CLEERS 2011 Workshop (Apr. 19-21, 2011) ♪

Urea/SCR Technology for removing NOx from Diesel Engine

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NOx emission standards

Emission standard for the diesel engine



Hackenberg et al., SAE, 2007-01-1239.



DeNOx technologies

Technology	Catalysts	Features	Limitations
<u>LNT</u>	- Pt/Ba/Al ₂ O ₃	 Cyclic operation Wide temperature window High activity No infrastructure problem 	 Periodic regeneration Sulfur tolerance High noble metal loading Low temperature activity
<u>HC/SCR</u>	 Ag/Al₂O₃ Pt/zeolite Cu/zeolite 	 Simple engine control Continuous operation HC (fuel) as reductant No infrastructure problem 	 Coking and HC slip Low temperature activity Poor durability and sulfur tolerance High fuel economy penalty
<u>Urea/SCR</u>	 Cu,Fe/zeolite V₂O₅/TiO₂ Mn/TiO₂ 	 Simple engine control Urea as reductant Wide temperature window High activity Mostly non-NM catalysts 	 Onboard urea tank / urea freezing Urea infrastructure NH₃/HC slip Public perception on the use of he avy metals including Cu & V as a cat alytic component



Superior deNOx performance of Urea/SCR technology



Personal Communication with Dr. Se Oh, GM R&D center



SCR by Urea

- Decomposition of urea
 - Thermal decomposition
 - $H_2N-CO-NH_2(s) \rightarrow NH_3(g) + HNCO(g)$
 - Hydrolysis of isocyanic acid
 - HNCO(g) + H₂O(g) \rightarrow NH₃(g) + CO₂(g)
 - Overall reaction
 - H_2N -CO- $NH_2(s) + H_2O(g)$ $\rightarrow 2NH_3(g) + CO_2(g)$
- Urea/SCR
 - $4NH_3(g) + 4NO(g) + O_2(g)$
 - $\rightarrow 4\mathrm{N}_{2}\left(\mathrm{g}\right)+6\mathrm{H}_{2}\mathrm{O}\left(\mathrm{g}\right)$
 - $2H_2N-CO-NH_2(s) + 4NO(g) + O_2(g)$ $\rightarrow 4 N_2(g) + 4H_2O(g) + 2CO_2(g)$



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Part A. Urea/SCR Catalysts

- i) Promising Eco-Friendly Urea/SCR catalysts
- ii) Deactivation of Urea/SCR catalysts
- iii) Fast SCR reaction





DeNOx performance over representative Urea/SCR catalysts

Catalyst: CuZSM5, FeZSM5 and V₂O₅-WO₃/TiO₂

Feed: 1,000 ppm NO, Variable amounts of NH₃ (10 ppm NH₃ slip), 10 % O₂, 5 % H₂O and N₂ balance
Reactor SV: 52,000 h⁻¹





CuCHA for the Urea/SCR technology

Catalysts: CuSSZ13, CuBEA and CuZSM5 Feed: 350 ppm NO, 350 ppm NH₃, 14 % O₂, 2 % H₂O and N₂ balance Reactor SV: 30,000 h⁻¹ Catalysts: Cu(2.9)SSZ13, Cu(3.8)SSZ16 and Cu(2.9)ZSM5 Feed: 500 ppm NO, 500 ppm NH₃, 10 % O₂, 0 % H₂O and N₂ balance Reactor SV: 42,500 cc/(h gcat) \rightarrow about 23,000 h⁻¹



Kwak et al., J. Catal., 275 (2010) 187.



Promising Eco-Friendly Low Temperature Urea/SCR catalyst

- Demand for ECO-friendly catalyst over Urea/SCR
 - The most common Urea/SCR catalysts using Heavy Metals
 - <u>CuZSM5 catalyst</u>
 - \rightarrow Best low temperature catalyst
 - $\frac{V_2O_5/TiO_2 catalyst}{V_2O_5/TiO_2 catalyst}$

 \rightarrow Most common commercial SCR catalyst for stationary source of NOx

Public Perception on Heavy Metals

Cu: cause of the disease of copper imbalance (Wilson's disease, Dioxin .. Etc) *Kim et al., Nat. Chem. Biol., 4 (2008) 176*

 V_2O_5 : toxicity and discharge from tail pipe (low melting point)

Li et al., *Chem. Commun.*, 12 (2008) 1470

Mn-based SCR catalyst

- A representative low temperature SCR catalyst, especially for the removal of NO x from stationary sources [Pena et al., J. Catal., 221 (2004) 421]
- Mn is commonly recognized as a less toxic metal compared to Cu, Ni and V [H. Hasan, Manganese, First ed, The Rosen Publishing Group, New York, 2008, pp. 31]

Mn-based catalyst may be a new ECO-friendly Urea/SCR catalyst.



Schematic Flow Diagram of NH₃(or Urea)/SCR Reactor System





DeNOx performance & N₂ selectivity over Mn-Fe catalysts

Catalyst: Mn-Fe/ZSM5, Mn-Fe/TiO₂, Mn-Fe/Al₂O₃ (impregnation) Mn-Fe/TiO₂ (sol-gel), CuZSM5 (ion-exchange)

Reaction condition: 500 ppm NO, 500 ppm NH₃, 5 % O₂, 10 % H₂O and N₂ balance.

Reactor SV: 100,000 hr⁻¹

 N_2 selectivity= [(Conversion of NO+NH₃)-(formation of N_2O+NO_2)] / (Conversion of NO+NH₃).



US Pat. Appl., 12/628,370 (2009. 12.01), Eur. Pat. Appl.,09177610.4-1270 (2009.12.01), Kor. Pat. Appl., 2008-0123578, (2008. 12. 05)

• Mn-Fe/ZSM5 catalyst shows excellent deNOx activity, N_2 selectivity and wider operating temperature window, compared to Mn-Fe/TiO₂ and Mn/Al₂O₃ catalysts.

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XPS spectra and atomic concentration of Mn

Catalysts: Mn-Fe/ZSM5, Mn-Fe/TiO₂, Mn-Fe/Al₂O₃ (impregnation)

Mn-Fe/TiO₂ (sol-gel), MnO_2 (reference), Mn_2O_3 (reference)



Atomic surface concentrations obtained by XPS spectra

◆ Mn over Mn-Fe based catalysts exists in a form of Mn⁴⁺, regardless of the catalysts.

• More Mn^{4+} exists on the surface of Mn-Fe/ZSM5 and Mn-Fe/TiO₂ (sol-gel) catalysts compared to M n-Fe/TiO₂ & Al₂O₃ prepared by impregnation method.



NH₃-TPD study over Mn-Fe catalysts

Catalysts: Mn-Fe/ZSM5, Mn-Fe/TiO₂, Mn-Fe/Al₂O₃ (impregnation), Mn-Fe/TiO₂ (sol-gel)



• Mn-Fe/ZSM5 catalyst shows much larger capacity of NH₃ adsorption, compared to th e Mn-Fe/TiO₂ and Mn-Fe/Al₂O₃ catalyst.



DeNOx performance over potential Urea/SCR Catalysts

Feed condition: 500 ppm NO, 500 ppm NH₃, 5 % O₂, 10 % H₂O and N₂ balance Reactor SV: 100,000 h⁻¹



Catal. Today, 151 (2010) 244.



Deactivation of Urea/SCR catalysts

Configuration of diesel after-treatment system



- Hydrothermal stability Hot exhaust gas stream
 - Top. Catal. 30/31 (2004) 37 and J. Catal. 240 (2006) 47.
- Sulfur tolerance Sulfur contained in fuel
 - Catalysis 16 (2002) 236.
- Hydrocarbon poisoning HC slip from diesel engine
 - Micropor. Mesopor. Mater., 141 (2011) 8 and Montreuil et al., SAE, 2008-01-1031.





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Hydrothermal stability of Urea/SCR catalysts

Catalysts: CuZSM5, FeZSM5 and V_2O_5 -WO₃/TiO₂ catalysts Feed: 500 ppm NO, 500 ppm NH₃, 5 % O₂, 10 % H₂O and N₂ balance Reactor SV: 100,000 h⁻¹ Aging condition: aged in air flow with 10% H₂O at 700 °C for 5 and 24 h





CuZSM5

Cause for thermal deactivation

Dealumination of ZSM5

Transformation of Cu²⁺ion

By loss of the Cu out of the lattice and its ag

glomeration (over-exchanged CuZSM5)

 $Cu^{2+} \rightarrow CuO \text{ or } Cu_2O$

~ Removal of the tetrahedral Al^{3+} , ~ The structural collapse of the zeolite \mathfrak{I}

 $Cu^{0} \xrightarrow[200\circ C]{1/2O_{2}} CuO \xrightarrow[2H^{+}/-H_{2}O]{} Cu^{2+} Cu^{2+} / [AlO_{2}^{-}]_{2} + H_{2}O + Al_{2}O_{3}$ Yan et al., J. Catal. 161 (1996) 43.

 \implies CuO/Al₂O₃ + 2H⁺/[AlO₂⁻].

Migration of Cu²⁺ ion

By migration of Cu^{2+} species to another location in ZSM5 where they are stabilized and become less active (<u>under-exchanged CuZSM5</u>)





Cause for thermal deactivation

FeZSM5

Reduction of acidity by dealumination of Fe-ZSM5

 \sim decrease of Brønsted acidity attributed to ammonia storage $\!$



Krocher et al., Appl. Catal. B, 66 (2006) 208.

V₂O₅₋WO₃/TiO₂

Phase transition of TiO₂

~ Anatase \rightarrow Rutile phase of TiO₂

Formation of crystalline V_2O_5

 \sim Transformation of monomeric vanadyl species in to crystalline V_2O_5



Catal. Today, 111 (2006) 242.



Hydrothermal stability of CuCHA

Catalysts: Cu(2.9)SSZ13 and Cu(3.8)ZSM5 catalysts Feed: 500 ppm NO, 500 ppm NH₃, 10 % O₂ and N₂ balance Reactor SV: 42,500 cc/(h gcat) \rightarrow about 23,000 h⁻¹ Aging condition: aged in N₂ balance with 5% H₂O and 10% O₂ at 750 °C for 3 or 7 h



Fickel et al., Appl. Catal. B, 102 (2011) 441.

Dealumination: extraction of Al³⁺ [Al(OH)₃ : 5.03 Å] The Al(OH)₃ unit cannot exit the pores of the SSZ13 framework [SSZ: 3.8 Å, ZSM5: 5.5 Å] → Reincorporation of Al(OH)₃ into the SSZ13 framework when the catalyst was cooled down.



SEM images (before/after hydrothermal aging)



Fickel et al., Appl. Catal. B, 102 (2011) 441.

The surface of CuZSM5 catalyst becomes rough upon the hydrothermal treatment, whereas the structural and morphological changes were hardly observed over CuSSZ13.



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Hydrothermal stability of the Mn-Fe/ZSM5 based and CuCHA catalysts

Catalysts: Mn-Fe/ZSM5, Mn-Fe-REM/ZSM5 and CuCHA catalysts Feed: 500 ppm NO, 500 ppm NH₃, 5 % O₂, 10 % H₂O and N₂ balance Reactor SV: 100,000 h⁻¹ Aging condition: aged in air flow with 10% H₂O at 650 °C for 24 h



US Pat. Appl., 12/628,370 (2009. 12.01), Eur. Pat. Appl.,09177610.4-1270 (2009.12.01), Kor. Pat. Appl., 2008-0123578, (2008. 12. 05)



XRD patterns of the Mn-Fe/ZSM5 based catalysts



The peaks attributed to the Mn₂O₃ over the aged Mn-Fe-REM/ZSM5 catalyst are much weaker compared to the aged Mn-Fe/ZSM5 catalyst

 \rightarrow The transformation of MnO₂ to Mn₂O₃ may be moderated upon the addition of REM.



Sulfur poisoning over Urea/SCR catalysts

Mechanism I



Catalyst sulfur content

2.88

300

7.34

380

Temperature (°C)

460

(wt %)

Mechanism II

$$SO_2 + O_2 \rightarrow SO_3$$

$$M + SO_3 \rightarrow MSO_4$$
 (metal sulfate)

Decomposed in higher temp. range (>700 °C)



Catal. Today 11 (1992) 611.

✓ Decomposition Temp: NH_4HSO_4 (400 °C), $(NH_4)_2SO_4$ (230 °C) and $AI_2(SO_4)_3$ (770 °C)

780

✓ Surface area was decreased as sulfur content increased

540

620

700



Veight (%)

80

60

60

Water

(1) CuHM (fresh)

140

(2) SO, 20,000 ppm 400 °C 1.78

220

(3) SO₂ 20,000 ppm 250 °C

(4) CuHM+(NH.),SO.

TG

Sulfur tolerance of Urea/SCR catalysts

Catalyst: **Mn-Fe/ZSM5, Mn-Fe-REM/ZSM5, CuCHA and CuZSM5** Feed: 500 ppm NO, 500 ppm NH₃, 5 % O₂, 10 % H₂O, 1 or 20ppm SO₂ and N₂ balance Reactor SV: 100,000 h⁻¹; Reaction Temperature: 200 °C





Retardation of NH₃/SCR performance by C₃H₆



Micropor. Mesopor. Mater., 141 (2011) 8.



Cause for retardation of NH₃/SCR by C₃H₆



Micropor. Mesopor. Mater., 141 (2011) 8. Nanba et al., J. Mol. Catal. A-Gen., 276 (2007) 130.

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CH₂=CHCN+O₂→COx+HCN

C₃H₆ inhibition

Retardation of SCR activity by C₃H₆ over Mn-Fe/ZSM5 based catalysts and CuCHA





Effect of NO₂/NOx ratio on deNOx performance



Stud. Sur. Sci. Catal., 159 (2006) 441.



SCR of NOx by NH₄NO₃ for enhancing low-temperature SCR activity

Catalysts: V₂O₅-WO₃/TiO₂ and FeZSM5 catalysts

Feed: 1,000 ppm NO or 500 ppm NO + 500ppm NO₂ (for Fast SCR), 1,000 ppm NH₃, 2 % O₂,





Forzatti et al., Angew. Chem. Int. Ed., 48 (2009) 8366.

 $2NH_3 + 2NO + (NH_4NO_3) \rightarrow 3N_2 + 5H_2O$



Forzatti et al., Ind. Eng. Chem. Res., 49 (2010) 10386.♪

Producing a key intermediate (HNO₃) in the Fast SCR reaction

The optimal concentration of NO₂ for the Fast SCR reaction may not be guaranteed at low tempera ture region (<200 °C), due to the low NO oxidation activity of DOC.

 \rightarrow Injection of NH₄NO₃ solution to feed-stream may be an alternative strategy to resolve this issue.



Reaction mechanism of fast SCR



Nova et al., Catal. Today, 114 (2006) 3.





Part B. Reaction Kinetics for Urea/SCR

- i) Urea decomposition kinetics
- ii) Urea/SCR kinetics for CuZSM5
- iii) Monolith reactor model for CuZSM5
- iv) Transient model





Reaction Kinetics & Model prediction (Urea thermal decomposition)





Reaction Kinetics & Model prediction (Urea thermal decomposition & hydrolysis of HNCO)



Feed: 250 ppm urea, 5 % O_2 , 2 % H_2O and N_2 balance; Thermal decomposition: 250 °C Catalyst: CuZSM5; After thermal decomposition: 250 ppm urea \rightarrow 115 ppm urea, 110 ppm HNCO and 125 ppm NH₃





Reaction Kinetics (NH₃/SCR over CuZSM5)





Model Prediction (NH₃/SCR over CuZSM5)

[Gas composition: 500 ppm NO, 500 ppm NH₃, 5 % O₂, 10 % H₂O and N₂ balance; SV: 100,000 ~ 400,000 h⁻¹]





Reaction Kinetics (Urea/SCR over CuZSM5)

• Urea

$$\frac{dX_{Urea}}{d\tau} = k_3(1 - X_{Urea})$$

$$\frac{dX_{HNCO}}{d\tau} = -\frac{k_3 C_{Urea}^0 (1 - X_{Urea})}{C_{HNCO}^0} + k_4 C_{H2O} (1 - X_{HNCO})$$

$$\frac{dX_{NO}}{d\tau} = \frac{k_1 C_{NH3}^0 (1 - X_{NO}) (1 - X_{NH3})}{\{1 + K_{NO} C_{NO}^0 (1 - X_{NO})\} \{1 + K_{NH3} C_{NH3}^0 (1 - X_{NH3})\}}$$

• NH₃

$$\frac{dX_{_{NH3}}}{d\tau} = \frac{k_1 C_{_{NO}}^0 (1 - X_{_{NO}}) (1 - X_{_{NH3}})}{\{1 + K_{_{NO}} C_{_{NO}}^0 (1 - X_{_{NO}})\} \{1 + K_{_{NH3}} C_{_{NH3}}^0 (1 - X_{_{NH3}})\}} + \frac{k_2 (1 - X_{_{NH3}})}{1 + K_{_{NH3}} C_{_{NH3}}^0 (1 - X_{_{NH3}})} - \frac{k_3 C_{_{Urea}}^0 (1 - X_{_{Urea}})}{C_{_{NH3}}^0} - \frac{k_4 C_{_{H2O}} C_{_{HNCO}} (1 - X_{_{HNCO}})}{C_{_{NH3}}^0}$$



Model Prediction (Urea/SCR over CuZSM5)

Effect of thermal decomposition reactor temperature

[Gas composition: 500 ppm NO, 250 ppm Urea, 5 % O_2 , 10 % H_2O and N_2 balance; SV: 100,000 h⁻¹]



 $T_{\text{Therm}} = 350 \text{ °C}$ Urea: 0 ppm, HNCO: 216 ppm, NH₃: 284 ppm T_{Therm} = 150 °C Urea: 143 ppm, HNCO: 107 ppm, NH₃: 107 ppm

Ind. Eng. Chem. Res.,45 (2006) 5260.♪



Monolith reactor fabrication♪

CuZSM5 p	owder	Washcoated honeycomb reactor		
Metal (Cu) content	2.9 wt.%	Porosity ^a	0.71	
Si/Al	14	Washcoats thickness	$27~\mu\mathrm{m}$	
Ion exchange level	97 %	Catalyst weight ^a	19.7 wt. %	
BET surface area	337 m ² /g	CPSI	200	

^a Washcoats (CuZSM5 + alumina binder, without cordierite)

SEM image









Monolith Reactor Model

Mole balance of the gas phase reactants in channel

$$-u\frac{dC_i^o}{dx} = k_{m,i}A_e(C_i^b - C_i^s) \qquad \text{at } \mathcal{I}x = 0 \qquad C_i^b = C_i^{b,0}$$

Mole balance over the catalyst layer of thickness dy

$$D_{e,i} \frac{d^2 C_i}{dy^2} = -r_i \qquad \text{at} \mathcal{Y} = 0 \qquad \frac{dC_i}{dy} = 0 \\ \text{at} \mathcal{Y} = R \qquad C_i = C_i^s$$

Mole balance at axial position x of the honeycomb reactor over the external gas film



• Identical conditions within each monolith channel

Ind. Eng. Chem. Res., 45 (2006) 5260.



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Model Prediction (NH₃/SCR over Monolith reactor)

Effect of Reactor SV

[Gas composition: 500 ppm NO, 500 ppm NH₃, 5 % O₂, 10 % H₂O and N₂ balance Catalyst: monolith reactor washcoated by CuZSM5; SV: 5,000 ~ 15,000 h^{-1}]



Ind. Eng. Chem. Res.,45 (2006) 5260.♪



Model Prediction (Urea/SCR over Monolith reactor)

Effect of Thermal Decomposition Reactor Temperature

[Gas composition: 500 ppm NO, 500 ppm NH_3 , 5 % O_2 , 10 % H_2O and N_2 balance Catalyst: monolith reactor washcoated by CuZSM5; SV: 10,000 h⁻¹]



Ind. Eng. Chem. Res.,45 (2006) 5260.♪



Transient Model (NH₃/SCR over CuZSM5 catalyst)

Governing equation for the gas species

$$\frac{w}{A_{\text{tot}}} \frac{\partial x_{\text{g},i}}{\partial z} = -k_{\text{m},i} S(x_{\text{g},i} - x_{\text{s},i}) = \sum_{j=1}^{\text{nr}} a_j s_{ij} r_j(T_{\text{s}}, c_{\text{s}}, \theta)$$

• Coverage of component k



- w: molar flow rate (mol/s)
- A_{tot} : front area of the monolith (m²)
- x_{g} : mole fraction of gas species
- x_s : mole fraction of gas species at surface
- $k_{\rm m}$: mass-transfer coeff. (mol/m²/s)
- S: geometric surface area per reactor volume (m ⁻¹)

a: active density (mol-site/m³)

- s: stoichiometric coeff.
- r: reaction rate (mol/mol-site/s)

• Reactions rate expressions for NH₃ adsorption/desorption, NH₃ oxidation and NO oxidation

Reaction number		Reaction	Reaction rate
1	NH ₃ adsorption/desorption	$NH_3 + S1 \xrightarrow{r_1} NH_3 - S1$	$r_1 = k_{1,f}c_{\mathrm{NH}_3}\theta_{\mathrm{S1-vacant}} - k_{1,b}\theta_{\mathrm{NH}_3-\mathrm{S1}}$
2	NH ₃ oxidation	$2NH_3 - S1 + \frac{3}{2}O_2 \xrightarrow{r_2} N_2 + 3H_2O + 2S1$	$r_2 = k_2 c_{\rm O2} \theta_{\rm NH_3-S1}$
3	NO oxidation	$NO + \frac{1}{2}O_2 \xrightarrow{r_3} NO_2$	$r_3 = k_{3,b} c_{\rm O_2}^{1/2} c_{\rm NO} - k_{3,b} c_{\rm NO_2}$

■ Reactions rate expressions for Standard SCR, Fast SCR, NO₂ SCR and N₂O formation

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Standard SCR Fast SCR NO₂ SCR N₂O formation

Olsson et al., Appl. Catal. B: Environ., 81 (2008) 203.



Model Prediction (NH₃/SCR over CuZSM5 catalyst)

Variation: Temperature

Feed: 500 ppm NO, 500 ppm NH₃, 8 % O₂, 5 % H₂O and Ar balance Reactor SV: 18,400 h⁻¹; Flow rate: 3,500cc/min

Variation: NH₃ concentration

Feed: 250 ppm NO, 250 ppm NO₂, 200~800 ppm NH₃ , 8 % O₂, 5 % H₂O and Ar balance Reactor SV: 18,400 h⁻¹; Flow rate: 3,500cc/min Reaction Temperature: 175 °C



Olsson et al., Appl. Catal. B: Environ., 81 (2008) 203.



Transient Model (other catalysts)

Fe/Zeolite catalyst

1. Eley-Rideal model: site 1 (surface acidic site) *Ind. Eng. Chem. Res., 50 (2011) 2850.* Predicting the conversion of NOx and NH₃ with respect to NO₂/NOx feed ratio.

2. Dual site model: site 1 (surface acidic site), site 2 (for the physisorbed NH₃ and NH₄NO₃) Sjövall et al., Ind. Eng. Chem. Res. 49 (2010) 39.
 Describing a variety of transient behaviors as a function of reaction temperature and concen tration of feed gas compositions.

V₂O₅-WO₃/TiO₂ catalyst

Redox kinetic model: site 1 (vanadyl species), site 2 (surface acidic site) Nova et al., AIChE J., 55 (2009) 1515, Tronconi et al., Ind. Eng. Chem. Res., 49 (2010) 10374. Unifying the Standard and Fast SCR reaction by redox mechanism

Describing the inhibition of deNOx performance by NH₃, which could be hardly predicted b y the previous model (Eley-Rideal based)

Modeling the transient behavior with respect to the feed gas composition including NOx and NH₃.



Summary

- Urea/SCR technology is one of the most promising technologies to meet the ever-tig htening worldwide environmental regulations including EURO V and SULEV for r educing NO emissions from diesel engine.
- CuZSM5, FeZSM5 and V₂O₅/TiO₂ catalysts have been recognized as a commercial catalyst for the Urea/SCR technology and the eco-friendly Mn-based catalyst devel oped and the CuSSZ13 catalyst recently reported may overcome the drawback of t he conventional catalysts.
- The deactivation of Urea/SCR catalyst including hydrothermal stability and Sulfur and HC tolerances should be resolved to directly apply to diesel after-treatment sys tem.
- The reaction kinetics developed well predict the reactor performance of urea deco mposition, NH₃/SCR as well as Urea/SCR over the wide range of experimental cond itions.
- A variety of transient kinetic models well describes the dynamic behavior over CuZ SM5, Fe/Zeolite and V₂O₅-WO₃/TiO₂ catalysts with respect to temperature, concent ration of feed gas compositions, etc.



Prospective Issues for urea/SCR technology

- Modification of the urea decomposition process to lower the urea decomposition temperature for guaranteeing the low-temperature activity of SCR catalysts.
- Combination of SCR technology with LNT or TWC catalytic system in cluding passive NH₃/SCR technology to remove NOx emitted from lean -burn engine.
- Application of Urea/SCR system to next-generation engine employing alternative fuel including biodiesel and diesel with alcohol, similar to E -85 for gasoline.
- Development of deactivation kinetic model for predicting the change of deNOx performance with respect to catalyst mileage.

Urea/SCR system for next-generation vehicle with high fuel efficiency under ever-tightening emission regulations



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