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Effect of CeO_2 for a high-efficiency CeO_2/WO_3-TiO_2 catalyst on the N_2O formation in NH_3-SCR: a kinetic study

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In this study, we investigated the effects of CeO_2 for a high-efficiency CeO_2/WO_3-TiO_2 catalyst on the N_2O formation in NH_3-SCR reaction using kinetic method. The results demonstrated that CeO_2 is very effective for enhancing SCR ($4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O$) reaction rate and thus depressing the NSCR reaction ($4NH_3 + 4NO + 3O_2 \rightarrow 4N_2O + 6H_2O$) due to the competition between these two reactions. Therefore, the N_2O formation under SCR reaction condition could be remarkably inhibited with the addition of CeO_2 to the catalyst. On the other hand, CeO_2 can also enhance the C-O reaction ($4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$) over the catalyst, so the N_2O formation under NH_3 oxidation condition was promoted due to the lack of SCR reaction. In addition, we also found another interesting phenomenon that the N_2O formation over WO_3-TiO_2 (without CeO_2) decreased gradually at high temperature from 350 to 450 °C, while the N_2O formation over CeO_2/WO_3-TiO_2 kept increasing with the reaction temperature, which was also associated with the promotional effect of CeO_2 on SCR reaction and the competition between SCR and NSCR reactions.

1. Introduction

Selective catalytic reduction of NO_x with NH_3 (NH_3-SCR) has been widely applied for the removal of NO_x generated from stationary sources since 1970s.[1] This technology has also become the dominant technology for meeting the ever tightened emission standards.[2,3] Due to the limited space onboard, one of the main challenges for diesel vehicles under increasingly stringent emission legislations is the reduction of catalyst volume, which requires the SCR catalyst should work efficiently under high space velocity conditions.[4]

Great efforts have recently been focused on the optimization of SCR catalysts for enhancing the catalytic efficiency and broadening the temperature window.[2,5,6] Ceria has been shown to be a very effective promoter for MnO_x-TiO_2,[7,8] V_2O_5/TiO_2,[9] and Fe-ZSM-5 catalysts[10]. In addition, ceria was widely used as the main active component[11-17] for NH_3-SCR catalysts.[18] In our previous study, a high-efficient CeO_2/WO_3-TiO_2 catalyst was prepared by a novel stepwise precipitation approach.[19] This catalyst showed excellent catalytic performance, with superior SCR activity, high N_2 selectivity and broad operation temperature window, even under extremely high space velocity conditions.

The main reaction under NH_3-SCR condition is the standard SCR reaction:

$$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O \quad (1)$$

At high temperature region, non-selective catalytic reduction reaction (NSCR reaction, reaction 2) and catalytic oxidation of NH_3 (C-O reaction, reaction 3), as two side reactions, will occurred simultaneously:

$$4NH_3 + 4NO + 3O_2 \rightarrow 4N_2O + 6H_2O \quad (2)$$

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O \quad (3)$$

The formed N_2O from reaction (2) is a strong greenhouse gas, which is usually notable at high temperatures and is mainly related to the NSCR reaction.[20] Isotopic labelling study has demonstrated that the two N atoms in N_2O are mainly due to a coupling of one nitrogen atom from NH_3 and the other one from NO.[21]

During the development of the CeO_2/WO_3-TiO_2 catalyst, we found that CeO_2 plays a key role in the catalyst for the excellent N_2 selectivity. In this study, we furtherly investigated the effects of CeO_2 for a CeO_2/WO_3-TiO_2 catalyst on the N_2O formation in NH_3-SCR reaction using kinetic method. Interestingly, we found that CeO_2 was effective for the inhibition of N_2O formation under SCR reaction condition over the catalyst, while it enhanced the N_2O formation under NH_3 oxidation condition. In addition, there was a peak of the N_2O formation at 350 °C over WO_3-TiO_2, but when CeO_2 was introduced the N_2O formation increased continuously with the increase of the reaction temperature over CeO_2/WO_3-TiO_2.

2. Experimental

2.1 Catalyst synthesis

The CeO_2/WO_3-TiO_2 catalyst was prepared by an optimized precipitation method. $Ce(NO_3)_3{\cdot}6H_2O$, $(NH_4)_{10}W_{12}O_{41}$ and $Ti(SO_4)_2$ were dissolved into distilled water together, with a Ce/W/Ti molar ratio of 0.2 : 0.1 : 1.0. Excessive urea was added into the mixed solution and then heated to 90 °C. After vigorous

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stirring for 12 h, the precipitated solids were collected by filtration and then washed with distilled water, dried at 100 °C for 12 h and calcinated at 500 °C for 5 h, orderly. In addition, a WO_3-TiO_2 catalyst was also prepared using the same method as a reference sample.

2.2 Catalytic test

Before NH_3-SCR activity test, the powder samples were pressed, crushed and sieved to 40-60 mesh. The SCR activity tests of the sieved powder catalysts were carried out in a fixed-bed quartz flow reactor at atmospheric pressure. The reaction conditions were controlled as follows: 500 ppm NO, 500 ppm NH_3, 5 vol.% O_2, N_2 balance, and 400 mL/min total flow rate. The effluent gas, including NO, NH_3, NO_2 and N_2O, was continuously analyzed by an online FTIR gas analyzer (Nicolet Antaris IGS analyzer). The concentration data were collected after 0.5 h when the SCR reaction reached a steady state.

2.3 Reaction kinetic study

To obtain the reaction rate constants of N_2 and N_2O formation over WO_3-TiO_2 and CeO_2/WO_3-TiO_2, steady-state kinetic investigations were performed. Gaseous NH_3 concentration in the inlet was kept at 500 ppm, while gaseous NO concentration varied from 0 to 700 ppm. To overcome the diffusion limitation (including inner diffusion and external diffusion), very high GHSVs were adopted to obtain less than 20% of NO_x conversion. The catalyst mass ranged from 3 to 200 mg for WO_3-TiO_2 and from 3 to 4 mg for CeO_2/WO_3-TiO_2, and the total flow rate was 200 or 400 mL min^{-1}.

2.4 Transient reaction study

To investigate the elemental reaction of N_2O formation over WO_3-TiO_2 and CeO_2/WO_3-TiO_2, transient reaction study was performed. The concentrations of NO, NH_3, NO_2, and N_2O in the outlet were recorded during passing 500 ppm of NO and 5% of O_2 over NH_3 (500 ppm) presorbed catalysts, and passing 500 ppm of NH_3 over NO (500 ppm) + O_2 (5%) presorbed catalysts, respectively.

2.5 *In situ* DRIFTS

To examine the surface NH_3 adsorbed species on WO_3-TiO_2 and CeO_2/WO_3-TiO_2, *in situ* DRIFTS study was performed. The in situ DRIFTS experiments were carried out on an FTIR spectrometer (Thermo Scientific Nicolet IS50) equipped with a smart collector and a MCT detector cooled by liquid nitrogen. The spectra were collected after the treatment of samples with 500 ppm NH_3 for 30 min and N_2 purge for 30 min. All spectra were recorded by accumulating 100 scans with a resolution of 4 cm^{-1}.

3. Results and discussion

3.1 NH_3-SCR performance

The NH_3-SCR performance of WO_3-TiO_2 and CeO_2/WO_3-TiO_2 were tested under a high GHSV of 400,000 h^{-1} (Fig. 1). The WO_3-TiO_2 showed almost no SCR activity in low temperature range. The NO_x conversion over WO_3-TiO_2 kept increasing with the reaction temperature and reached high level in the high temperature region. With the introduction of CeO_2 onto the surface of WO_3-TiO_2, the profile of NO_x conversion over CeO_2/WO_3-TiO_2 was quite different with that over WO_3-TiO_2. The low-temperature activity over CeO_2/WO_3-TiO_2 was remarkably enhanced, while the NO_x conversion exhibited a decrease trend in high temperature region due to the oxidation of NH_3, which even made the NO_x conversion over CeO_2/WO_3-TiO_2 being lower than that over WO_3-TiO_2 at 450 °C.

The N_2O formation profiles over WO_3-TiO_2 and CeO_2/WO_3-TiO_2 were also quite different with each other. The addition of CeO_2 remarkably inhibited the formation of N_2O during NH_3-SCR reaction in the whole temperature range. Interestingly, there was a peak value (37.4 ppm) of the N_2O formation appeared at 350 °C over WO_3-TiO_2, while the N_2O formation increased continuously with the increase of the reaction temperature over CeO_2/WO_3-TiO_2.

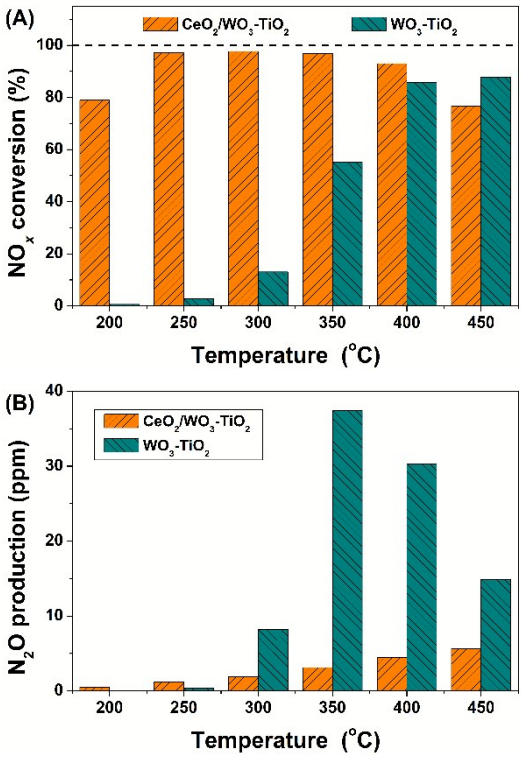

Fig. 1 (A) NO_x conversions and (B) N_2O formations during NH_3-SCR reactions over WO_3-TiO and CeO_2/WO_3-TiO_2. Reaction conditions: [NO] = [NH_3] = 500 ppm, [O_2] = 5 vol.%, N_2 balance and GHSV = 400,000 h^{-1}.

3.2 NH_3 oxidation

To investigate the origination of N_2O over the catalysts, NH_3 oxidation tests were carried out over WO_3-TiO_2 and CeO_2/WO_3-TiO_2 (Fig. 2). The NH_3 conversion over CeO_2/WO_3-TiO_2 was obviously higher than that over WO_3-TiO_2, indicating that the introduction of CeO_2 could promote the catalytic oxidation of NH_3. Different with the results of NH_3-SCR tests, the N_2O formation profiles over WO_3-TiO_2 and CeO_2/WO_3-TiO_2 were similar with each other. Both showed an increase trend of N_2O formation with the increase of reaction temperature. The introduction of CeO_2 significantly promoted the formation of N_2O during NH_3 oxidation reaction in the whole temperature range. In addition to N_2O, NO was also detected at high temperature region over both of the catalysts (inserted). The NO formation over CeO_2/WO_3-TiO_2 was higher than that over

WO_3-TiO_2, and both of them showed an increase trend with the increase of reaction temperature.

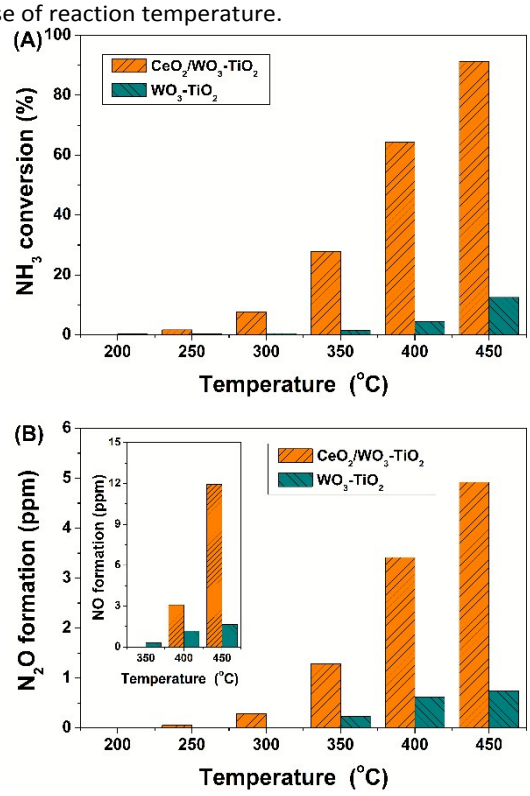

Fig. 2 (A) NH_3 conversions and (B) N_2O formations during NH_3 oxidation reactions over WO_3-TiO and CeO_2/WO_3-TiO_2. Reaction conditions: [NH_3] = 500 ppm, [O_2] = 5 vol.%, N_2 balance and GHSV = 400,000 h^{-1}.

3.3 Transient reaction

To investigate the mechanism of N_2O formation over WO_3-TiO_2 and CeO_2/WO_3-TiO_2, transient reaction analyses were performed at 350 °C (Fig. 3). When NO + O_2 passed over the NH_3 presorbed catalysts, N_2O rapidly formed over WO_3-TiO_2 (Fig. 3A). There was also a small amount of N_2O formed over CeO_2/WO_3-TiO_2 (Fig. 3B). The formation of N_2O during the tests were mainly through Eley-Rideal mechanism, i.e., the reaction between adsorbed NH_3 species and gaseous NO.[20, 22-24]

On the other hand, when NH_3 passed over NO + O_2 presorbed catalysts, no N_2O was detected over WO_3-TiO_2 (Fig. 3C). Small amount of N_2O with stable concentration was slowly and continuously formed over CeO_2/WO_3-TiO_2, which should be resulted from the NH_3 oxidation (Fig. 3D). It indicates that the N_2O formation according to Langmuir-Hinshelwood mechanism (the reaction between adsorbed NO_x and NH_3 species) could be neglected, and the reaction route for N_2O formation mainly follows Eley-Rideal mechanism under NH_3-SCR condition over both of the WO_3-TiO_2 and CeO_2/WO_3-TiO_2.[20, 22-24]

3.4 *In situ* DRIFTS study

The *in situ* DRIFTS of NH_3 adsorption were measured to examine the surface adsorbed NH_3 species on WO_3-TiO_2 and CeO_2/WO_3-TiO_2 (Fig. 4). After NH_3 adsorption at 350 °C, the observed bands at 1605 cm^{-1} and 1256, 1226/1249, 1220 cm^{-1} can be assigned to the asymmetric and symmetric bending vibrations of coordinated NH_3 linked to Lewis acid sites;[25-27] the bands at 3260, 3352 and 3385 cm^{-1} are assigned to the N-H stretching vibration modes of the coordinated NH_3;[26,28] the bands at 1422 cm^{-1} are assigned to the symmetric and asymmetric bending vibrations of NH_4^+ on Brønsted acid sites;[28-30] and the bands at 3685 and 3645 cm^{-1} are assigned to the hydroxyl consumption due to the interaction with NH_3 to form NH_4^+.[25,28] When the reaction temperature was decreased to 250 °C, a band at 1553 cm^{-1} due to the scissoring vibration mode of NH_2 species was observed on CeO_2/WO_3-TiO_2.[26,31] Since W and Ti species can play as acid sites for NH_3 adsorption, the NH_3 adsorption peaks on WO_3-TiO_2 were generally higher than those on CeO_2/WO_3-TiO_2. However, the activation of the adsorbed NH_3 species on WO_3-TiO_2 was much weaker than that on CeO_2/WO_3-TiO_2. Therefore, the band (1553 cm^{-1}) associated with NH_2 species was only observed on CeO_2/WO_3-TiO_2. Due to the higher capability for NH_3 activation, CeO_2/WO_3-TiO_2 catalyst is more active than WO_3-TiO_2 for NH_3-SCR and NH_3 oxidation.

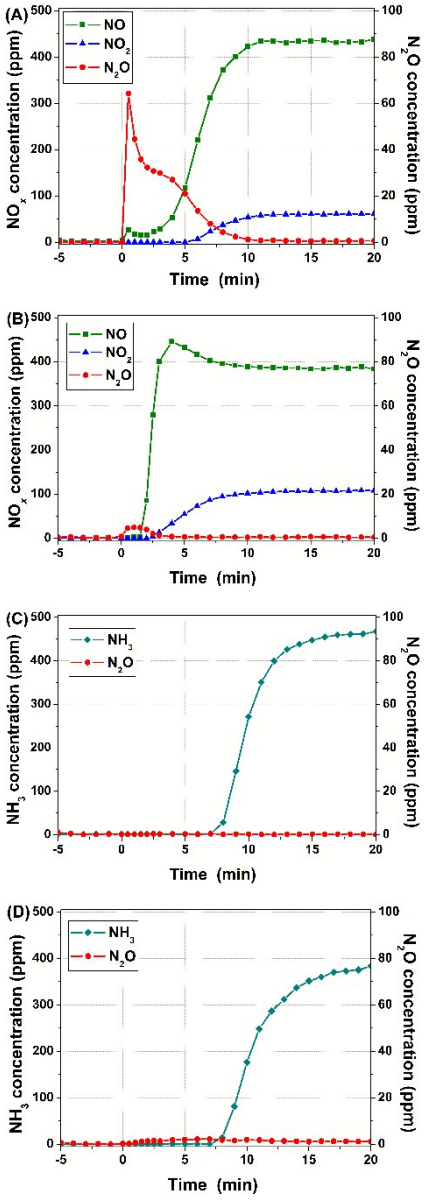

Fig. 3 Transient reactions at 350 °C upon passing 500 ppm NO + 5% O_2 over NH_3 presorbed (A) WO_3-TiO_2 and (B) CeO_2/WO_3-TiO_2 and passing 500 ppm NH_3 over NO + O_2 presorbed (C) WO_3-TiO_2 and (D) CeO_2/WO_3-TiO_2.

Many previous studies have focused on the reaction mechanisms of NH_3-SCR and selective catalytic oxidation of NH_3.[22-24,32] Based on these previous results and the *in situ* DRIFTS, the main reaction routes through Eley-Rideal mechanism can be described as follows:

$NH_{3(g)} \rightarrow NH_{3(ad)}$ (4)

$NH_{3(ad)} \rightarrow NH_2 + H$ (5)

$NH_2 \rightarrow NH + H$ (6)

$NH + O_2 \rightarrow NO + OH$ (7)

$NH_2 + NO_{(g)} \rightarrow N_2 + H_2O$ (8)

$NH + NO_{(g)} \rightarrow N_2O + H$ (9)

NH_3 is firstly adsorbed on the surface of catalyst (reaction 4). The adsorbed NH_3 species can be activated to form NH_2 species (reaction 5), and the formed NH_2 can be oxidized to NH (reaction 6). Further oxidation of NH will induce the formation of NO (C-O reaction, reaction 7). On the other hand, the formed NH_2 and NH species on the catalyst surface can react with gaseous NO to form N_2 (SCR reaction, reaction 8) and N_2O (NSCR reaction, reaction 9), respectively.

All of these three reactions would contribute to NH_3 consumption.[33,34] Therefore, the rate of NH_3 conversion (δ_{NH_3}) can be described as:

$$\delta_{NH_3} = \delta_{SCR} + \delta_{NSCR} + \delta_{C-O} \quad (10)$$

Where δ_{SCR}, δ_{NSCR} and δ_{C-O} refer to the reaction rates of SCR (*i.e.* N_2 formation), NSCR (*i.e.* N_2O formation), and C-O reactions, respectively.

Both of the SCR and NSCR reactions could contribute to NO consumption, while the C-O reaction contributes to NO formation. Therefore, the rate of NO conversion (δ_{NO}) can be described as:

$$\delta_{NO} = \delta_{SCR} + \delta_{NSCR} - \delta_{C-O} \quad (11)$$

From the equations (10) and (11), we can obtain the rate of C-O reaction as:

$$\delta_{C-O} = (\delta_{NH_3} - \delta_{NO})/2 \quad (12)$$

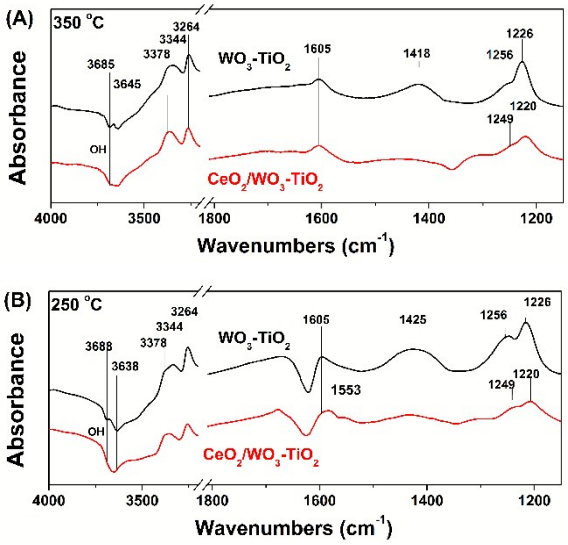

Fig. 4 *In situ* DRIFTS of NH_3 adsorption at (A) 350 °C and (B) 250 °C.

3.5 Steady-state reaction kinetic study

3.5.1 SCR reaction rates The SCR reaction rate was represented by the N_2 formation rate, while the N_2 formation was calculated by the following equation:

$$N_2 \text{ formation} = ([NO_x]_{in} + [NH_3]_{in} - [NO_x]_{out} - [NH_3]_{out} - 2[N_2O]_{out})/2 \quad (13)$$

The SCR reaction rates as a function of NO concentration over WO_3-TiO_2 and CeO_2/WO_3-TiO_2 were shown in Fig. 5. With the increase of NO concentration, both of the reaction rates over WO_3-TiO_2 and CeO_2/WO_3-TiO_2 increased gradually. Furthermore, the SCR reaction rates all showed excellent liner correlation with NO concentrations at each temperature, with the correlation coefficients for WO_3-TiO_2 and CeO_2/WO_3-TiO_2 all over 0.991 and 0.996, respectively. It is consistent with the previous test results on MnO_x-based catalysts, indicating that the reaction order of SCR over WO_3-TiO_2 and CeO_2/WO_3-TiO_2 with respect to gaseous NO concentration were both nearly 1.[20,24]

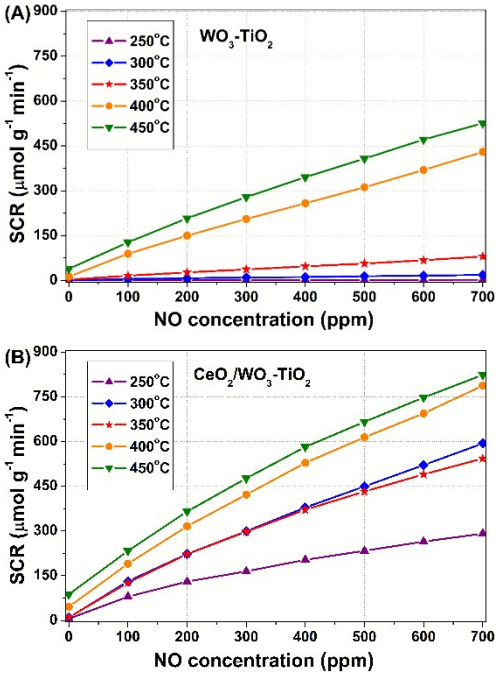

Fig. 5 SCR reaction rates as a function of gaseous NO concentration over (A) WO_3-TiO_2 and (B) CeO_2/WO_3-TiO_2. Reaction conditions: [NO] = 0-700 ppm, [NH_3] = 500 ppm, [O_2] = 5 vol.%, N_2 balance and catalyst mass = 3-200 mg.

At all the tested temperature points from 250 to 450 °C, the SCR reaction rates over CeO_2/WO_3-TiO_2 were obviously higher than those over WO_3-TiO_2, which is consistent with the SCR activity test result in Fig. 1(A), i.e., the SCR activity of CeO_2/WO_3-TiO_2 was much higher than that of WO_3-TiO_2.

3.5.2 C-O reaction rates The C-O reaction (oxidation of NH_3 to NO) rates, calculated by equation (12), as a function of NO concentration over WO_3-TiO_2 and CeO_2/WO_3-TiO_2 were shown in Fig. 6. Below 350 °C, both of the reaction rates over WO_3-TiO_2 and CeO_2/WO_3-TiO_2 were relatively low. When reaction temperature increased to 400 and 450 °C, the C-O reaction rates were remarkably promoted, particularly for CeO_2/WO_3-TiO_2. It indicates that more NH_3 could be oxidized to NO over

CeO_2/WO_3-TiO_2 at high temperature and the C-O reaction would induce significant influence on SCR reaction, which was the reason for the decrease of NO_x conversions over CeO_2/WO_3-TiO_2 during SCR activity test at high temperature, as shown in Fig. 1(A).

From Fig. 6 we can also see that, the C-O reaction rates over WO_3-TiO_2 and CeO_2/WO_3-TiO_2 both decreased with the increase of NO concentration, indicating that the C-O reaction rates over the two catalysts with respect to NO concentration were both lower than 0. At high temperatures, the C-O reaction rates of CeO_2/WO_3-TiO_2 were much higher than those of WO_3-TiO_2, which is consistent with the NH_3 oxidation results in Fig. 2, with higher NO formation over CeO_2/WO_3-TiO_2 at 400 and 450 °C.

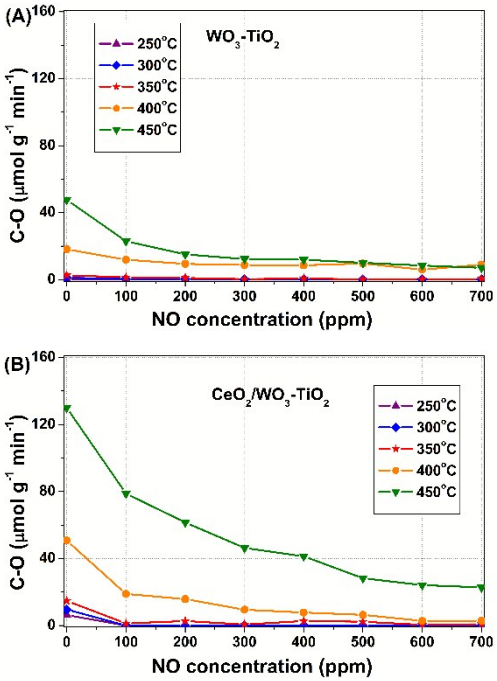

Fig. 6 C-O reaction rates as a function of gaseous NO concentration over (A) WO_3-TiO_2 and (B) CeO_2/WO_3-TiO_2. Reaction conditions: [NO] = 0-700 ppm, $[NH_3]$ = 500 ppm, $[O_2]$ = 5 vol.%, N_2 balance and catalyst mass = 3-200 mg.

3.5.3 NSCR reaction rates The NSCR reaction (represented by N_2O formation) rates as a function of NO concentration over WO_3-TiO_2 and CeO_2/WO_3-TiO_2 were shown in Fig. 7. The NSCR reaction rates of CeO_2/WO_3-TiO_2 were much lower than those of WO_3-TiO_2, which is consistent with the low N_2O formation of CeO_2/WO_3-TiO_2 during SCR activity test in Fig. 1(B).

With the increase of NO concentration, the NSCR reaction rates over WO_3-TiO_2 increased gradually, and the reaction rates remarkably correlated with NO concentration, with the liner correlation coefficients all above 0.957, indicating that the reaction order of NSCR with respect to NO concentration over WO_3-TiO_2 was 1. This result is different with the previously reported reaction order of 0 over MnO_x-based catalysts.[20,24] In addition, the reaction order over CeO_2/WO_3-TiO_2 was nearly 0, especially at high temperature region.

The NSCR reaction mainly follows the Eley-Rideal mechanism, i.e., adsorbed NH_3 species react with gaseous NO to form N_2O, as demonstrated by the transient reaction study in Fig. 3. Due to the low SCR and C-O reaction rates, the consumption of adsorbed NH_3 species over WO_3-TiO_2 was relatively low, thus the adsorbed NH_3 species on the surface of WO_3-TiO_2 would probably be sufficient for the NSCR reaction. Therefore, the reaction order of NSCR with respective to NO concentration could be 1.

Usually, the N_2O formation increase gradually with the reaction temperature during SCR reaction. Interestingly, we found that N_2O formation over WO_3-TiO_2 exhibited a decrease trend over 350 °C in the SCR performance tests, as shown in Fig. 1(B). However, the N_2O formation kept increase during NH_3 oxidation test in the absence of NO. To investigate the reason for the decrease of N_2O formation over WO_3-TiO_2, the N_2O selectivity during SCR activity test and the kinetic test were both calculated by the following equation:

$$N_2O \text{ selectivity} = \frac{2[N_2O]_{out}}{[NO_x]_{in} + [NH_3]_{in} - [NO_x]_{out} - [NH_3]_{out}} \times 100\%$$

$$= 1 - N_2 \text{ selectivity} \quad (14)$$

Similar with that of N_2O formation, both of the N_2O selectivity during activity test and kinetic test decreased gradually from 350 to 450 °C (Fig. 8). Considering the relatively high SCR reaction rates at 400 and 450 °C (Fig. 5A), the decrease of N_2O selectivity indicates intense competition between SCR and NSCR reactions at high temperatures over WO_3-TiO_2, which should be the main reason for the decrease of N_2O formation.

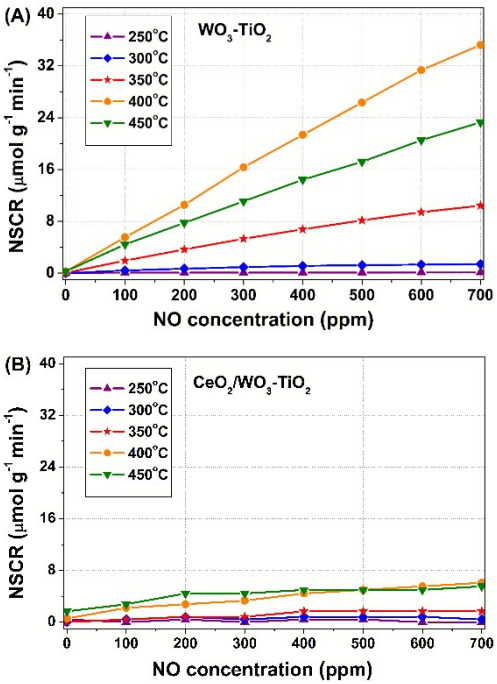

Fig. 7 NSCR reaction rates as a function of gaseous NO concentration over (A) WO_3-TiO_2 and (B) CeO_2/WO_3-TiO_2. Reaction conditions: [NO] = 0-700 ppm, $[NH_3]$ = 500 ppm, $[O_2]$ = 5 vol.%, N_2 balance and catalyst mass = 3-200 mg.

With the introduction of CeO_2, the CeO_2/WO_3-TiO_2 showed remarkably enhanced SCR reaction rate, and thus depressed the NSCR reaction. Therefore, the N_2O formation over CeO_2/WO_3-TiO_2 was very low. Without the feed of gaseous NO, SCR

reaction was inhibited during NH_3 oxidation test. Therefore, both of the N_2O formations over WO_3-TiO_2 and CeO_2/WO_3-TiO_2 increased gradually with the reaction temperature.

Previous studies on the mechanism of N_2O formation in NH_3 oxidation have revealed a two-step reaction pathway involving NO as an intermediate: (1) NH_3 is first oxidized to NO by O_2 (C-O reaction), and then (2) the NO react with adsorbed NH_3 species to form N_2O (NSCR reaction).[32,35-37] Therefore, the higher C-O reaction rate over CeO_2/WO_3-TiO_2 resulted in higher NO formation and thereby induced higher N_2O formation during the NH_3 oxidation in this study (Fig. 2B).

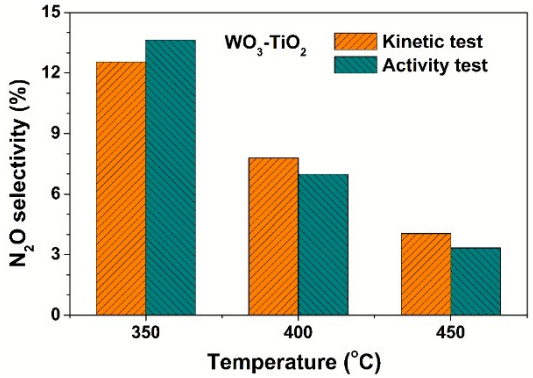

Fig. 8 N_2O selectivity in the NH_3-SCR reactions over WO_3-TiO_2 during kinetic study and activity test. Reaction conditions: [NO] = [NH_3] = 500 ppm, [O_2] = 5 vol.%, and N_2 balance.

Conclusions

The effects of CeO_2 for a high-efficiency CeO_2/WO_3-TiO_2 catalyst on the N_2O formation during NH_3-SCR reaction were investigated by kinetic method. Interestingly, we found that CeO_2 was effective for the inhibition of N_2O formation under SCR reaction condition over the catalyst, while it enhanced the N_2O formation under NH_3 oxidation reaction condition. The kinetic investigations showed that CeO_2 is very effective for enhancing SCR and C-O reaction rates and depressing the NSCR reaction. Therefore, the N_2O formation under SCR reaction condition could be remarkably inhibited due to the competition between SCR and NSCR reactions. On the other hand, under NH_3 oxidation condition without the feed of gaseous NO, the enhanced C-O reaction promoted N_2O formation due to the lack of SCR reaction.

In addition, we found another interesting phenomenon that the N_2O formation over WO_3-TiO_2 decreased gradually at high temperature from 350 to 450 °C, but when CeO_2 was introduced the N_2O formation kept increasing with the reaction temperature over CeO_2/WO_3-TiO_2. The different N_2O formation profiles of the two catalysts was also associated with the promotional effect of CeO_2 on SCR reaction and the competition between SCR and NSCR reactions.

Acknowledgements

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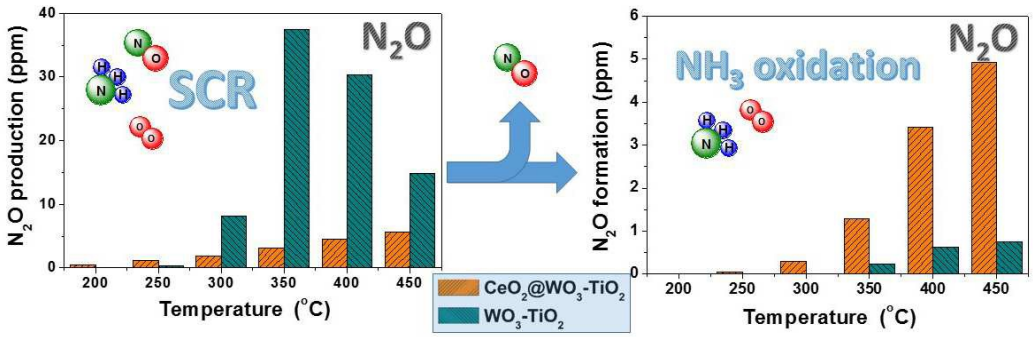

The effect of CeO_2 for a high-efficiency CeO_2/WO_3-TiO_2 catalyst on the N_2O formation in NH_3-SCR reaction was investigated using kinetic method.