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Design strategies for the development of a Pdbased acetylene hydrochlorination catalyst: improvement of catalyst stability by nitrogencontaining ligands†

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Acetylene hydrochlorination is an attractive chemical reaction for the manufacture of polyvinyl chloride (PVC), and the development efforts are focused on the search for non-mercury catalyst systems. Supported Pd-based catalysts have relatively high activity in the catalytic hydrochlorination of acetylene but are still deactivated rather quickly. Herein, we demonstrated that the atomically dispersed (NH₄)₂PdCl₄ complex, distributed on activated carbon, enabled the highly active and stable production of the vinyl chloride monomer (VCM) through acetylene hydrochlorination under low temperature conditions. We found that the presence of nitrogen-containing ligands in the structure of the active center could remarkably improve the stability of the Pd-based catalysts when compared with the case of the conventional PdCl₂ catalyst. Further analyses via X-ray diffraction (XRD), transmission electron microscopy (TEM), X-ray photoelectron spectroscopy (XPS) and temperature-programmed reduction (TPR) show that the variations in the Pd dispersion, chemical state and reduction property are caused by the nitrogen-containing ligands. Temperature-programmed desorption (TPD) characterizations illustrated that the N-containing ligands over the (NH₄)₂PdCl₄/AC catalyst might enhance the adsorption of HCl. These findings suggest that in addition to strategies that target the doping modification of support materials, optimization of the structure of the active center complexes provides a new path for the design of highly active and stable Pd-based catalysts.

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1 Introduction

Polyvinyl chloride (PVC) is commonly used in various manufacturing processes due to its advanced performance in mechanical enhancement, chemical inertness and stability. PVC is produced by the polymerization of the vinyl chloride monomer (VCM), synthesized either *via* the oxychlorination reaction of ethylene or *via* hydrochlorination of acetylene, and the latter approach usually employs supported mercuric chloride as a catalyst. However, mercuric chloride vapor may release into the environment easily under the reaction conditions and poison human beings and the environment. The Minamata Convention on Mercury was approved by delegates from over 140 countries in 2013 for limiting the emission and use of hazardous mercury, and now, the treaty has entered into

force. Considering the current severe mercury limitations, it is urgent to develop a new mercury-free catalyst for this process.

As the selection of non-mercury catalysts poses a significant

challenge, a number of catalytic formulations have been proposed including noble metal chlorides, 6-29 non-noble metal chlorides30-35 and even non-metallic materials.36-44 Among them, Pd catalysts have been considered to be very effective for the hydrochlorination of acetylene. For example, Hutchings et al. explored the catalytic performance of carbon supported with a series of metal chlorides and found that the conversion of acetylene to VCM decreased in the following order: Pd(II) > Hg(II) $> Cu(II) \sim Cu(I) > Ag(I) > Cd(II) > Zn(II)$.⁴⁵ Although the Pd-based catalysts exhibited excellent hydrochlorination activity, similar to most other precious metal catalysts, they could not maintain a high level of stability. It appears that the inherent volatilization loss of the Pd active species restrains the application of Pdbased catalysts for the hydrochlorination of acetylene. Therefore, the stabilization of volatile Pd active species under the reaction conditions has become an urgent technical issue to make acetylene hydrochlorination applicable.

To date, the main strategies used for the stabilization of Pd species are still focused on the doping modification of support materials to improve the stability of the metal catalysts by

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RSC Advances

enhancing the interactions of the Pd species with the supports. For example, Wang et al. showed that upon adjusting the surface acidity of the support, an NH₄F-modified Pd/HY catalyst delivered enhanced stability;46 Bao et al. showed that upon doping of the carbon structure with certain nitrogen species, the stability of the PdCl₂/AC-N catalyst was significantly improved.47 These experimental results suggest that one of the effective solutions to overcome the volatilization issue of Pd species is to develop a suitable support that can exhibit enhanced interaction with the Pd active centers. However, only few studies have been reported on the optimization of the structure of the active center to enhance the catalytic performance of Pd-based catalysts. Recently, it has been found that the coordination of an ionic liquid to the Pd active center can stabilize the Pd species against volatilization and then improve the catalytic stability. 48 In this study, the well-defined (NH₄)₂-PdCl₄ complex was prepared, and an attempt was made to explore the catalytic performance of the carbon-supported (NH₄)₂PdCl₄ complex catalysts. It was found that the (NH₄)₂-PdCl₄ active center could significantly stabilize the Pd species. Furthermore, the stabilization mechanism of Pd species in the (NH₄)₂PdCl₄/AC catalyst was proposed on the basis of TEM, XPS, ICP, H2-TPR and TPD characterization. To the best of our knowledge, this is the first study that reports the use of nitrogen-containing Pd complexes in the preparation of supported Pd-based catalysts for acetylene hydrochlorination.

Experimental 2

Catalyst preparation 2.1

The (NH₄)₂PdCl₄ complex was synthesized according to the literature. 49,50 The representative procedures were conducted as follow: 35.3 mg H₂PdCl₄ (Sigma-Aldrich) and 23 mg NH₄Cl (Sigma-Aldrich) were dissolved in 8 ml water at 80 °C via ultrasonication for 60 min to obtain yellow-brown (NH₄)₂PdCl₄ crystals, and then, the catalyst preparation was conducted using an incipient wetness impregnation technique; after this, 3 g of active carbon was added to the abovementioned mixture under agitation. After drying the mixture for 12 h at 110 °C in an oven under vacuum, the synthesized catalyst was obtained, named (NH₄)₂PdCl₄/AC. A carbon-supported PdCl₂ catalyst (PdCl₂/AC) was synthesized as a reference catalyst following the abovementioned methods except for the addition of the reagent NH₄Cl. Unless otherwise specified, the loading amount of Pd in all Pd-based catalysts was 0.5 wt%.

2.2 Catalyst characterization

XPS spectra were obtained by the Kratos AXIS Ultra DLD apparatus, with a monochromatized aluminum X-ray source, and the passing energy was 40 eV. The C 1s line (284.8 eV) was adopted as the corrected benchmark for all the measured spectra. The specific surface areas were measured using N₂ adsorptiondesorption at 77 K via the Micromeritics ASAP 2000 instrument. TEM was used to characterize the catalyst morphology and microstructures via the Tecnai G2 F30 S-Twin electron microscope. The TPD was conducted in a tubular quartz reactor.

Herein, 75 mg of each catalyst sample was initially treated with pure C₂H₂ or HCl at 180 °C for 30 min; after adsorption and sweeping with pure Ar for 60 min at the gas flow rate of 30 ml min⁻¹, a temperature-programmed route was carried out from 25 °C to 550 °C at the heating rate of 10 °C min⁻¹.

2.3 Catalytic test

Activity tests for the hydrochlorination of acetylene were conducted in a heterogeneous fixed-bed reactor. Prior to the reaction, nitrogen (N₂) was passed through the reactor for 30 min to remove any water and air remaining. Then, C_2H_2 (5 ml min⁻¹, 1 bar) and HCl (6 ml min⁻¹, 1 bar) were added to the clean and dry reactor using a mass flow controller. The output gas products were passed through a vessel with the NaOH solution to remove excess HCl. The composition of the output was analyzed by gas chromatography (GC-9790A).

3 Results and discussion

3.1 Catalytic performance of Pd-based catalysts

The catalytic performances of (NH₄)₂PdCl₄/AC and PdCl₂/AC catalysts are shown in Fig. 1 at the reaction temperature of 100 °C and C₂H₂ GHSV of 100 h⁻¹. We could observe that the (NH₄)₂PdCl₄/AC catalyst showed superior catalytic performance than that of the PdCl₂/AC catalyst, resulting in a 99.7% acetylene conversion (Fig. 1a) and 99.5% VCM selectivity (Fig. 1b). Compared with PdCl₂/AC, the (NH₄)₂PdCl₄/AC catalyst also shows a remarkable robust catalytic behavior under these conditions. Note that the acetylene activity of the catalyst (NH₄)₂PdCl₄ at this low temperature (100 °C) was equivalent to that of the typical Pd-based catalyst reported at high temperatures (typically exceeding 140 °C, as listed in Table S1†).

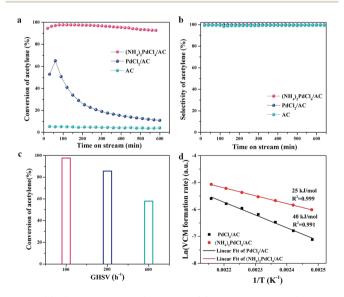


Fig. 1 (a) Conversion of C₂H₂ and (b) selectivity to VCM over $(NH_4)_2$ PdCl₄/AC, PdCl₂/AC and AC catalysts. Reaction conditions: T =100 °C, GHSV(C_2H_2) = 100 h^{-1} , and HCl/ C_2H_2 = 1.2. (c) Catalytic activity of (NH₄)₂PdCl₄/AC as a function of space velocities. Reaction conditions: T = 100 °C and HCl/C₂H₂ = 1.2. (d) Arrhenius plot for VCM formation using the (NH₄)₂PdCl₄/AC and PdCl₂/AC catalysts.

Paper

The effect of space velocity on the hydrochlorination of acetylene was further investigated. As shown in Fig. 1c, the acetylene conversion remained at 85% and 57% as the space velocity of C_2H_2 was increased from $100\ h^{-1}$ to $200\ h^{-1}$ and then to $600\ h^{-1}$ at $100\ ^{\circ}$ C, respectively. We have demonstrated that the designed (NH₄)₂PdCl₄/AC catalyst is suitable for the hydrochlorination of acetylene in a wide range of space velocities.

To further clarify the structural evolution of the active phase for $PdCl_2/AC$ and $(NH_4)_2PdCl_4/AC$, the kinetic behaviors were discussed by calculating the approximate activation energy (E_a) (Fig. 1d). Ea was calculated based on the Arrhenius plots (ln(R) versus 1/T), and all the kinetic data were obtained and calculated at the level of <15% yield of vinyl chloride, which excluded the effect of internal and external diffusion. Contrary to the E_a calculated for the $PdCl_2/AC$ catalyst, the E_a of $(NH_4)_2PdCl_4/AC$ was markedly decreased from 40 to 25 kJ mol⁻¹. The improvement in the catalytic performance may be assigned to the modulation of the intrinsic structure of the catalysts as well as the synergetic effect of Pd and the nitrogen-containing ligands on the catalytic performance.

3.2 Catalytic characterization

As shown, $(NH_4)_2PdCl_4/AC$ illustrated excellent catalytic performance for the hydrochlorination of acetylene. To elucidate the influence of nitrogen-containing ligands on the catalyst microstructure, valence and adsorption properties, a series of structural characterizations were employed to analyze the Pdbased catalysts. XRD analysis was employed to probe the characteristics of the support and the Pd species. No discernible Pd⁰ characteristic diffraction peaks were observed in the XRD patterns of the fresh $(NH_4)_2PdCl_4/AC$ and $PdCl_2/AC$ catalysts; this suggested that most of the Pd species were present in small nanoclusters and/or non-crystalline isolated atoms (Fig. 2).

Fig. 3 shows an HAADF-STEM image of the (NH₄)₂PdCl₄/AC and PdCl₂/AC catalysts. As observed, the HAADF-STEM analysis clearly demonstrated the existence of isolated Pd atoms with high number density in (NH₄)₂PdCl₄/AC (Fig. 3a). They are observed as bright spots evenly distributed on the surface of carbon. The light dots cannot be attributed to nitrogen species as nitrogen species cannot be distinguished from carbon in the current analysis mode. Therefore, the light dots must be assigned to Pd species. Furthermore, since the light gray dot has the typical size of 2-3 Å, these dots should be mainly assigned to single atoms/cations. For PdCl₂/AC, it can be observed that except for the presence of isolated Pd atoms as big bright white spots, the image also illustrates the presence of Pd clusters with a few atoms (Fig. 3b). This observation provides a good reason to believe that the single isolated Pd atoms can be the active sites for the reaction, providing the observed promotion of the catalytic activity. More importantly, except for the amorphous diffraction peaks of carbon, no discernible diffraction peak was detected in the XRD pattern of the used (NH₄)₂PdCl₄/AC and PdCl₂/AC catalysts (Fig. 2); this indicated that the used Pd-based catalysts did not show the aggregation of particles.

Further insights into the material structure were obtained by X-ray photoelectron spectroscopy, and the deconvolution

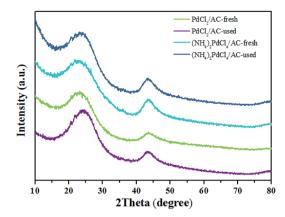


Fig. 2 XRD patterns of the $(NH_4)_2PdCl_4/AC$ and $PdCl_2/AC$ catalysts.

results are shown in Table 1 and Fig. 4. It is apparent that the catalyst prepared with the (NH₄)₂PdCl₄ precursor presents a relatively high amount of N species (3.12%), which is absent in the PdCl₂/AC sample; this indicates that nitrogen-containing ligands can remain stable during the preparation process. More importantly, the proportion of surface N/C has no dramatic changes before and after the reaction (Table 1 and Fig. 4b); this indicates that the (NH₄)₂PdCl₄ phase does not obviously decompose during the reaction. The structure of the (NH₄)₂PdCl₄ phase can remain relatively stable on the AC support. In addition, the surface content of Pd is 0.32% and 0.31% for the fresh (NH₄)₂PdCl₄/AC and PdCl₂/AC catalysts according to the XPS analysis, respectively, suggesting that the Pd species have been well dispersed on the support. After the reaction, the content of the Pd species reduces obviously to only 0.18% for PdCl₂/AC; this may be explained by the leaching of Pd

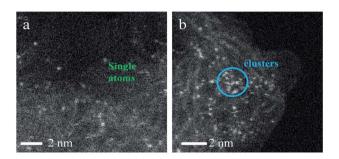


Fig. 3 Aberration-corrected HAADF-STEM images of the (a) $(NH_4)_2$ -PdCl₄/AC and (b) PdCl₂/AC catalysts.

Table 1 Surface composition of the fresh and used $(NH_4)_2PdCl_4/AC$ and $PdCl_2/AC$ catalyst, determined by XPS

Catalysts	Elemental composition (wt%)			
	C	Cl	Pd	N
Fresh (NH ₄) ₂ PdCl ₄ /AC	94.28	2.28	0.32	3.12
Fresh PdCl ₂ /AC	97.12	2.57	0.31	_
Used (NH ₄) ₂ PdCl ₄ /AC	93.62	3.14	0.28	2.96
Used PdCl ₂ /AC	95.26	4.56	0.18	_

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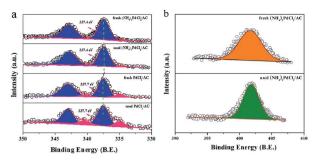


Fig. 4 (a) XPS spectra and simulation of the fresh and used $(NH_4)_2$ -PdCl₄/AC and PdCl₂/AC catalysts. (b) N 1s spectra for the fresh and used (NH₄)₂PdCl₄/AC catalyst.

species; by contrast, there is a negligible change in the content of the Pd species for the used (NH₄)₂PdCl₄/AC catalyst, which may be fairly stable in the reaction environment. Consistent with the XPS analysis, the ICP results of the fresh and used (NH₄)₂PdCl₄/AC and PdCl₂/AC catalysts also revealed that the Pd species was more stable in the presence of nitrogen-containing ligands (Table 2). Actually, the leaching of the PdCl₂ active component was often thought to be the cause of deactivation for Pd-based catalysts in the hydrochlorination of acetylene. 44-46,51,52 For example, Wang41 demonstrated that 44.7% Pd species had leached from HY zeolite-supported Pd-based catalysts after reaction; in addition, Wang suggested that the Pd loss was responsible for the deactivation of the Pd/HY catalysts, and the ICP analysis indicated that about 37.8% Pd species had been lost after 10 h time on stream as compared to the case of the fresh catalyst.

Fig. 4a displays the high-resolution spectra for the Pd 3d regions of Pd-based catalysts. The binding energies of the Pd 3d_{5/2} signals for the fresh (NH₄)₂PdCl₄/AC catalyst at 337.4 eV and 335.1 eV correspond to the Pd2+ and Pd0 species (Fig. 4a).53,54 It is well-accepted that Pd in the cationic form works as an active species for acetylene hydrochlorination. However, the Pd 3d_{5/2} signals of the (NH₄)₂PdCl₄/AC catalyst, corresponding to Pd2+, which represent a negative shift of 0.3 eV as compared to that of the PdCl₂/AC catalyst (337.7 eV), demonstrate that the electronic structure of Pd changes with the incorporation of nitrogen-containing ligands. Table 3 lists the relative ratio of Pd2+/Pd0 for the fresh and used Pd-based catalysts. The results indicate that the Pd2+/Pd0 ratio in the used catalysts observably decreases when compared with that for the fresh catalysts; this indicates that the active Pd²⁺ species has been reduced under the reaction conditions. However, the (NH₄)₂PdCl₄/AC catalyst experiences a slower reduction during

Table 2 Pd contents of the fresh and used (NH₄)₂PdCl₄/AC and PdCl₂/ AC catalysts, determined by ICP

		Results of ICP (wt%)		
Catalysts	Nominal loading wt%	Fresh	Used	Loss ratio of Pd (%)
(NH ₄) ₂ PdCl ₄ /AC PdCl ₂ /AC	0.5 0.5	0.52 0.53	0.46 0.32	11.5 39.6

Table 3 The relative ratio of Pd²⁺/Pd⁰ for Pd-based catalysts

Catalysts	Pd ²⁺ /Pd ⁰ ratio		
Fresh (NH ₄) ₂ PdCl ₄ /AC	14.46		
Used (NH ₄) ₂ PdCl ₄ /AC	14.07		
Fresh PdCl ₂ /AC	7.54		
Used PdCl ₂ /AC	6.34		

the reaction for the Pd²⁺ species when compared with the PdCl₂/ AC catalyst. This is likely one of the reasons for the rapid deactivation observed for PdCl2/AC as compared to that of (NH₄)₂PdCl₄/AC. Thus, nitrogen-containing ligand modalities that can enhance the stability of the Pd2+ species are very important for the practical applications of these catalysts.

H₂-TPR was employed to analyse the reduction ability of the active cationic Pd species. For both PdCl₂/AC and (NH₄)₂PdCl₄/ AC, a discernible characteristic reduction band in the range of 500-800 °C can be observed (Fig. 5). This band was attributed to the reduction of the surface oxygenated groups on the AC support.55 Apart from this, the clear bands at around 160-250 °C were due to the reduction of the cationic Pd species. The TPR profiles were analyzed by peak-differentiation-imitating analysis (Fig. S1†).56 Through calibration with a CuO standard, the Pd^{2+} content for the fresh catalysts can be estimated (Table S2†); the estimated Pd2+ contents for the fresh PdCl2/AC and (NH₄)₂PdCl₄/AC catalysts are ca. 76.3% and 80.2%, respectively, which are consistent with the XPS analysis results. A more pronounced change occurred in the reduction temperature of the Pd²⁺ species. It can be seen clearly from the graph that for the (NH₄)₂PdCl₄/AC catalyst, the peak for Pd²⁺ reduction is evidently increased as compared to that of PdCl₂/AC (Fig. 5). The increased reduction temperature of (NH₄)₂PdCl₄/AC can be attributed to the existence of nitrogen-containing ligands, which probably inhibit the reduction of the cationic Pd species.

The surface areas of the Pd-based catalysts were evaluated via the low-temperature N2 adsorption/desorption experiments. Table 4 lists the catalyst texture parameters of the Pd-based catalysts. It is shown that the AC support has a microporous

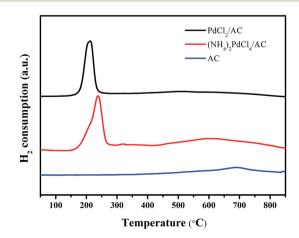


Fig. 5 H_2 -TPR profiles of the fresh $(NH_4)_2$ PdCl₄/AC and PdCl₂/AC catalysts.

Paper

Table 4 Surface areas of the AC support and Pd-based catalysts

	$S_{\rm BET} \left({\rm m}^2 \ {\rm g}^{-1} \right)$		
Catalysts	Fresh	Used	$\Delta S_{\mathrm{BET}} \left(\mathrm{m}^2 \; \mathrm{g}^{-1} \right)$
AC (NH ₄) ₂ PdCl ₄ /AC PdCl ₂ /AC	1162.1 1056.1 1081.3	— 836.5 614.4	— 219.6 466.9

structure, and the specific surface area is up to 1162.1 $\text{m}^2\text{ g}^{-1}$. Fresh catalysts, including PdCl₂/AC and (NH₄)₂PdCl₄/AC, show specific surface areas lower than that of the AC support probably due to the blockage of pores by the active Pd species. In addition, the used catalysts exhibit lower specific surface areas when compared with those of the fresh catalysts. For example, about 43.1% of the specific surface area is lost after reaction for 10 h. The loss of the active surface area may be caused by carbon deposition (acetylene may oligomerize over the catalyst) on the catalyst surface, which may result in clogged pores and decreased catalyst activity; moreover, this is likely the cause for catalyst deactivation. However, the surface area loss was only 20.8% for (NH₄)₂PdCl₄/AC. This result indicates that the amount of coke deposition is significantly reduced when (NH₄)₂PdCl₄ is used for Pd-based catalysts although the underlying mechanism for this reduction requires further investigation.

3.3 Mechanism insight

The adsorption and activation of substrates are important steps in a catalytic reaction. Through TPD characterization, we studied the adsorption properties of the two substrates C₂H₂ and HCl over the (NH₄)₂PdCl₄/AC and PdCl₂/AC catalysts. In Fig. 6, the individual C₂H₂-TPD results exhibit that the desorption temperature of the surveyed catalysts follows the order of PdCl₂/AC (387 °C) < (NH₄)₂PdCl₄/AC (410 °C), demonstrating that (NH₄)₂PdCl₄/AC displays strong adsorption capacity for C₂H₂, followed by PdCl₂/AC. The reactivity of Pd²⁺ towards C_2H_2 is usually explained by π -coordination and σ coordination between the Pd2+ and triple bond of C2H2; thereby, C₂H₂ is activated. In addition, by comparing the desorption temperature of C₂H₂ for the two catalysts, it was found that the

adsorption capacity of (NH₄)₂PdCl₄/AC to C₂H₂ was stronger than that of PdCl₂/AC. Similar phenomena were found in the results of HCl-TPD, where (NH₄)₂PdCl₄/AC exhibited a stronger ability to absorb HCl than PdCl2/AC. The desorption temperatures of HCl for (NH₄)₂PdCl₄/AC and PdCl₂/AC were 369 and 264 °C, respectively. From the C₂H₂- and HCl-TPD results, we can observe that the desorption content of C2H2 changes negatively for (NH₄)₂PdCl₄/AC and PdCl₂/AC, whereas higher HCl desorption content has been found for (NH₄)₂PdCl₄/AC than that for PdCl₂/AC. Upon comparing the coordination structures of the Pd active sites in the catalysts (NH₄)₂PdCl₄/AC and PdCl₂/AC, it was found that the difference in the HCl desorption properties might be influenced by the presence of [NH₄]⁺ in the (NH₄)₂PdCl₄/AC catalysts. The existence of the basic ion $[NH_4]^+$ in the $(NH_4)_2$ PdCl₄ catalyst promoted the adsorption of acidic HCl molecules. In addition, because the differences between the HCl desorption temperatures and desorption contents of (NH₄)₂PdCl₄/AC and PdCl₂/AC are significantly high, HCl may be adsorbed on different sites: HCl is likely adsorbed on Pd²⁺ of the PdCl₂/AC catalyst and [NH₄]⁺ of the (NH₄)₂PdCl₄/AC catalyst. Moreover, previous studies have shown that once the Pd-based catalyst is exposed to the feed gases, only C2H2 can be adsorbed on Pd2+ and HCl cannot be adsorbed due to the stronger adsorptive capacity of the catalyst for C₂H₂ than that for HCl. Under these conditions, the reaction follows the typical E-R mechanism for the classical PdCl₂/AC catalyst; that is, HCl reacts with the adsorbed C2H2 on Pd2+ to produce vinyl chloride.

Since HCl can be adsorbed by [NH₄]⁺, which indicates that the HCl molecule is activated during the adsorption process, there is another possibility for the mechanism of acetylene hydrochlorination over the (NH₄)₂PdCl₄/AC catalyst. The possible reaction mechanism is shown in Fig. 6c. The proposed reaction mechanism was further validated by kinetic experiments. As mentioned in Fig. 1d, compared with the E_a calculated from PdCl₂/AC, the E_a of the (NH₄)₂PdCl₄/AC catalyst decreases significantly from 40 to 25 kJ mol⁻¹. This is precisely due to the further activation of HCl molecules on [NH₄]⁺ such that the energy required for the reaction becomes lower. Under the same conditions, (NH₄)₂PdCl₄/AC exhibits a higher catalytic performance than PdCl₂/AC, as shown in Fig. 1a.

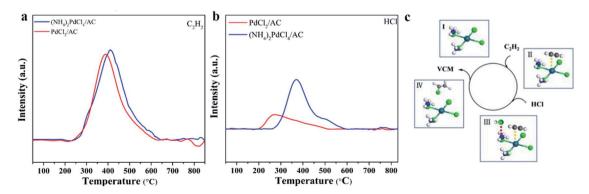


Fig. 6 (a) C_2H_2 -TPD and (b) HCl-TPD profiles of the fresh $(NH_4)_2PdCl_4/AC$ and $PdCl_2/AC$ catalysts; and (c) the proposed catalytic mechanism for the (NH₄)₂PdCl₄/AC catalyst.

4 Conclusions

In summary, we adopted an innovative strategy to synthesize non-mercury catalysts using the compound $(NH_4)_2PdCl_4$ instead of traditional $PdCl_2$. The prepared catalyst $(NH_4)_2PdCl_4/AC$ demonstrated excellent activity and stability in the hydrochlorination of acetylene. This indicated that the microelectronic environment of the active Pd^{2+} sites was regulated and the reduction resistance of cationic palladium was improved via the addition of nitrogen-containing ligands $[NH_4]^+$ to the structure of the active center. In particular, nitrogen-containing ligand additive not only can enhance the dispersion of Pd species, but can also promote the activation ability of $PdCl_4/AC$ and then reduce the activation energy of the reaction. Therefore, our study proves that the $(NH_4)_2PdCl_4/AC$ catalyst can be a hopeful candidate for efficient, well-stabilized non-mercury catalysts in the manufacture of vinyl chloride.

Conflicts of interest

There are no conflicts to declare.

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