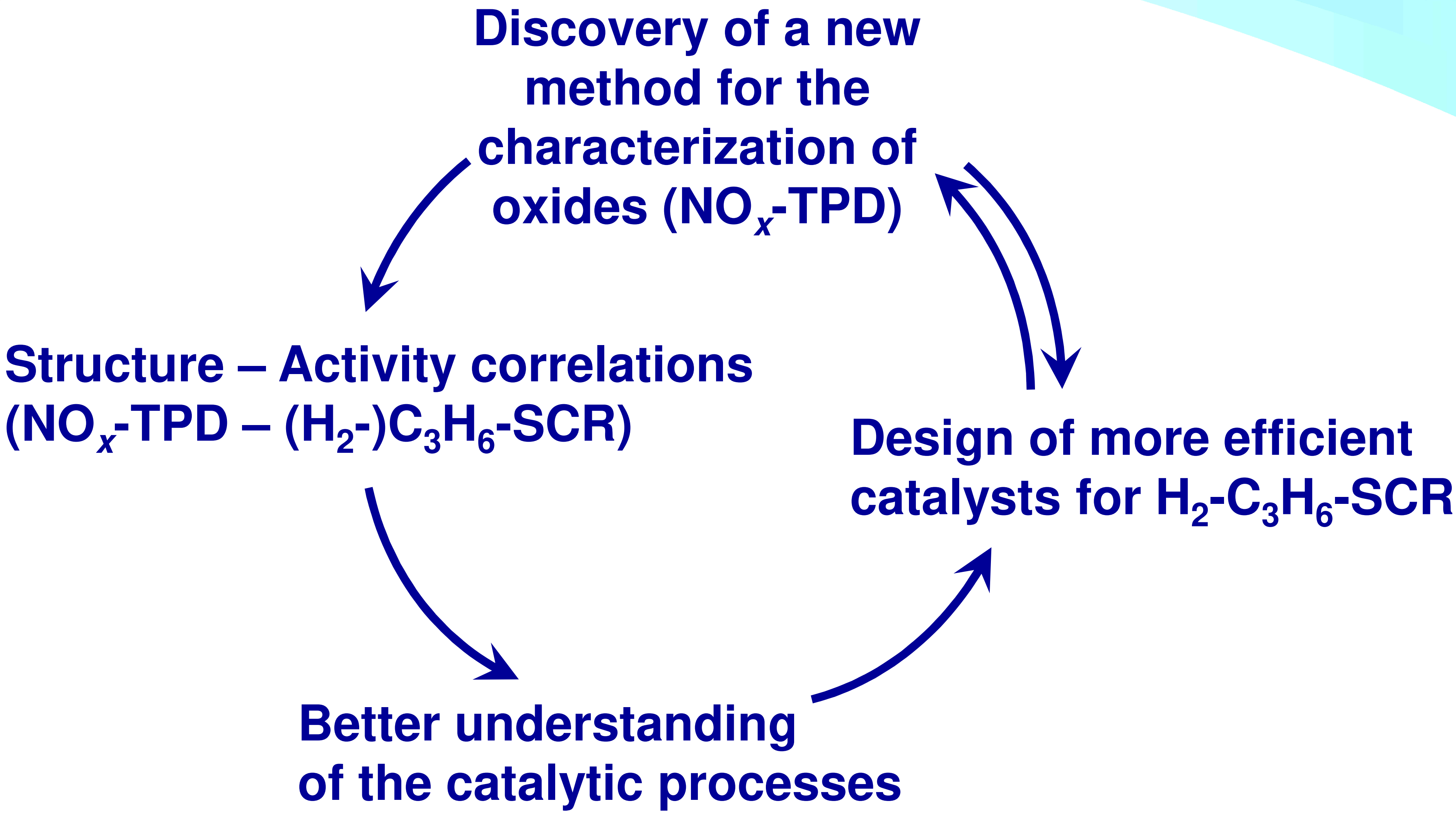
3- HC-SCR catalysts: Ag/Al_2O_3

$$NO_x + HC + O_2 = N_2 + CO_2 + H_2O$$

Miyadera, Appl. Catal. B 2 (1993) 199

No commercial application

Outline



Discovery of a new method for the characterization of oxides (NO_x-TPD)

Structure – Activity correlations (NO_x-TPD – (H_2-)C_3H_6-SCR)

Better understanding of the catalytic processes

Design of more efficient catalysts for H_2-C_3H_6-SCR

The NO_x-TPD technique

NO_x-TPD as an innovative characterization approach for the characterization of oxides : WO_x-ZrO_2 as a case-study

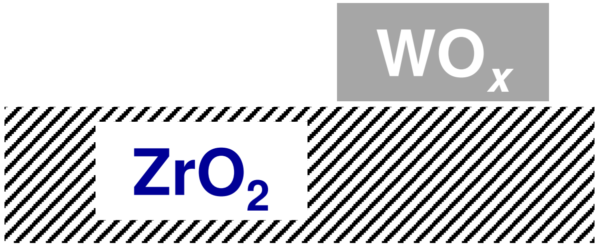
H-Y. Law, J. Blanchard, X. Carrier, C. Thomas
J. Phys. Chem. C 114 (2010) 9731-9738

C. Thomas
J. Phys. Chem. C 115 (2011) 2253-2256

State of the art

Characterization of oxide surfaces much more difficult than that of metal surfaces

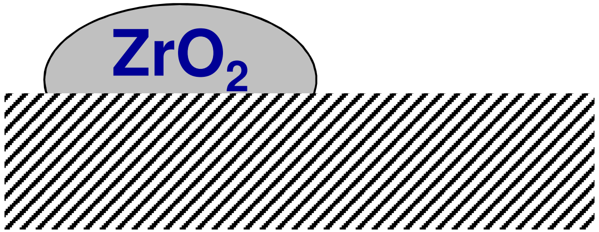
Challenge: characterization of oxide-supported oxides



Physical methods: XPS, ISS,…

Niemantsverdriet and Co, Appl Catal. 70 (1991) 53
Wachs and Co, J. Catal. 256 (2008) 108
Hercules and Co, Surf. Interface Anal. 26 (1998) 415

Useless for porous materials



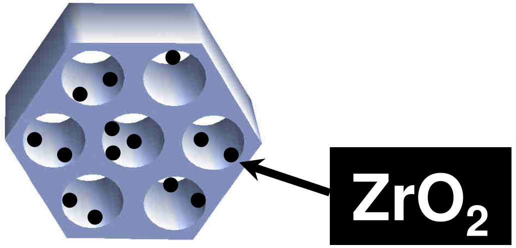
Need to resort to other methods

Aim of the present work:

Establish a reliable tool to estimate:

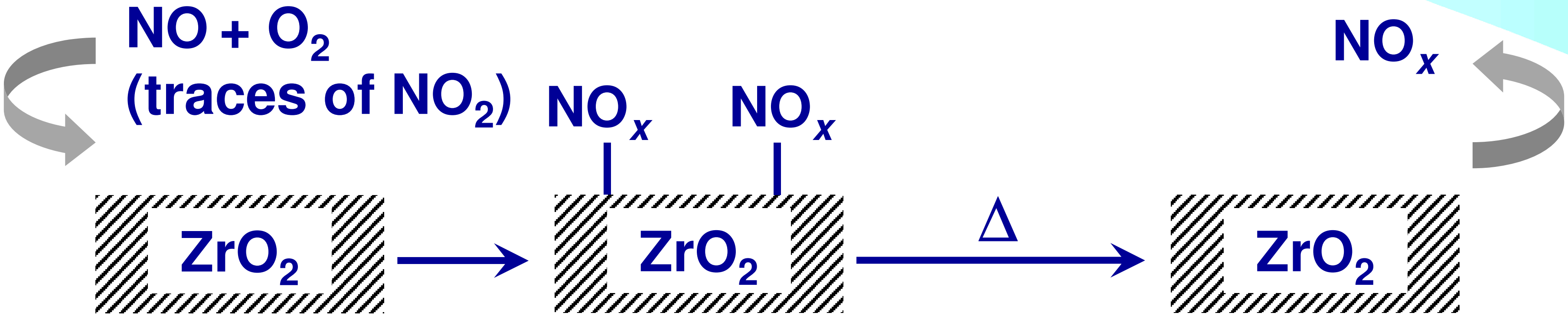
Surface coverage of ZrO_2 by another oxide (ZrO_2 as a support)
WO_x-ZrO_2

Accessible surface of ZrO_2 nanoparticles supported on a porous oxide (ZrO_2 as a supported oxide)
ZrO_2/SBA-15



NO_x adsorption followed by NO_x-TPD

NO_x adsorption - TPD principle:



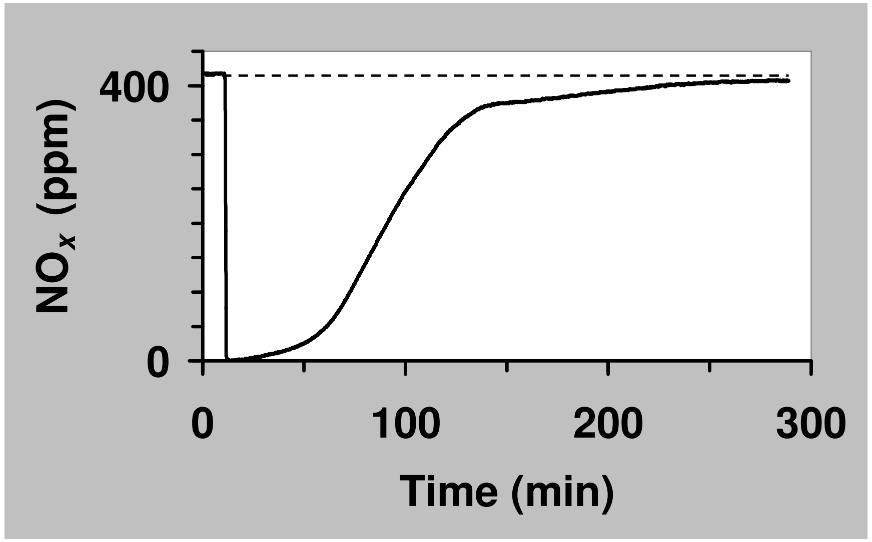
$NO + O_2$

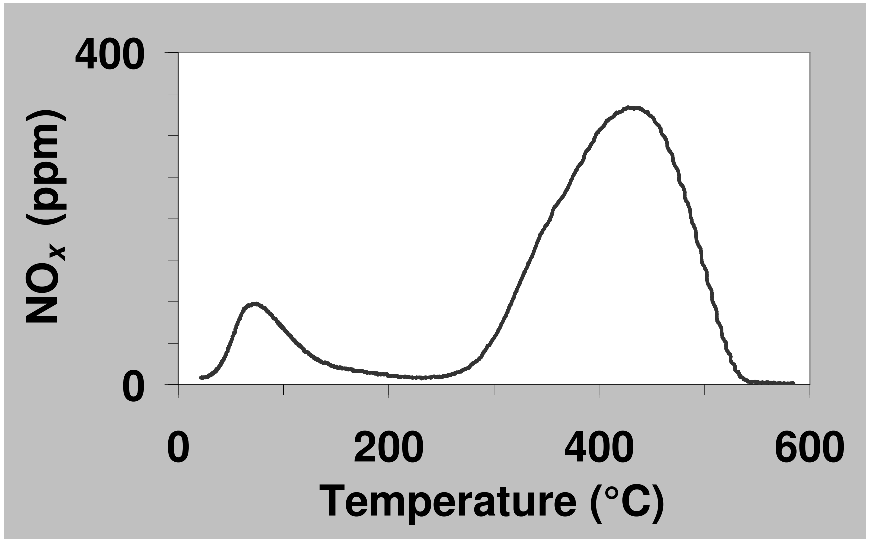
(traces of NO_2)

NO_x NO_x

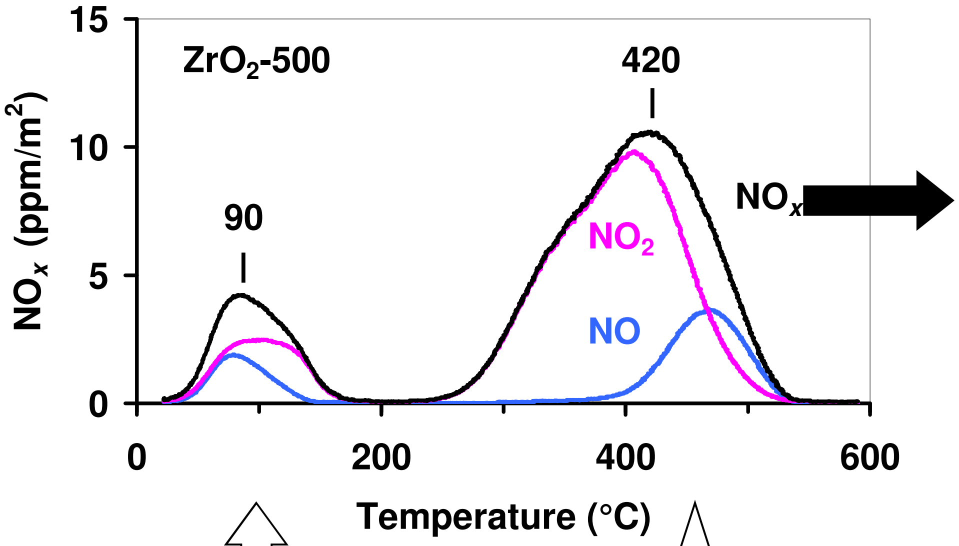
ZrO_2 → ZrO_2 $\xrightarrow{\Delta}$ ZrO_2

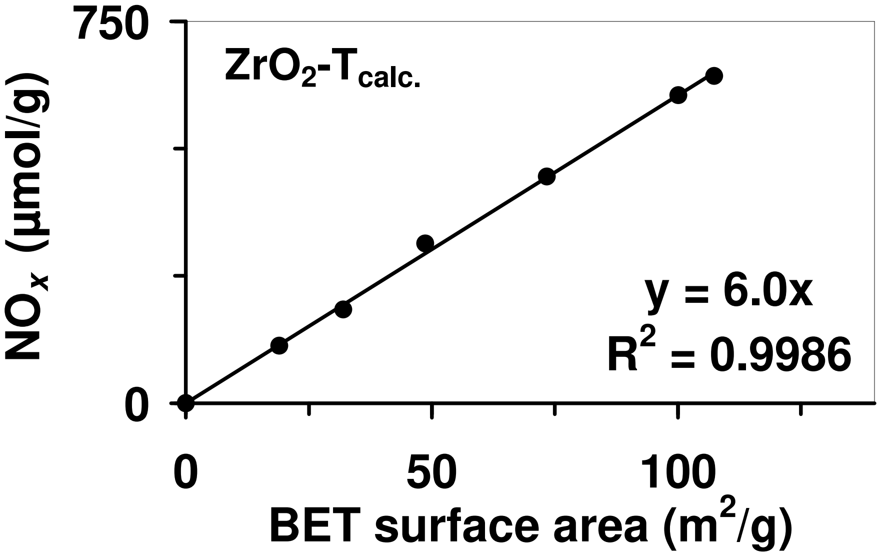
NO_x





NO_x-TPD on ZrO_2 samples:





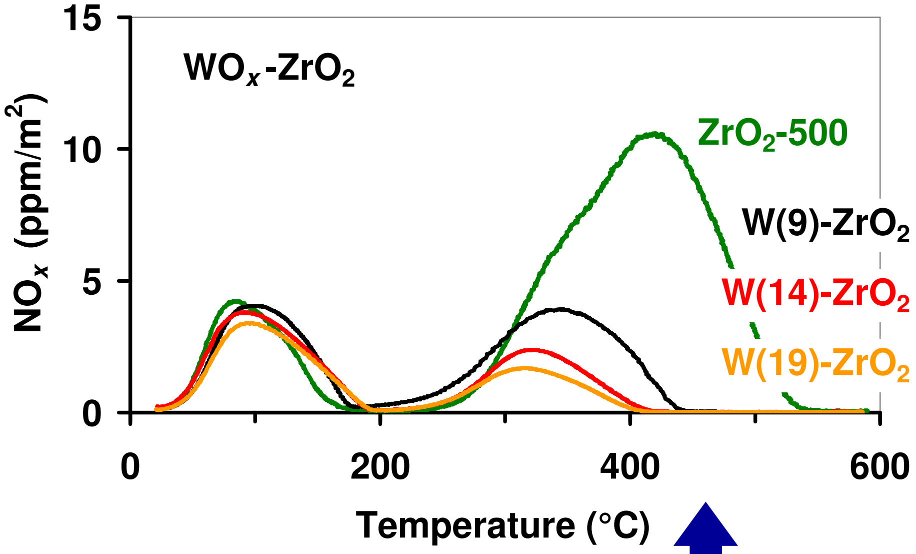
LT desorption peak

HT desorption peak

6.0 µmol NO_x / $m^2_{ZrO_2}$

Independent of the ZrO_2 polymorph
(60 < *m*-ZrO_2 < 89 %)

NO_x-TPD on WO_x-ZrO_2 samples:



Decrease in the intensity of the HT-peak

WO_x reacted with the sites responsible for NO_3^- formation (most basic Zr-OH groups: $3\ NO_2 + 2\ OH^- = 2\ NO_3^- + H_2O + NO$)

NO_x-TPD on WO_x-ZrO_2: W density (δ) calculation ?

2 calculation methods for the estimation of the W surface density (W/nm²):

δ_1

$$\delta_1 = \frac{\dfrac{\frac{wt\%\,W}{100}}{M_W} \times 6.023 \times 10^{23}}{S.A. \times 10^{18}}$$

δ_2

$$\delta_2 = \frac{\dfrac{\frac{wt\%\,W}{100}}{M_W} \times 6.023 \times 10^{23}}{\dfrac{S.A. \times 10^{18}}{1 - \left(\dfrac{wt\%W}{100} \times \dfrac{M_{WO_3}}{M_W}\right)}}$$

Most of the authors used this calculation method:

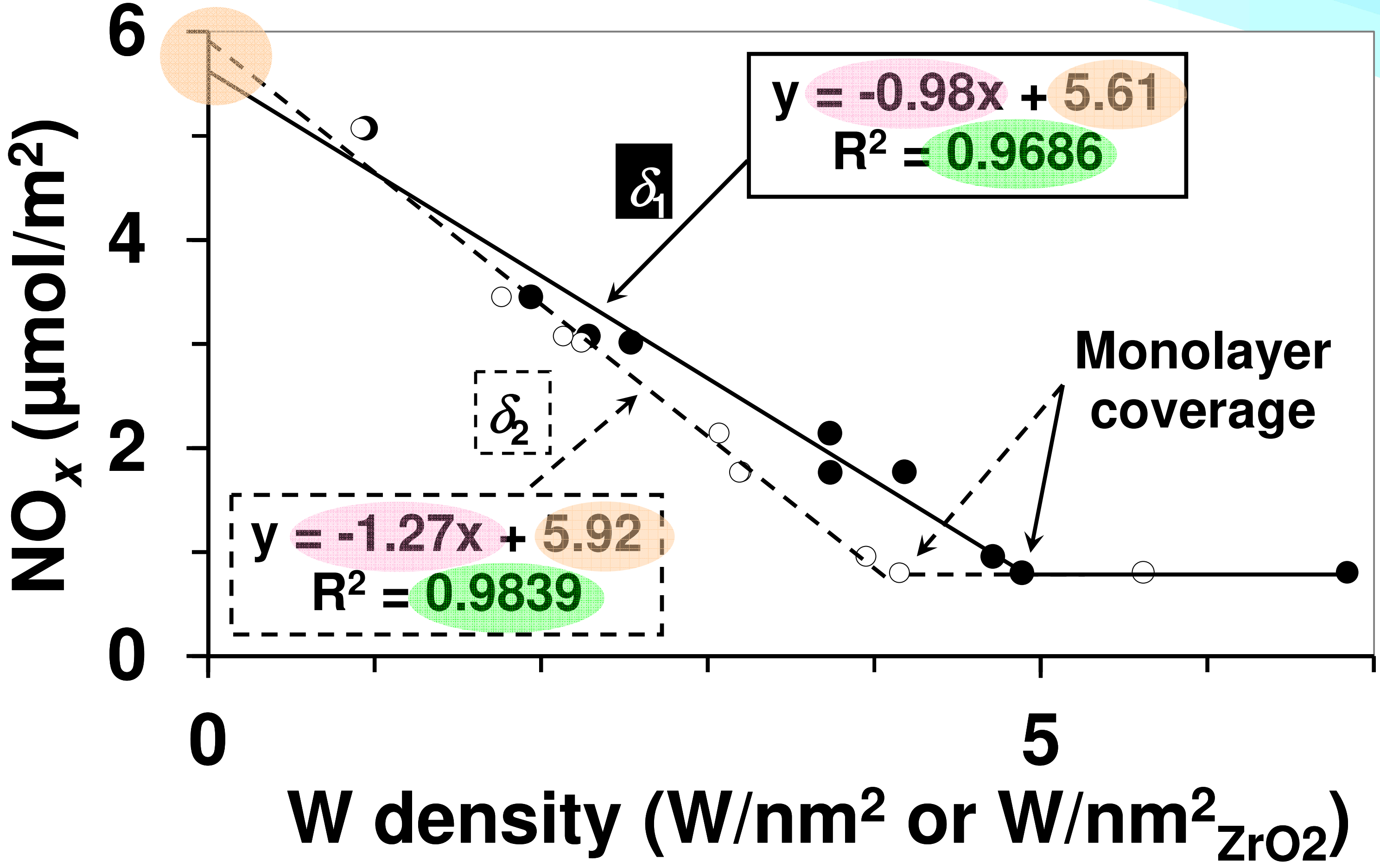
Iglesia & Co., J. Catal. 181 (1999) 57
Knözinger & Co., J. Catal. 209 (2002) 539
Wachs & Co., J. Catal. 256 (2008) 108
….

Very few authors:

Houalla & Co.,
J. Phys. Chem B 109 (2005) 3345

Hypothesis: WO_3 does not contribute to the specific surface area of the sample

NO_x-TPD on WO_x-ZrO_2: W density (δ) calculation ?



Differences in correlation coefficients, *y* intercepts and slopes values

NO_x-TPD on WO_x-ZrO_2: W density (δ) calculation ?

Sample	δ_1	δ_2	R^2	NO_x SD	$W_{NOx\ inhib.}$	W-O-Zr (EXAFS)	Refs.
	(W / nm²)			(µmol / m²)			
ZrO_2	0		0.9988	6.03			J. Phys. Chem. C 114 (2010) 9731
WO_x-ZrO_2	0 - 7		0.9686	5.61	0.98 [(a)] 0.59 [(b)]		
WO_x-ZrO_2		0 - 6	0.9839	5.92	1.27 [(a)] 0.77 [(b)]		J. Phys. Chem. C 115 (2011) 2253
$3WZ(ZrCl_4)_{923}$	2.04	1.98				0.76	Carrier et al. PCCP 11 (2009) 7527

(a) µmol m^{-2} / W nm^{-2}

(b) NO_x / W

First scientific arguments to justify for W density (W/nm²) to be calculated as δ_2

NO_x-TPD on WO_x-ZrO_2: W density (δ) calculation ?

Critical discussion on previous studies for which unexpected results have been reported

W surface density for which pseudo monolayer coverage is reached on WO_x/ZrO_2 materials

4-5 W/nm^2
Wachs & Co., J. Catal. 256 (2008) 108

O-xylene TOR as a function of the W surface density

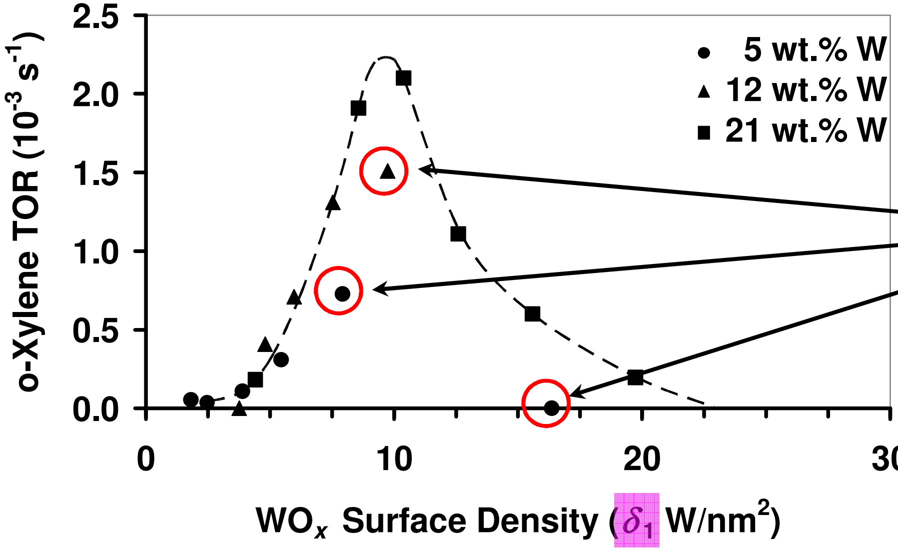
Barton, Soled, Meitzner, Fuentes, Iglesia
J. Catal. 181 (1999) 57

NO$_x$-TPD on WO$_x$-ZrO$_2$: W density (δ) calculation ?

Sample	Technique	S.A. (m^2/g)	δ_1 monolayer (W/nm^2)	δ_2	Refs.
WO$_x$-ZrOH	FTIR	96	5.1	4.2	Scheitauer et al., J. Catal. 180 (1996) 1
WO$_x$-ZrO$_2$	ISS	36	4.7-5.8	4.4-5.3	Vaidyanathan et al., Surf. Interface Anal. 26 (1998) 415
WO$_x$-ZrOH	BAT	92	4.3	3.7	Naito et al., J. Phys. Chem. B 103 (1999) 630
WO$_x$-ZrOH	Raman	n.a.	4.5		Barton et al., J. Catal. 181 (1999) 57
WO$_x$-ZrO$_2$	XPS	36	5.2	4.1	Vaidyanathan et al., Anal. Bioananal. Chem. 373 (2002) 547
WO$_x$-ZrOH	XPS	43	4.9	4.5	Valigi et al., Appl. Catal. A 231 (2002) 159
WO$_x$-ZrOH	CO uptake	n.a.	4.9		Ferraris et al., Appl. Catal. A 240 (2002) 119
WO$_x$-ZrOH	XPS	50	3.5-5.9	3.3-5.2	Di Gregorio et al., J. Catal. 225 (2004) 45
WO$_x$-ZrOH	NO$_x$-TPD	68-124	4.9	4.1	J. Phys. Chem. C 114 (2010) 9731 J. Phys. Chem. C 115 (2010) 2253
WO$_x$-ZrO$_2$	Raman	39	4.0	3.8	Wachs, Catal. Today 27 (1996) 437
WO$_x$-ZrO$_2$	Raman	56	4.4	4.0	Wachs et al., Catal. Today 116 (2006) 162
WO$_x$-ZrOH	XPS	80	4.9	4.1	Ross-Medgaarden et al., J. Catal. 256 (2008) 108

NO_x-TPD on WO_x-ZrO_2: W density (δ) calculation ?

Barton, Soled, Meitzner, Fuentes, Iglesia
J. Catal. 181 (1999) 57

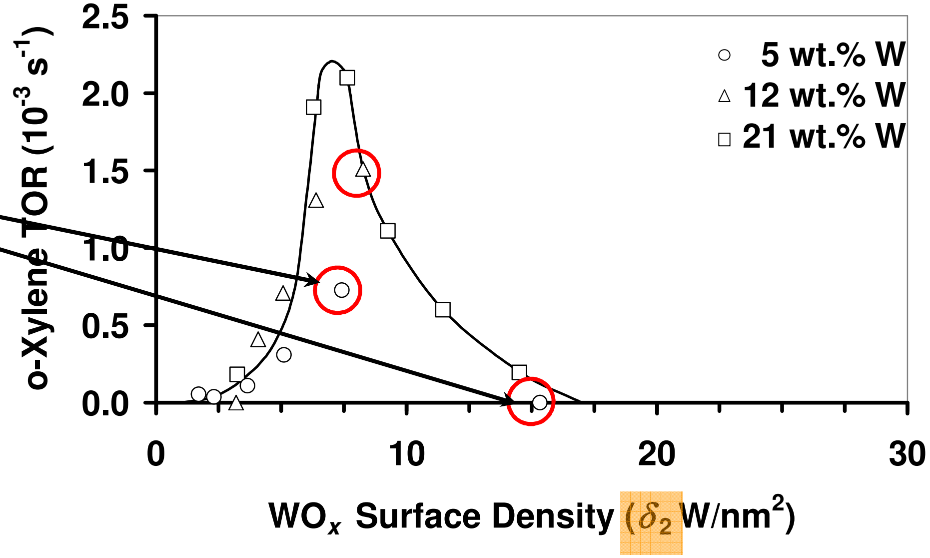


unexpected values ?

Lowest specific surface areas of all samples (10 and 21 m^2/g)

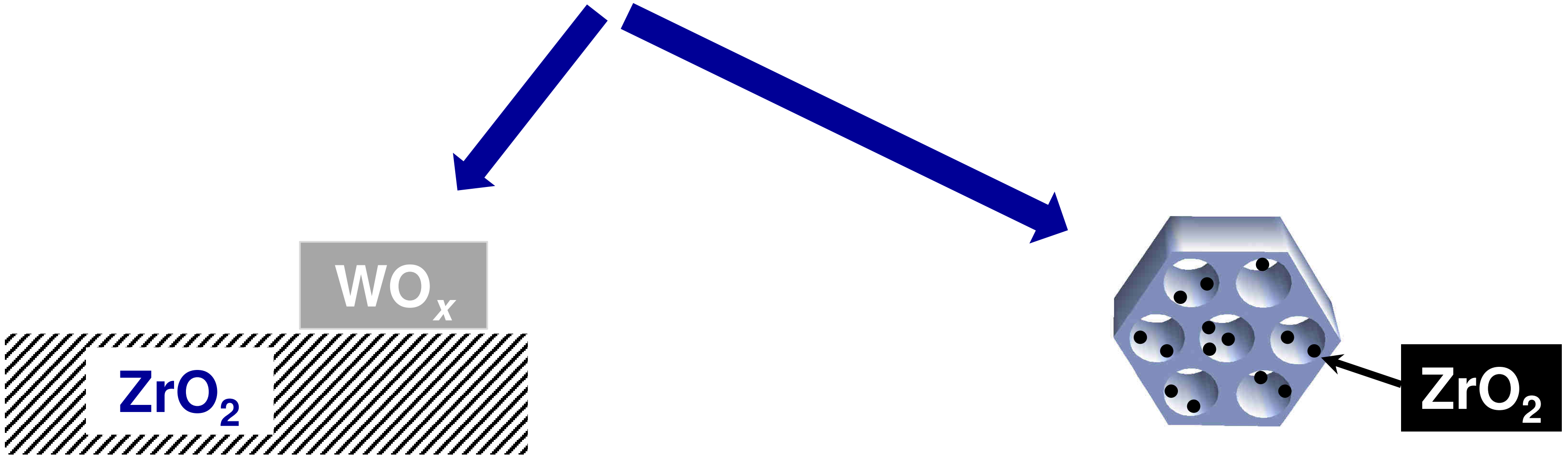
⬇

Limited accuracy on δ



Conclusions

Development of a reliable tool for oxide surface characterization
(NO_x-TPD method)



BET surface to be corrected for the content of W as WO_3 to calculate W surface density (δ_2)

Determination of the accessible surface of ZrO_2 particles located inside the porosity of a silica support (for which the common spectroscopic techniques are useless)

Structure-Activity (NO_x-TPD - (H_2)-C_3H_6-SCR) correlations on Ag(x wt%)/Al_2O_3

1- Why does the 2 wt% Ag/Al_2O_3 act as an optimum catalyst in C_3H_6-SCR?

T. Chaieb, L. Delannoy, C. Louis, C. Thomas
Appl. Catal. B: Environmental 142-143 (2013) 780

2- Is there any Ag loading optimum for H_2-C_3H_6-SCR ?

T. Chaieb, L. Delannoy, C. Louis, C. Thomas
Appl. Catal. B: Environmental 156-157 (2014) 192

State of the art:

✓ **Existence of an optimum loading of Ag (~ 2 wt%) on Al_2O_3 in the C_3H_6-SCR of NO_x**

Miyadera, Appl. Catal. B 2 (1993) 199

Hoost et al., Appl. Catal. B 13 (1997) 59

Shimidzu et al., Appl. Catal. B 30 (2001) 151

Lindfors et al., Topics Catal. 28 (2004) 185

Arve et al., Topics Catal. 30/31 (2004) 91

Zhang and Kaliaguine, Appl. Catal. B 78 (2008) 275

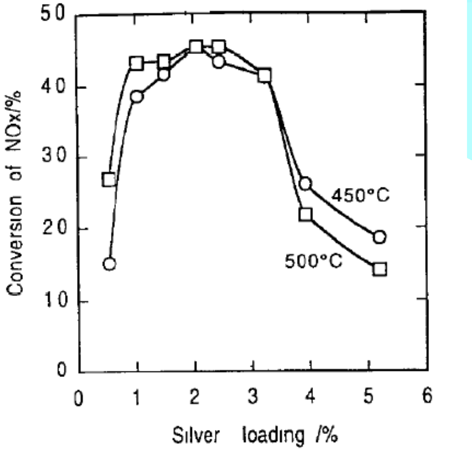


Fig 1 Effect of silver loading on the conversion
conditions 500 ppm NO, 333 ppm C_3H_6, 10% C

✓ **HC-SCR activity of Ag(2 wt%)/Al_2O_3 >>> Ag(>>2 wt%)/Al_2O_3**

Bethke and Kung, J. Catal. 172 (1997) 93

Seker et al., Appl. Catal. A 183 (1999) 121

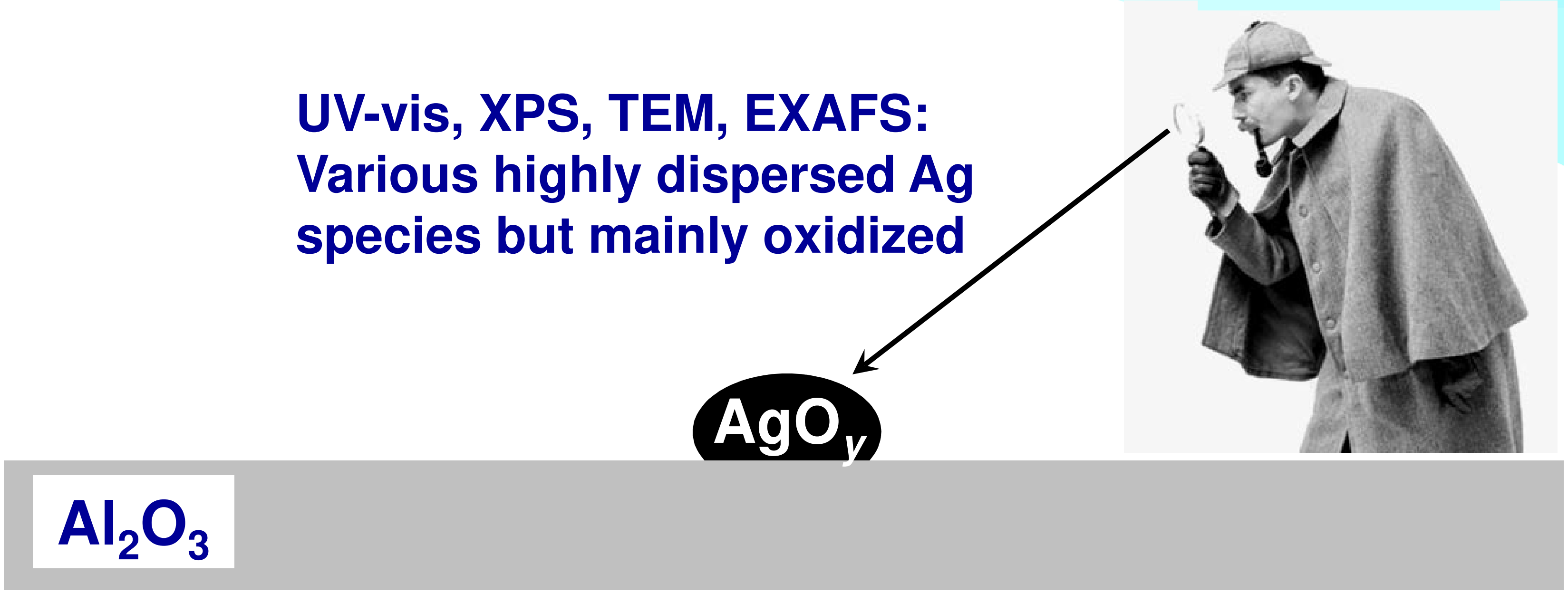
Kannisto et al., J. Mol. Catal. A 302 (2009) 86

✓ **Few others found an optimum at lower or higher Ag loading than 2 wt%**

Meunier et al., Appl. Catal. B 30 (2001) 163

He et al., Catal. Today 90 (2004) 191

State of the art: Ag/Al_2O_3 characterization



UV-vis, XPS, TEM, EXAFS:
Various highly dispersed Ag species but mainly oxidized

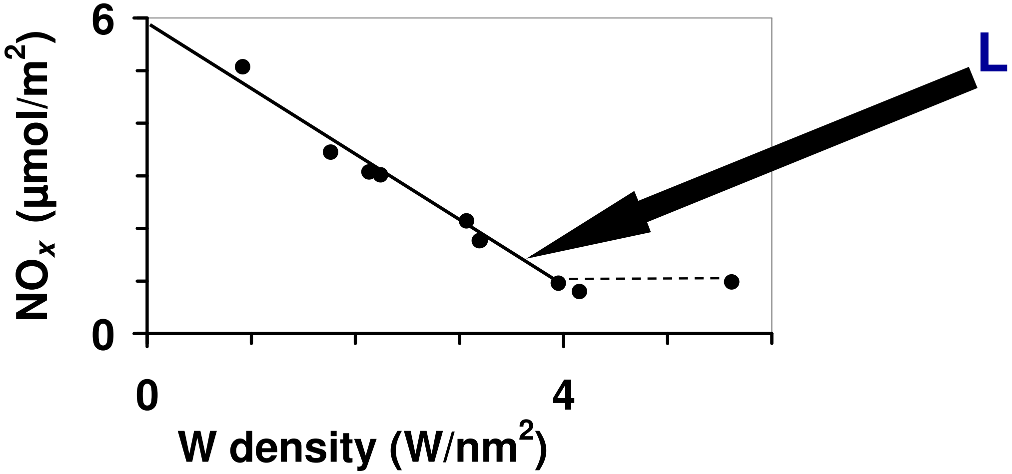
Jen, Catal. Today 42 (1998) 37 — 2 wt% Ag on ≠ Al_2O_3 supports (porosity)

Wang et al., Phys. Chem. Chem. Phys. 2 (2000) 3007 — FTIR (acid-base properties) of Al_2O_3 (≠ Ag loadings)

➡ The reason for the existence of an optimum Ag loading in the HC-SCR of NO_x is not clearly understood to date

State of the art: Development of an innovative tool (NO_x-TPD) for the characterization of oxides

Thomas and co, J. Phys. Chem. C 114 (2010) 9731
Thomas, J. Phys. Chem. C 115 (2011) 2253

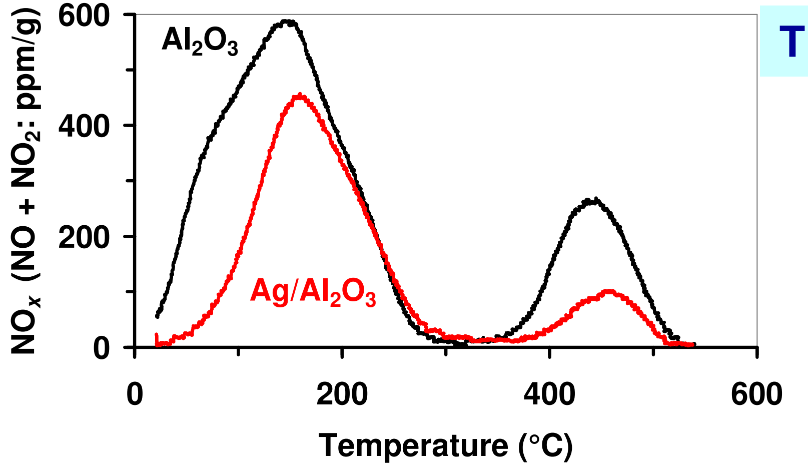


Linear decrease of the NO_x uptake up to 4.0 W/nm^2

⬇

Excellent agreement with Pseudo monolayer coverage

Wachs and Co, J. Catal. 256 (2008) 108



Thomas and co., Topics Catal. 56 (2013) 134

Decrease in the NO_x uptake with the introduction of Ag

⬇

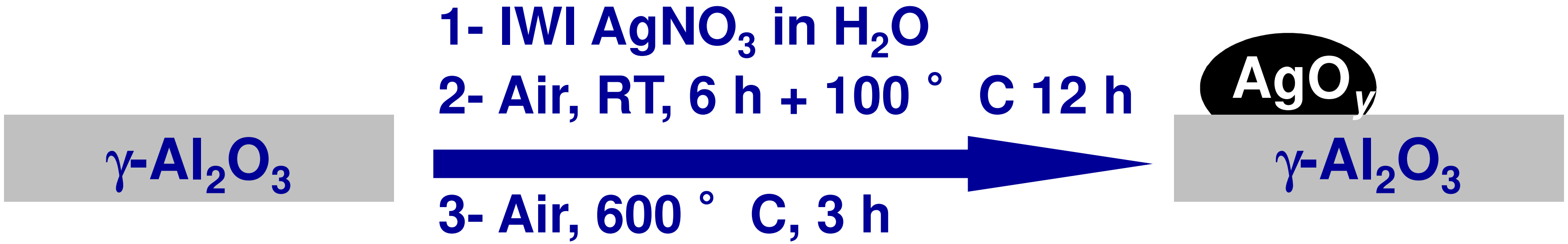
NO_x not chemisorbed on the Ag species (only on Al_2O_3)

Aims of the present work:

Influence of the loading of Ag on Al_2O_3 on the:
- ✓ C_3H_6-SCR of NO_x?
- ✓ NO_x-TPD profiles?

To gain further understanding on the origin of the existence of an optimum Ag loading in the C_3H_6-SCR of NO_x via the characterization of Al_2O_3

Synthesis of a series of Ag(0 - 4.3 wt%)/Al_2O_3 samples



Influence of Ag loading on Al_2O_3: C_3H_6-SCR of NO_x

T Miyadera/Appl Catal B 2 (1993) 199-205

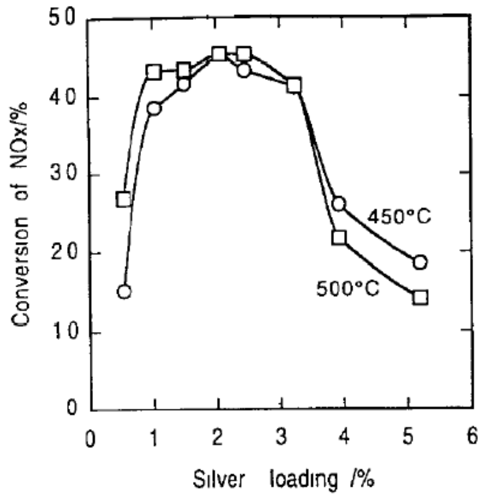
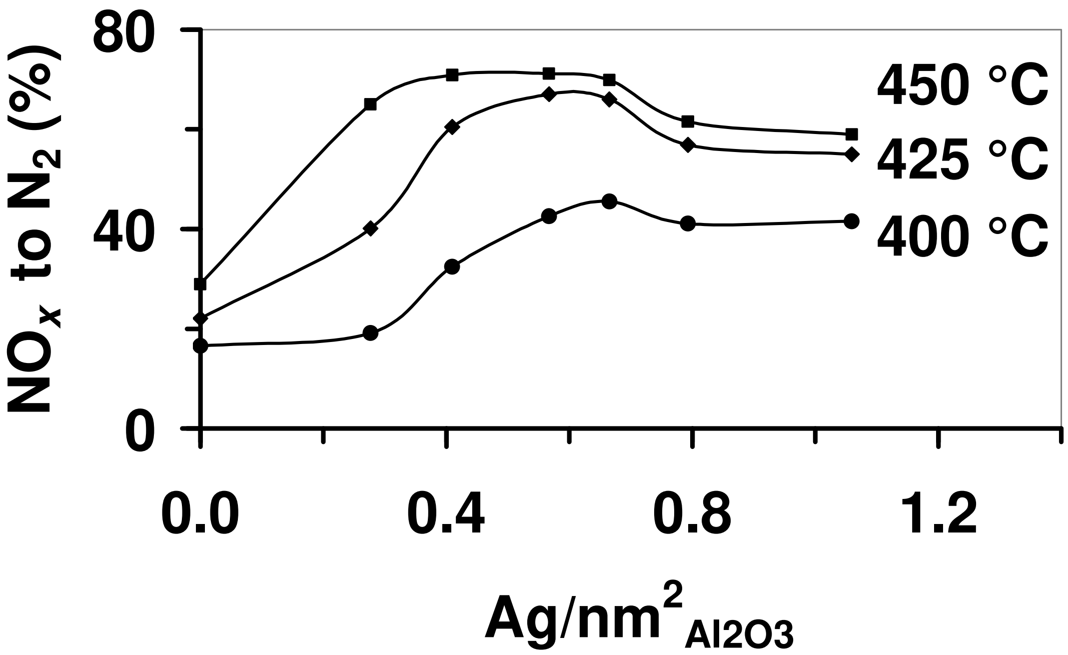


Fig 1 Effect of silver loading on the conversion of
conditions 500 ppm NO, 333 ppm C_3H_6, 10% O_2, 1
space velocity 6400/h, conversion rate of NO_x= (N
in the following figures and tables)

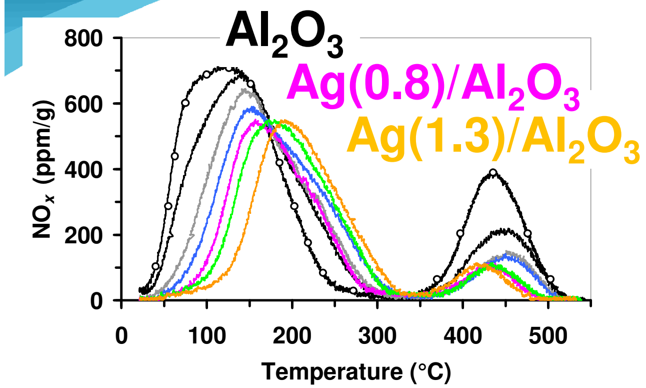


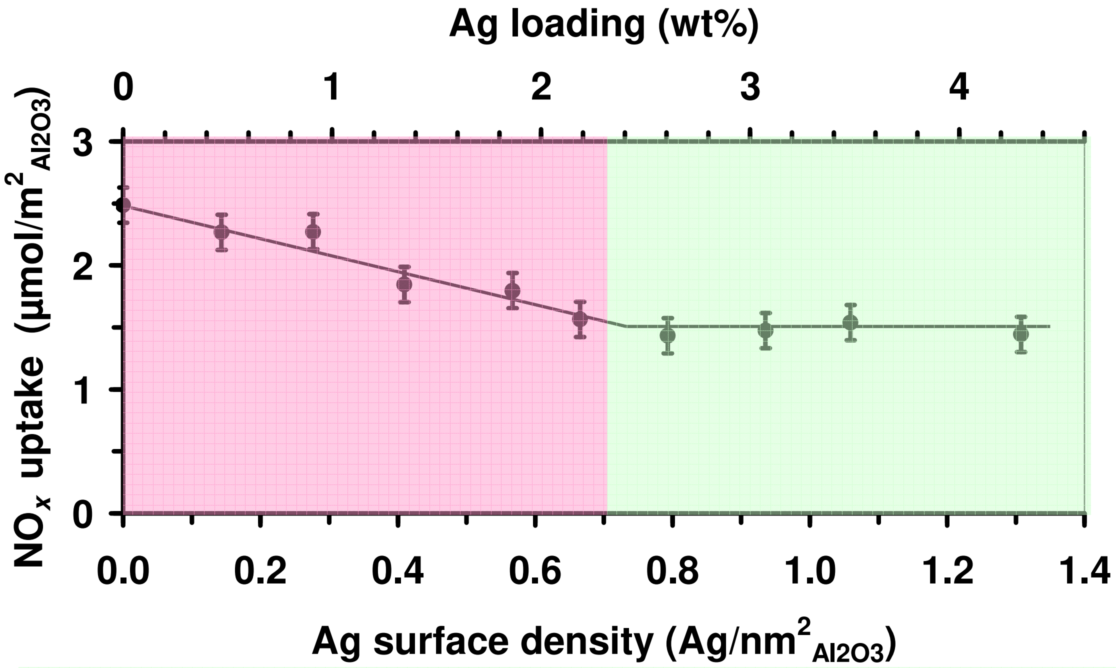
✓ Increase in NO_x conversion to N_2 for Ag surface densities up to 0.7 Ag/nm^2 (Ag content of 2.2 wt%)

✓ Decrease in NO_x conversion to N_2 for Ag surface densities greater than 0.7 Ag/nm^2 in agreement with earlier studies

Miyadera, Appl. Catal. B 2 (1993) 199; Shimidzu et al., Appl. Catal. B 30 (2001) 151; Lindfors et al., Topics Catal. 28 (2004) 185

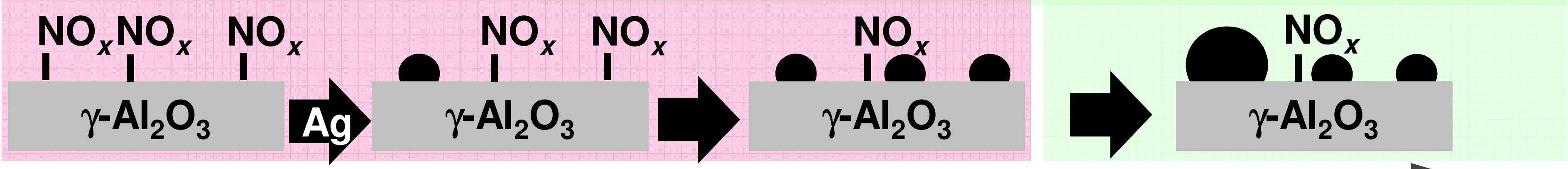
Influence of Ag loading on Al_2O_3: NO_x uptake





Linear decrease in the NO_x uptake up to 0.7 Ag/nm² (~ 2 wt% Ag)

Al_2O_3 surface sites onto which Ag is anchored saturated for Ag surface densities greater than 0.7 Ag/nm² (⇨ cluster growing)



↗ Ag surface density (W/nm²)

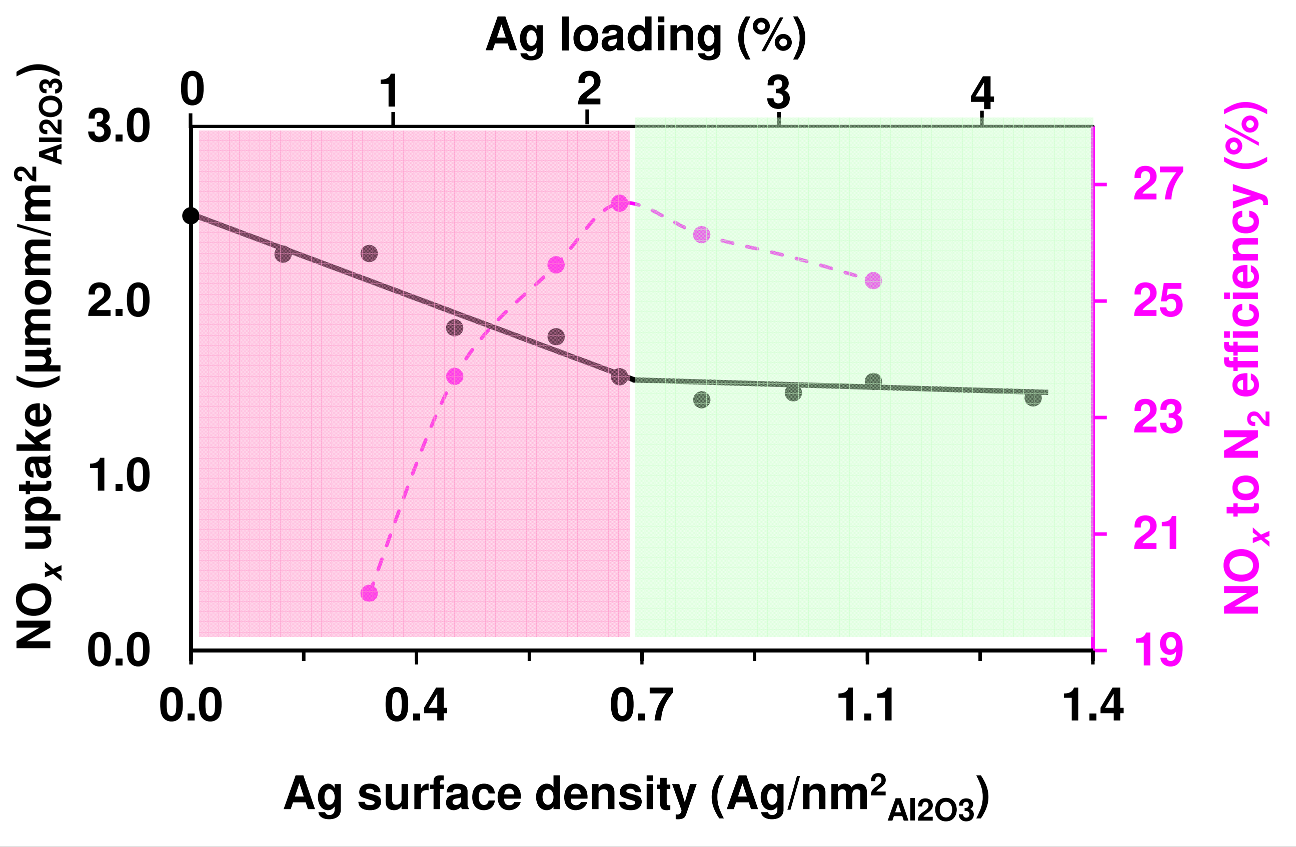
Structure-activity correlation: NO_x uptake - C_3H_6-SCR

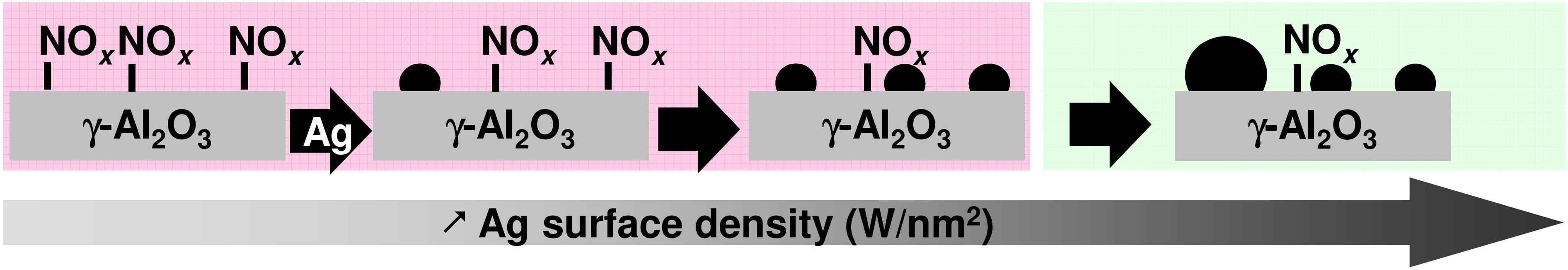
Highest C_3H_6-SCR activity close to the optimum Ag dispersion (0.7 Ag/nm² ~ 2 wt% Ag)

Optimum Ag loading at ~ 2 wt%?

⬇

Maximum loading of Ag for which high Ag dispersion is preserved (~ 200 m²/g_{Al2O3})





Critical analysis of previous literature reports on the basis of the Ag surface density concept:

Meunier et al., Appl. Catal. B 30 (2001) 163

166 *F.C. Meunier et al. / Applied Catalysis B:*

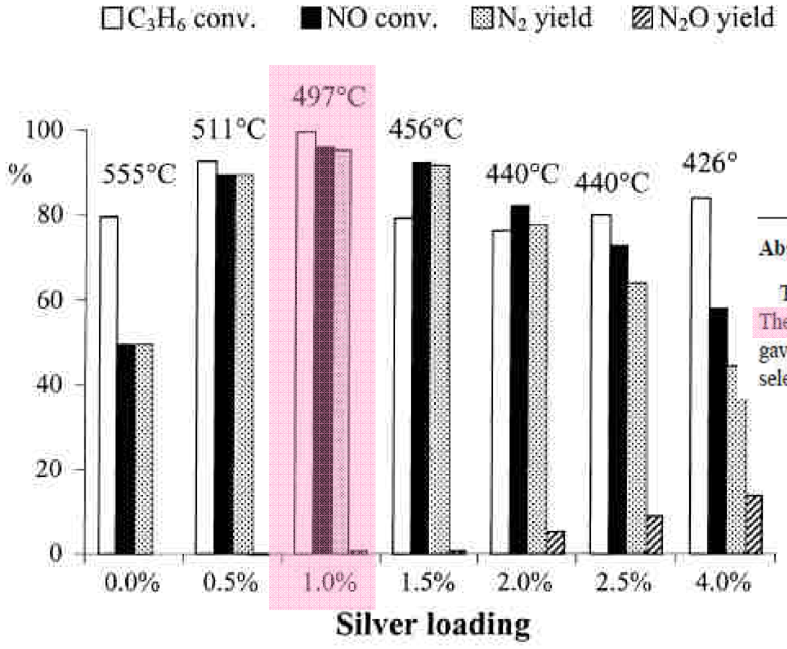


Fig. 1. Propene-SCR of NO: effect of the loading of silver over γ-Al_2O_3 (γ-Al_2O_3: 115 $m^2\,g^{-1}$). The T_{max} is given at the top of the bars for each silver loading. Feed: 0.1% NO + 0.1% C_3H_6 + 5% O_2 in He; $W/F = 0.12\,g\,s\,cm^{-3}$. GHSV = 25,000 h^{-1}.

Optimum Ag loading of 1 wt%

F.C. Meunier[a,*], R. Ukropec[b], C. Stapleton[b], J.R.H. Ross[b,1]

[a] *Institut für Technische Chemie-2, Technische Universität München, Lichtenbergstrasse 4, D-85747 Garching, Germany*
[b] *Centre for Environmental Research, University of Limerick, Limerick, Ireland*

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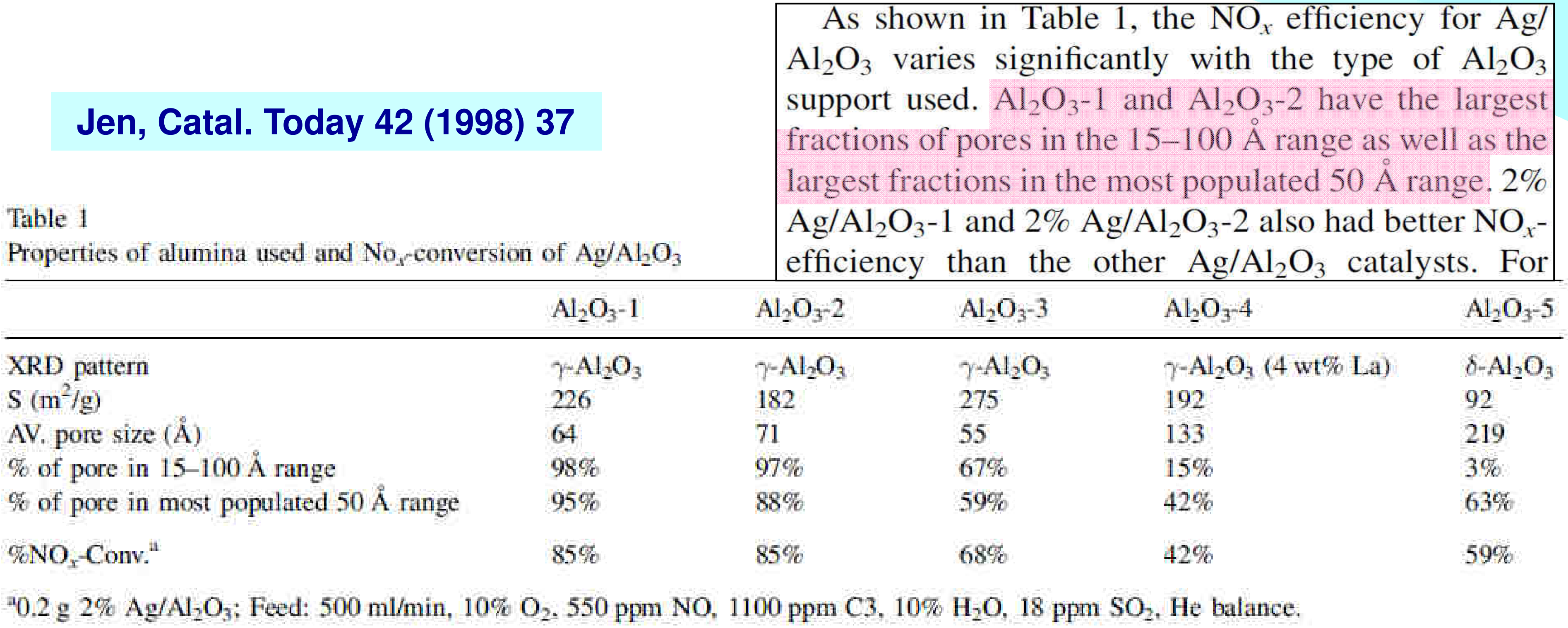
Abstract

The present work reports data on the activity of silver, alumina and zirconia based-catalysts for the C_3H_6-SCR of NO. The optimum silver loading for Ag/γ-Al_2O_3 catalysts for the C_3H_6-SCR of NO was about $8.7 \times 10^{-5}\,g_{silver}\,m^{-2}_{alumina}$, which gave the best compromise between a higher activity at low temperatures (favoured on high loading materials) and a high selectivity to N_2 (favoured on low loading materials). The effect of the residence time was also investigated on a 1.2 wt.%

➡ **Optimum at 0.5 Ag/nm^2_{Al2O3} and decrease in activity for > 0.7 Ag/nm^2_{Al2O3} (> 1.5 wt% Ag) (good agreement with the results of the present study)**

Critical analysis of previous literature reports on the basis of the Ag surface density concept:

Jen, Catal. Today 42 (1998) 37



As shown in Table 1, the NO_x efficiency for Ag/Al_2O_3 varies significantly with the type of Al_2O_3 support used. Al_2O_3-1 and Al_2O_3-2 have the largest fractions of pores in the 15–100 Å range as well as the largest fractions in the most populated 50 Å range. 2% Ag/Al_2O_3-1 and 2% Ag/Al_2O_3-2 also had better NO_x-efficiency than the other Ag/Al_2O_3 catalysts. For

Table 1
Properties of alumina used and No_x-conversion of Ag/Al_2O_3

	Al_2O_3-1	Al_2O_3-2	Al_2O_3-3	Al_2O_3-4	Al_2O_3-5
XRD pattern	γ-Al_2O_3	γ-Al_2O_3	γ-Al_2O_3	γ-Al_2O_3 (4 wt% La)	δ-Al_2O_3
S (m^2/g)	226	182	275	192	92
AV. pore size (Å)	64	71	55	133	219
% of pore in 15–100 Å range	98%	97%	67%	15%	3%
% of pore in most populated 50 Å range	95%	88%	59%	42%	63%
%NO_x-Conv.[a]	85%	85%	68%	42%	59%

[a] 0.2 g 2% Ag/Al_2O_3; Feed: 500 ml/min, 10% O_2, 550 ppm NO, 1100 ppm C3, 10% H_2O, 18 ppm SO_2, He balance.

Ag/nm^2_{Al2O3}	**0.5**	**0.6**	**0.4**		**1.2**

Ag surface densities close to the optimum one (0.7 Ag/nm^2_{Al2O3})

Ag surface density too low

Ag surface density too high

Conclusions

1- Why does the 2 wt% Ag/Al_2O_3 act as an optimum catalyst in C_3H_6-SCR?

⬇

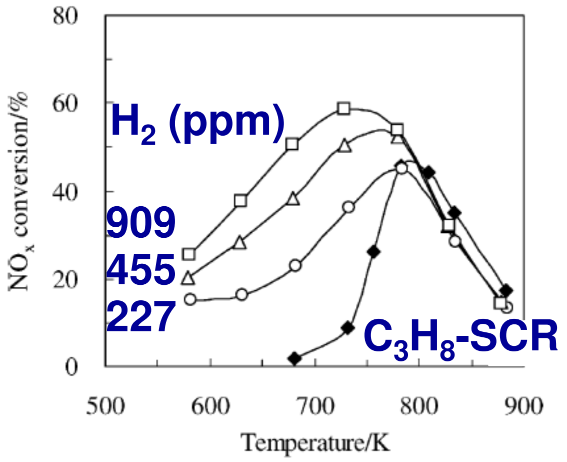
Structure (NO_x-TPD) – activity (C_3H_6-SCR) correlation

⬇

maximum Ag loading per unit surface area of Al_2O_3
(Ag surface density)
for which AgO_x clusters remain highly dispersed

State of the art: H_2-SCR

HC-SCR drawback: Ag/Al_2O_3 poorly active at low-T



Satokawa, Shibata, Shimizu, Satsuma, Hattori
Appl. Catal. B 42 (2003) 179

Breakthrough discovery of the outstanding promoting effect of H_2 in HC-SCR on Ag/Al_2O_3

The influence of Ag loading scarcely studied in H_2-HC-SCR (most of the studies performed on Ag(~ 2wt%)/Al_2O_3)

State of the art: Influence of the Ag loading in H_2-HC-SCR

Shimizu, Tsuzuki, kato, Yokota, Okumara, Satsuma, J. Phys. Chem C 111 (2007) 950

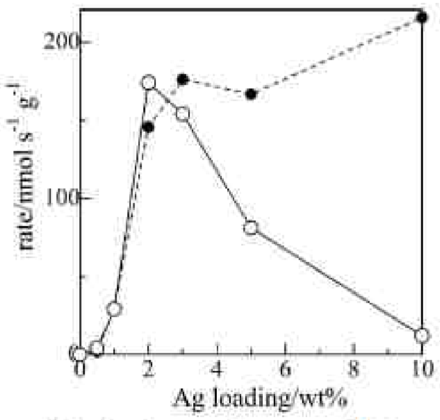
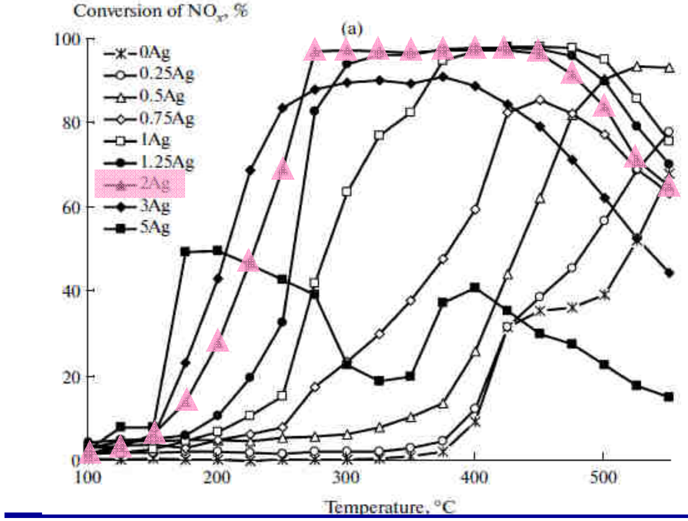


Figure 2. Effect of Ag loading on the rates of NO reduction (○) and C_3H_8 reaction (●) in H_2-C_3H_8-SCR over Ag/Al_2O_3-2 at 573 K. Conditions: 0.1% NO, 0.1% C_3H_8, 0.5% H_2, 10% O_2.

Optimum Ag loading (2 wt%) in the H_2-C_3H_8-SCR for a given reaction temperature

Sadokhina, Prokhorova, Kvon, Mashkovskii, Bragina, Baeva, Bukhtyrarov, Stakheev, Kinet. Catal. 53 (2012) 107



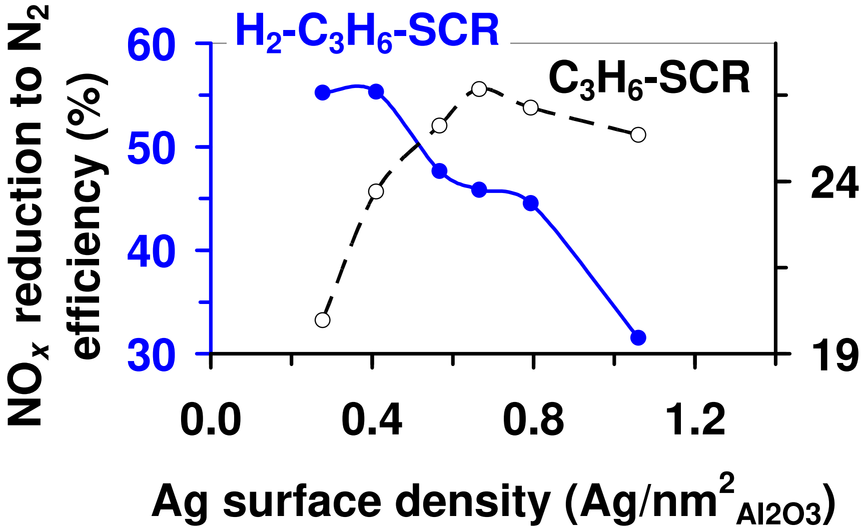
Optimum Ag loading (2 wt%) in the H_2-C_6H_{14}-SCR over a broad T domain (100-550 ° C) with 100 % conversions on some samples

Aims of the present work:

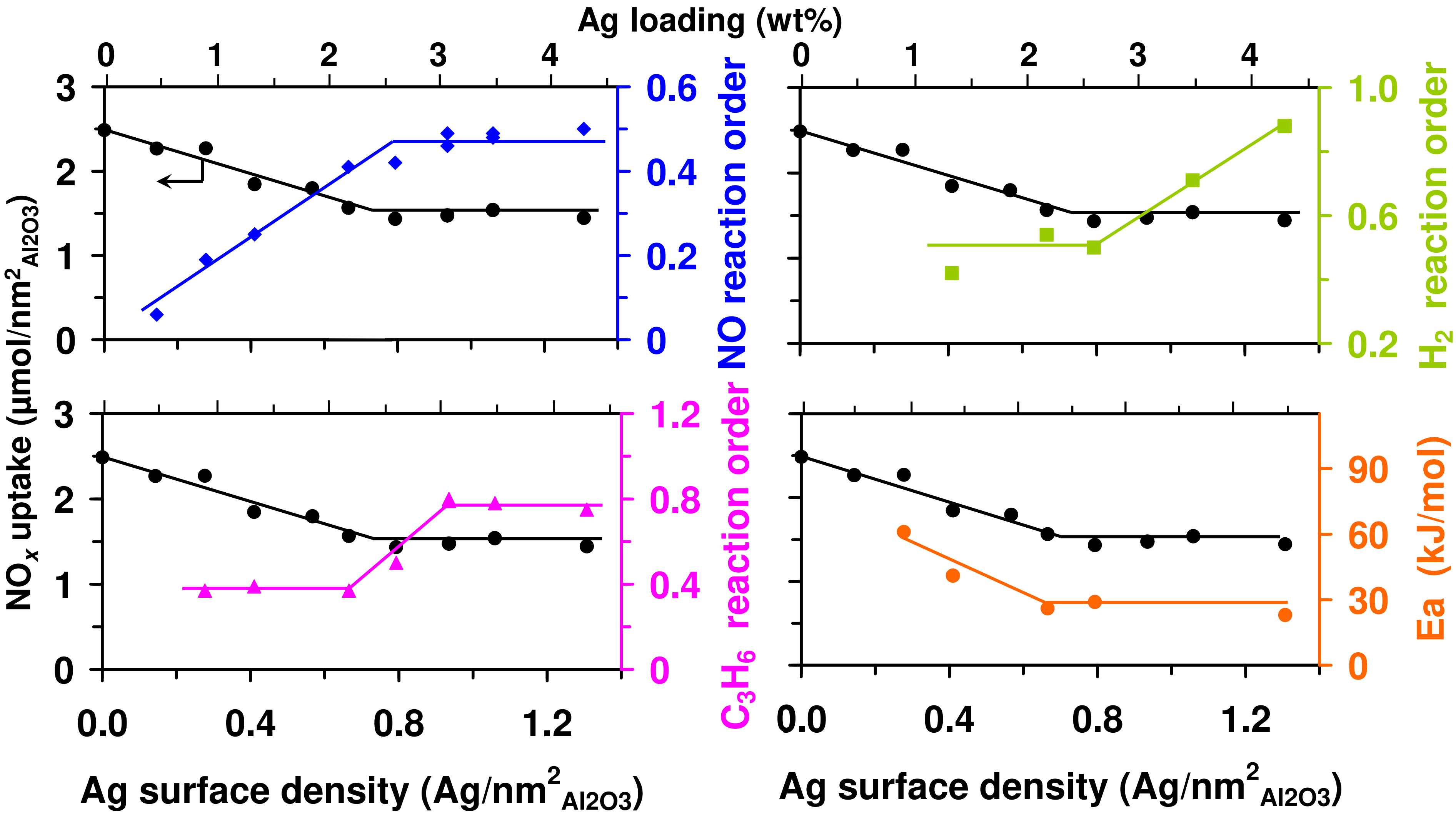
- ✓ Influence of the Ag loading on Al_2O_3 in H_2-C_3H_6-SCR
- ✓ H_2-C_3H_6-SCR kinetics – NO_x-TPD correlations

To gain further understanding of H_2-HC-SCR

Increase in N_2 production when the Ag loading ➘

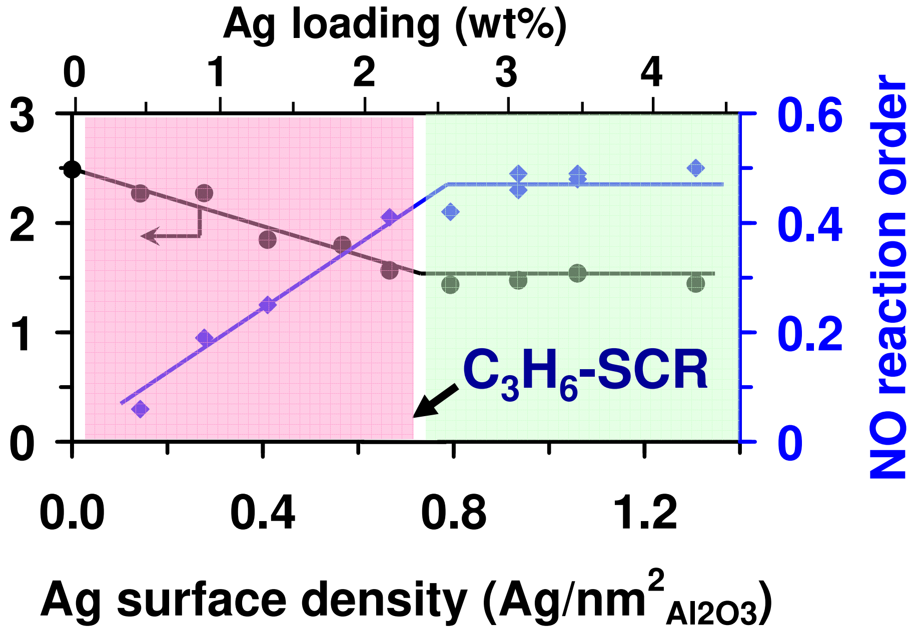


H_2-C_3H_6-SCR kinetics at 325 ° C



Remarkable kinetic parameters – NO_x uptake correlations

H_2-C_3H_6-SCR kinetics: NO reaction order



NO reaction order and NO_x uptake essentially constant for Ag loading > 2 wt%

and

changes for both for lower Ag loadings

NO_x species activated on Al_2O_3

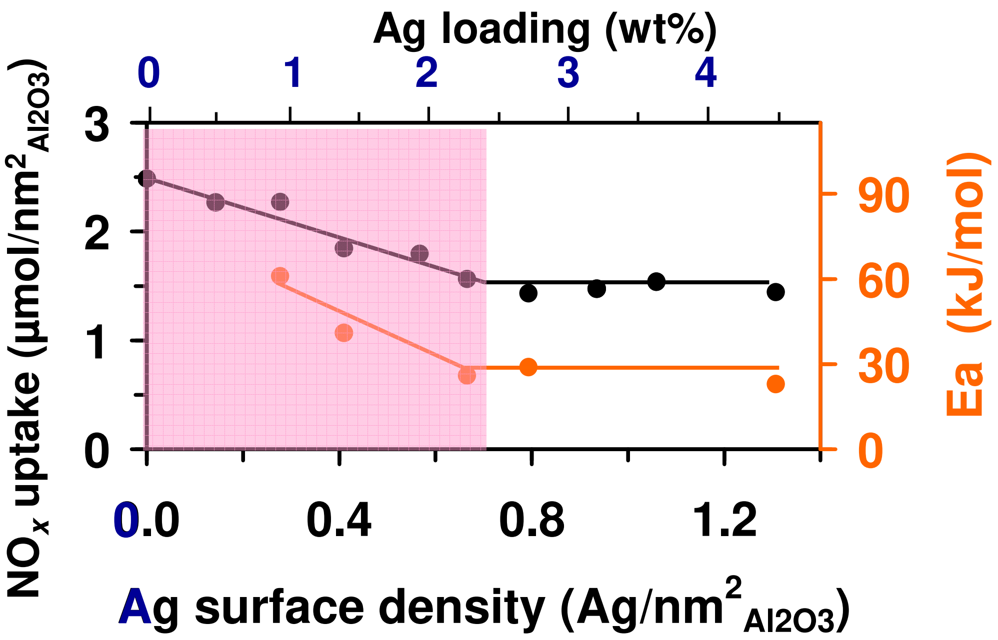
	NO order
C_3H_6-SCR	0
H_2-C_3H_6-SCR	+ 0.4

NO_x coverage depletion for H_2-C_3H_6-SCR due to the drastic increase in reaction rate

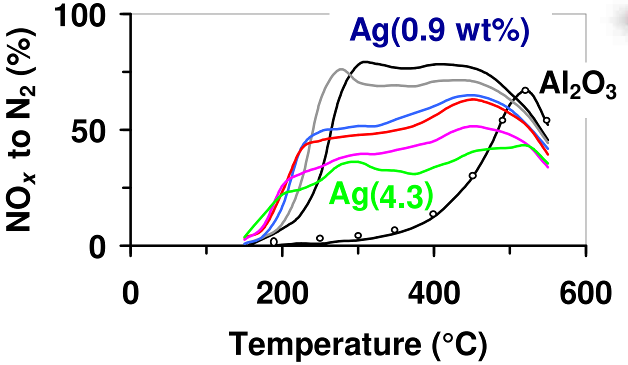
↘ in NO_3^- coverage with H_2 addition
Shimizu, Shibata, Satsuma, J. Catal. 239 (2006) 402

↗ NO reaction order when Ag loading ↗ → NO_x coverage depletion when Ag loading ↗ (in agreement with the ↘ in NO_x uptake)

H_2-C_3H_6-SCR kinetics: Activation Energy (E_a)



H_2-C_3H_6-SCR activity ↗ as
the Ag loading ↘
although E_a ↗



$$r\ N_2 = A_0 \exp(-E_a/RT)\ [NO]^{\alpha}\ [O_2]^{\beta}\ [C_3H_6]^{\gamma}\ [H_2]^{\eta}$$

Concentration of
active sites

compensation phenomenon between A_0 and E_a:
the more active samples also display the higher
number of NO_x adsorption sites

Conclusions

2- Is there any Ag loading optimum for H_2-C_3H_6-SCR ?

⬇

Contrary to C_3H_6-SCR:
no Ag loading optimum could be found for H_2-C_3H_6-SCR

(H_2-C_3H_6-SCR activity increases as the loading of Ag decreases)

⬇

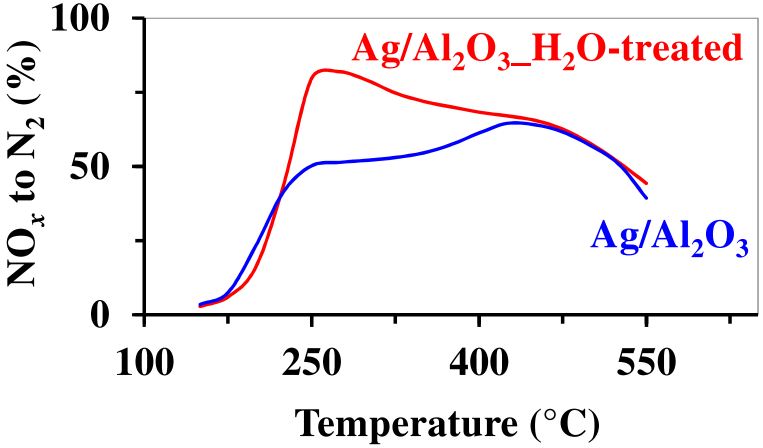
Kinetic parameters (reaction orders, E_a) – NO_x-TPD correlations

⬇

importance of NO_x coverage on Al_2O_3 for H_2-C_3H_6-SCR

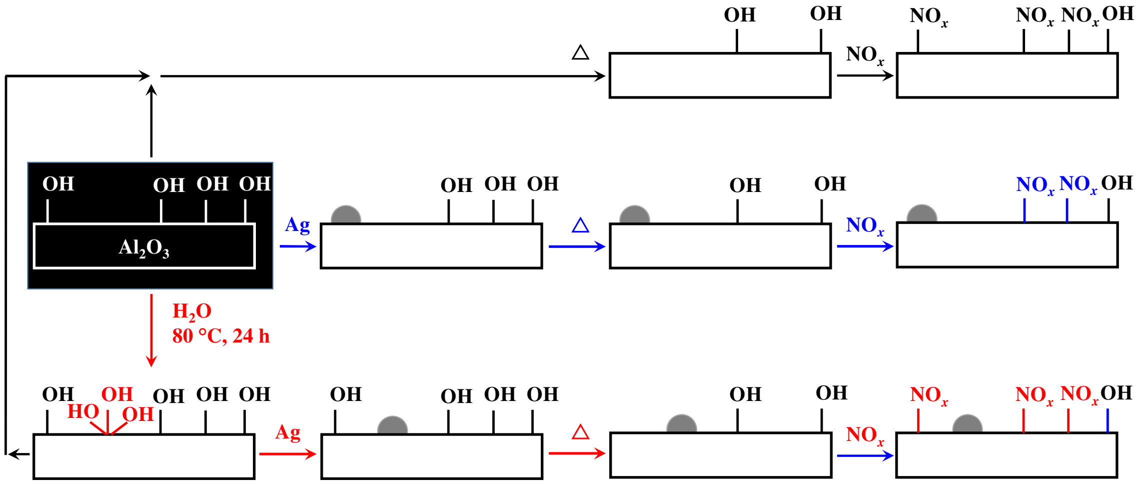
Promoting Ag/Al_2O_3 performance in low-temperature H_2-C_3H_6-SCR by support modification?

H_2-C_3H_6-SCR



NO_x-TPD data (μmol NO_x/g_{Al2O3})

	As-received	H_2O-treated
Al_2O_3	446	439
Ag/Al_2O_3	337	442



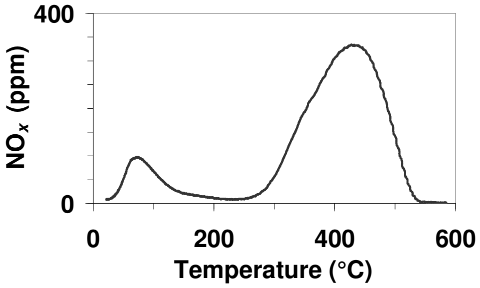
❶ Remarkable ↗ in H_2-C_3H_6-SCR on Ag/Al_2O_3-H_2O

❷ NO_x uptake preserved on Ag/Al_2O_3-H_2O

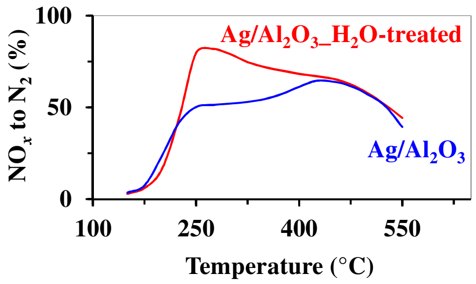
❸ Ag anchored onto sites newly-created on Ag/Al_2O_3-H_2O

Taieb, Delannoy, Louis, Thomas, Catal. Lett. 146 (2016) 2622

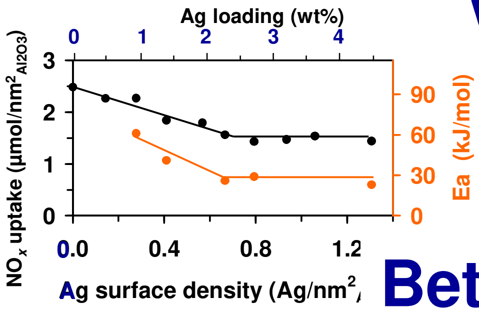
Concluding remarks



Discovery of a new method for the characterization of oxides (NO_x-TPD)

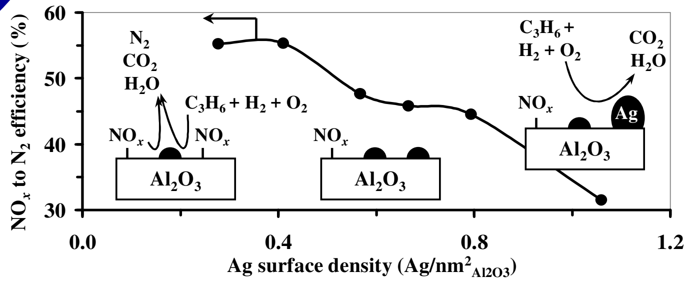


Structure – Activity (NO_x-TPD – H_2-C_3H_6-SCR) correlations



Design of more efficient catalysts for H_2-C_3H_6-SCR

Better understanding of the catalytic processes



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H. Jurado
O. Gorce
J. Chaubet
I. Manuel
S. Toppi
F. Baudin
C. Fontaine
N. El Kolli
M. Alame
A. Perrier

H-Y. Law
E. Pougoué
R.P. Doherty
K. Malinger
T. Bonnotte
T. Chaieb
S. Petit
J. Schnee
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D. Reja

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