Catalytic Hydrogenation of *o*-Nitrochlorobenzene to 3,3'-Dichlorobenzidine

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2.2'-Dichlorohydroazobenzene was prepared by selective hydrogenation of *o*-nitrochlorobenzene with hydrogen in the presence of 0.8% and 5% Pd/C catalyst. *o*-Chloroaniline was a minor product in the catalytic hydrogenation of *o*-nitrochlorobenzene. The effects of base, Pd/C catalyst, and co-catalyst were discussed on catalytic hydrogenation. 2.2'-Dichlorohydroazobenzene, as an intermediate, was rearranged to 3.3'-dichlorobenzidine after reacting with HCl. It was shown that selectivity of catalytic hydrogenation of *o*-nitrochlorobenzene is affected strongly by concentration of base, Pd/C catalyst, and co-catalyst. ^{1}H and ^{13}C NMR spectroscopy confirmed the chemical structures of 2.2'-dichlorohydrazobenzene and 3.3'-dichlorobenzidine.

Key Words : *o*-Nitrochlorobenzene, 3.3'-Dichlorobenzidine, Pd/C catalyst, Hydrogenation

Introduction

The selective hydrogenation of nitrocompounds is commonly used to prepare amine, such as amino compounds, benzidine, and their derivatives that are important intermediates for dyes, drugs, and agro-chemicals. Palladium is one of the best catalysts for catalytic hydrogenation of nitro compounds. The synthesis using Pd catalyst has replaced the old Bechamp process[1,2] using Fe and acid catalyst. It is known that the preparation of hydrazobenzene requires the nitro compounds as a starting material and Zinc and alkaline as the reducing agents. Working with Zinc, which entails many drawbacks, may be avoided by using of other reducing agents. However, the reducing agents such as formaldehyde and hydrazine hydrate usually require particular azoxy-benzene as a starting material and cause environmentally severe problem.[3,4]

Haber was pioneer to disclose a process for hydrogenation reaction of nitrobenzene.[5] This reaction has been investigated in detail by Smith *et al.*[6-8] 2.2'-Dichlorohydrazoxybenzene (3) can be obtained from *o*-nitrochlorobenzene (1) by catalytic hydrogenation. In fact, the catalytic hydrogenation is a multiphase system consisting of many components, *viz.*, H₂, organic phase (*o*-nitrochlorobenzene (1) and organic solvent), base, and catalyst. The selective hydrogenation of *o*-nitrochlorobenzene (1) would be influenced by all phases.[9,10]

The selective hydrogenation of *o*-nitrochlorobenzene (1) to 2.2'-dichlorohydrazobenzene (3) is a key reaction toward the synthesis of 3.3'-dichlorobenzidine (4). This diamine was supposed to be produced by virtue of acid catalyzed isomerization of 2.2'-dichlorohydrazobenzene (3) (Scheme 1).[11,12]

In this case, the goal is to hydrogenate the nitro group without hydrogenolysis of the C–Cl bond.[13] Vollheim *et al.*[9] reported that Pd/C catalyst treated by sulfoxide previously

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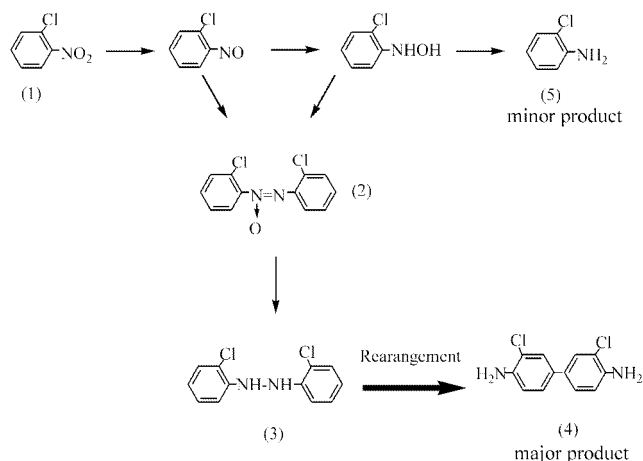
Scheme 1. Synthetic scheme for the preparation of 3,3'-dichlorobenzidine.

was used for hydrogenation of *o*-nitrochlorobenzene (1). In the recent study, it was postulated that Pd-Pt colloidal alloys protected by polymer increases the reaction rate and improve the selectivity of the hydrogenation of *o*-nitrochlorobenzene (1) largely.[14,15]

In this paper, we report the synthesis of 3.3'-dichloro-benzidine (4) with *o*-nitrochlorobenezene (1) using 0.8% Pd/C and 5% Pd/C catalysts. The purpose of this work was to investigate the optimum reaction conditions and the effects of base, catalyst, and co-catalyst on the selectivity of catalytic hydrogenation. The synthetic experimental results were obtained under 5% and 0.8% Pd/C catalysts, co-catalyst, and different concentration of base. ^{1}H and ^{13}C NMR spectroscopy confirmed the chemical structures of 2.2'-dichlorohydrazo-benzene (3) and 3.3'-dichlorobenzidine (4).

Experimental Section

The catalysts for hydrogenation were 5% and 0.8% Pd/C

that were available commercially in Jilin Chemicals Ltd. (China). Hydrogen gas was used with purity >99.9% (Jilin Chemicals Ltd.. China). Toluene. NaOH. hydrochloric acid. and *o*-nitrochlorobenzene (1) with purity >99% were purchased from Dalian Fine Chemicals Ltd. (China). Co-catalyst of 1.4-dihydronaphthoquinone was supplied by Shenyang Chemical reagent Ltd. (China). ^{1}H NMR and ^{13}C NMR spectra were recorded on Varian INOVA-400 NMR spectrometer.

All hydrogenation experiments were carried out in a 200 cm^3 autoclave. The reactor was supplied by Dalian Instruments Ltd. (China) and equipped with mechanical stirrer. gas inlet/outlet system. automatic temperature controller. high-pressure cut off, and pressure recording with a transducer.

2,2'-Dichlorohydrazobenzene (3). 30 g *o*-Nitrochlorobenzene (1). a NaOH aqueous solution (30 g. corresponding to a 25 wt%). 0.05 g 0.8% Pd/C catalyst (the weight ratio of palladium metal to *o*-chlorontrobenzene (1) is 0.00016 : 1). and 30 g toluene were charged into an autoclave and flushed with nitrogen. Then hydrogenation reaction was performed with vigorous stirring under a hydrogen pressure of 0.5 MPa. When the reaction mixture was kept for 4h at 50 °C. the temperature inside the vessel increased to 75 °C at which it was kept for another 5 h. The hydrogenation reaction was completed as hydrogen absorption ceased and the residual catalyst was filtered off at 75-80 °C. The solution was cooled down and kept until two remaining liquid phases were completely separated. After removing the heavy aqueous phase. the upper organic phase containing the reduced product. 2,2'-dichlorohydrazobenzene (3) was remained for rearrangement reaction. After the solvent of organic phase was evaporated. a solid crude product could be obtained. The crude product contained 94-95 wt% 2.2'-Dichloro-hydrazobenzene (3). 1-3 wt% *o*-chloroaniline (5). and 1.5-2 wt% mono-chlorohydrazobenzene. A white crystal (3) was collected after crystallization from organic phase and recrystallization in anhydrous ethanol. m.p. 86-87 °C (lit. m.p. 86-87 °C).

^{1}H NMR (400 MHz. CDCl$_3$) δ (ppm) 6.67-6.70 (m. 2H). 6.82-6.84 (d. 2H). 7.05-7.09 (m. 2H). 7.25-7.27 (d. 2H). 7.40-7.46 (d. 2H). ^{13}C NMR (100 MHz. CDCl$_3$) δ (ppm) 112.5. 116.6. 118.7. 127.5. 128.9. 144.5.

3,3'-Dichlorobenzidine (4). A mixture of toluene (31 g) and 2.2'-dichlorohydrazobenzene (3) (9 g) was added to 400 g hydrochloric acid (20%wt) at 0-5 °C for 4 h and the mixed solution was stirred at room temperature overnight. Then the temperature of the solution was raised to 50 °C over 5 h and the solution was stirred for another 30 minutes at this temperature. After completion of rearrangement of 2.2'-dichlorohydrazobenzene (3) to 3.3'-dichlorobenzidine (4). reaction mixture was stood until two liquid phases were separated completely. Removing the organic phase. 7.7 g pink crystal of 3.3'-dichlorobenzidine hydrochloric salt (4) was collected by filtering the heavy aqueous phase. After recrystallization in anhydrous ethanol. an off-white crystal (5.1 g) could be obtained. m.p. 132-133 °C (lit. m.p. 132-

133 °C).

^{1}H NMR (400 MHz. CDCl$_3$) δ (ppm) 7.16-7.26 (m. 6H). 7.42-7.45 (d. 2H). 7.45-7.60 (s. 2H). ^{13}C NMR (100 MHz. CDCl$_3$) δ (ppm) 120.3. 122.6. 125.4. 126.7. 133.1. 136.2.

Results and Discussion

We studied the selective hydrogenation of *o*-nitrochloro-benzene (1) to 2,2'-dichlorohydrazobenzene (3). Rearrangement of 2.2'-dichlorohydrazobenzene (3) to 3,3'-dichloro-benzidine (4) was observed, which was consistent with the literature.[9] Conversion and selectivity were well defined by the results from HPLC analysis. It was thought that catalyst, co-catalyst. and the concentration of NaOH solution affected the selective hydrogenation of *o*-nitrochlorobenzene (1). The hydrogenation procedure of *o*-nitrochlorobenzene (1) could be divided into two parts. In the first part. the major reaction was the conversion of *o*-nitrochlorobenzene (1) to 2,2'-dichloroazoxybenzene (2) and 2.2'-dichloroazoxybenzene (2) would change to 2,2'-dichlorohydrazobenzene (3) chiefly at second part. We investigated the related change between *o*-nitrochlorobenzene (1). 2.2'-dichloroazoxybenzene (2). and 2.2'-dichlorohydrazobenzene (3) with HPLC analysis. Some experiments on recycling of the catalyst were carried out since 5% and 0.8% Pd/C catalysts had different selectivity and activity.

The catalytic hydrogenation is a complex process consisting of four phases. *viz.*, gaseous phase (H$_2$). organic phase (*o*-nitrochlorobenzene (1)). aqueous phase (alkali solution), and solid (Pd/C). In fact, catalysts play an important role in the hydrogenation and keep the reaction in progress on its active sites. First of all, we investigated the process of catalytic hydrogenation from *o*-nitrochlorobenzene(1) to 2.2'-dichlorohydrazobenzene (3) using 5% Pd/C catalyst and found that the catalytic reaction could be divided into two parts. After 4 hr reaction. *o*-nitrochlorobenzene (1) was converted into 2,2'-dichloroazoxybenzene (2) completely at the first section. At this time, the reaction temperature
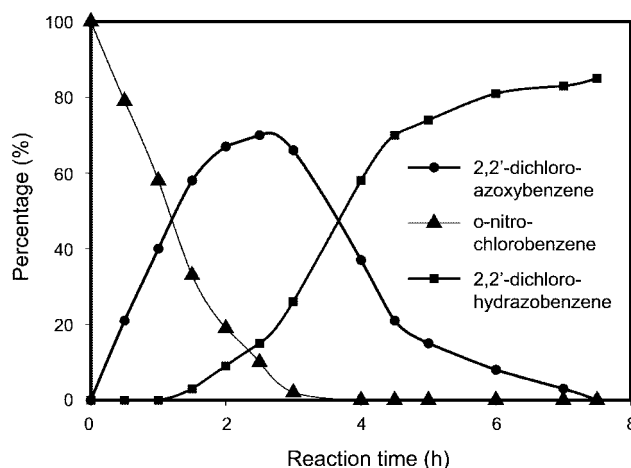

Figure 1. The relative changes between *o*-nitrochlorobenzene. 2.2'-dichloroazoxybenzene and 2.2'-dichlorohydrazobenzene during the catalytic hydrogenation using 5% Pd/C.
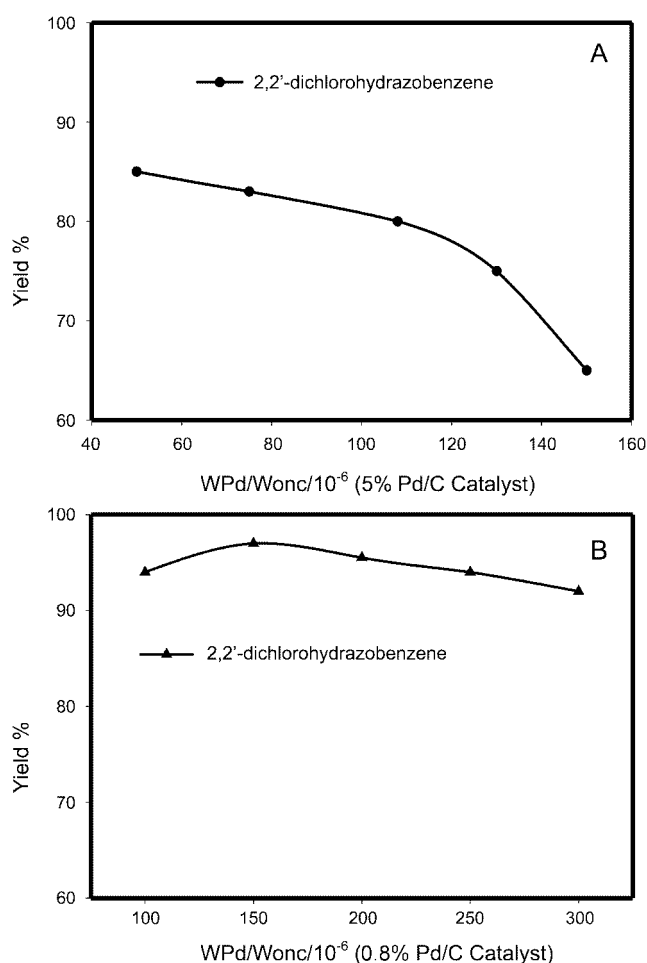
Figure 2. Effect of the used level of Pd/C catalyst on hydrogenation of o-nitrochlorobenzene for A; 5% Pd/C and B; 0.8% Pd/C catalyst.

increased and the second part of reaction started at elevated temperature. In the second part, the main reaction was conversion of 2,2'-dichloroazoxybenzene (2) to 2,2'-dichloro-hydrazobenzene (3) (Fig. 1). In Figure 1, it was indicated that the quantity of 2,2'-dichlorohydrazobenzene (3) increased

when the quantity of o-nitrochlorobenzene (1) decreased. At the same time, the concentration of 2,2'-dichloroazoxyben-zene (2) increased in the initial period and then decreased gradually. The reaction should be completed until 2,2'-dichloroazoxybenzene (2) was converted to 2,2'-dichloro-hydrazobenzene (3) entirely.

The effects of Pd/C catalysts on the selectivity of hydro-genation from o-nitrochlorobenzene (1) to 2,2'-dichloro-hydrazobenzene (3) were different at each concentration (0.8% or 5%). In fact, 0.8% Pd/C catalyst showed better selectivity than 5% Pd/C catalyst as shown in Figure 2. When we used a proper amount of Pd/C catalyst, the selectivity of catalytic hydrogenation could be kept stable to a certain degree. However, the selectivity was found to be different with 0.8% Pd/C and 5% Pd/C catalyst respectively. As the used level of 0.8% Pd/C catalyst (WPd/Wonc) varied from 1.2×10^{-4} to 2.0×10^{-4}, the percent yield of 2,2'-dichlorohydrazobenzene (3) was determined from 91 to 94%. The percentage yield of 2,2'-dichlorohydrazobenzene (3) decreased after the used level of 5% Pd/C increased from 1.2×10^{-4} to 2.0×10^{-4}. When the used level of 5% Pd/C catalyst (WPd/Wonc) was 5.0×10^{-4}, the conversion of 2,2'-dichlorohydrazobenzene (3) would reach its maximum value (~85%).

For studying the stability of 5% Pd/C and 0.8% Pd/C catalyst, the catalytic hydrogenation was repeated and the results were shown in Table 1 and Table 2. From the second experiment, the used Pd/C catalyst and one fourth of new Pd/C catalyst were employed together on the hydrogenation of o-nitrochlorobenzene (1). It was investigated that 0.8% Pd/C catalyst has a better capacity and provides better stability than 5% Pd/C with higher conversion to 2,2'-dichlorohydrazobenzene and lower conversion to o-chloro-aniline (5) (see Table 1 and Table 2).

In the selective hydrogenation from o-nitrochlorobenzene (1) to 2,2'-dichlorohydrazobenzene (3), 1,4-dihydronaphtho-quinone was used as a co-catalyst to reduce dehalogenation and formation of o-chloroaniline (5). The experimental results are shown in Table 3. It was observed that co-catalyst

Table 1. Experimental results of 5% Pd/C catalyst for hydrogenating o-nitrochlorobenzene

Repeat time	Replenishment of 5% Pd/C catalyst (g)	2,2'-dichlorohydrazobenzene (%)	o-Chloroaniline (%)	Aniline (%)	Reaction time (h)
1	–	83.5	4.1	12.9	8
2	0.0025	81.6	4.8	12.5	11.5
3	0.0025	80.6	4.4	13.4	10
4	0.0025	76.0	7.6	15.4	12

Table 2. Experimental results of 0.8% Pd/C catalyst for hydrogenating o-nitrochlorobenzene

Repeat time	Replenishment of 0.8% Pd/C catalyst (g)	2,2'-dichlorohydrazobenzene (%)	o-Chloroaniline (%)	Aniline (%)	Reaction Time (h)
1	–	95.5	2.46	1.5	9
2	0.125	93.9	2.99	2.2	13
3	0.125	95.2	3.05	1.25	12.5
4	0.125	93.8	3.28	2.1	11.5

Table 3. Effect of co-catalyst on selective hydrogenation of *o*-nitrobenzene to 2,2'-dichlorohydrazobenzene

No.	Catalyst	The used level of catalyst (WPd/Wonc)	The used level of co-catalyst (Wco/Wonc)	2,2'-dichlorohydrazo-benzene (%)	*o*-Chloroaniline (%)	Aniline (%)
1	5% Pd/C	8×10^{-5}	1.42×10^{-3}	66.2	17.3	12.7
2	5% Pd/C	8×10^{-5}	2.9×10^{-3}	80.2	10.5	7.5
3	5% Pd/C	1.6×10^{-4}	0	81.5	14.2	10.32
4	5% Pd/C	1.6×10^{-4}	1.42×10^{-3}	85.7	6.1	7.32
5	0.8%Pd/C	1.6×10^{-4}	0	92.1	3.5	3.46
6	0.8%Pd/C	1.6×10^{-4}	1.42×10^{-3}	94.9	2.1	1.76
7	0.8%Pd/C	1.6×10^{-4}	2.15×10^{-3}	95.2	1.8	1.21
8	0.8%Pd/C	1.6×10^{-4}	2.83×10^{-3}	95.1	2.5	1.14

Table 4. Effect of base on selective hydrogenation of *o*-nitrobenzene to 2,2'-dichlorohydrazobenzene

No.	Catalyst	Concentration of NaOH and weight ratio to *o*-nitrochlorobenzene	2,2'-dichlorohydrazobenzene (%)	Reaction time (h)
1	0.8% Pd/C	15%, 0.65	75.6	5
2	0.8% Pd/C	20%, 0.65	85.4	6.5
3	0.8% Pd/C	25%, 0.43	92.3	13
4	0.8% Pd/C	25%, 0.65	93.5	9
5	0.8% Pd/C	25%, 1.3	93.9	8

affects the hydrogenation selectivity of *o*-nitrochlorobenzene (1) (Table 3). If 0.8% Pd/C catalyst was used for reaction, we could select 2.15×10^{-3} as a proper level of co-catalyst and had a better selectivity to 2,2'-dichlorohydrazobenzene (3).

Base played an important role in the catalytic hydrogenation of *o*-nitrochlorobenzene (1) to 2,2'-dichlorohydrazobenzene (3). As the concentration of base changed from 15% to 25%, the selectivity of catalytic hydrogenation showed difference in reactivity (Table 4). When the weight ratio of NaOH to *o*-nitrochlorobenzene (1) reached 0.65 and concentration of NaOH increased up to 25 wt%, we found a better selectivity and a shorter reaction time.

Rearrangement reaction from 2,2'-dichlorohydrazobenzene (3) to 3,3'-dichlorobenzidine (4) was performed following the literature[9] method and the results are shown at Table 5. These data clearly showed a good reproducibility and indicated that the percentage yield of rearrangement from 2,2'-dichlorohydrazobenzene (3) to 3,3'-dichlorobenzidine (4) was found about 94% within 1% difference.

When the catalytic hydrogenation of *o*-nitrochlorobenzene (1) was completed, 2,2'-dichlorohydrazobenzene (3) was rearranged in the presence of 20% HCl and a solid product of 3,3'-dichlorobenzidine (4) was obtained. After recrystalli-
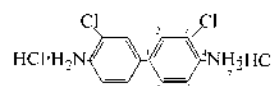
zation of these crude products in anhydrous ethanol, a pink crystal of 2,2'-dichlorohydrazobenzene and an off-white crystal of 3,3'-dichlorobenzidine (4) were also collected. For confirming the chemical structures of the synthesized compounds, ^{1}H and ^{13}C NMR spectra were recorded. From NMR spectra of 2,2'-dichlorohydrazobenzene (3) and 3,3'-

Table 6. ^{1}H-NMR (CDCl₃) and ^{13}C-NMR (CDCl₃) data of 2,2'-dichlorohydrazobenzene
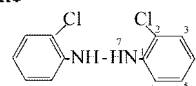
C/H No.	δ ppm (^{1}H)	δ ppm (^{13}C)
1	–	144.5
2	–	116.6
3	7.25-7.27, 2H	128.9
4	6.67-6.70, 2H	118.7
5	7.05-7.09, 2H	127.5
6	6.82-6.84, 2H	112.5
7	7.40-7.46, 2H	–

Table 7. ^{1}H-NMR (CDCl₃) and ^{13}C-NMR (CDCl₃) data of 3,3'-dichlorobenzidine

C/H No.	δ ppm (^{1}H)	δ ppm (^{13}C)
1	–	133.1
2	7.45-7.60, 2H	126.7
3	–	122.58
4	–	136.2
6	7.42-7.45, 2H	125.4
5, 7	7.16-7.25, 6H	120.3

Table 5. The results of rearrangement from 2,2'-dichlorohydrazobenzene to 3,3'-dichlorobenzidine

No.	The content of amino-compound (%)	Percentage yield (%)	Melting point (°C)	Crystal appearance
1	98.5	94.3	130-132	light brown
2	97.6	93.0	130-132	offwhite
3	98.7	95.4	129-131	pink
4	98.2	94.2	131-133	offwhite
5	97.9	93.7	130-132	pink

dichlorobenzidine (4), each number of the distinct types of hydrogen nuclei as well as the carbon nuclei was demonstrated. NMR spectral data of 2.2'-dichlorohydrazobenzene (3) and 3.3'-dichlorobenzidine hydrochloric salt (4) are tabulated in Table 6 and 7. After the rearrangement of 2.2'-dichlorohydrazobenzene (3) to 3.3'-dichlorobenzidine (4), the aromatic 4-H signal of 3 in the region of 6.67-6.70 ppm disappeared and the pattern of the 3-H proton peak was observed at 7.25-7.59. The chemical shift of 1-C at 144.5 in 3 was observed at different chemical shift of 136.2 (see Table 6 and Table 7).

Conclusion

The catalytic hydrogenation of *o*-nitrochlorobenzene to 2.2'-dichlorohydrazobenzene using 0.8% Pd/C and 5% Pd/C catalyst, has been studied. In fact, 0.8% Pd/C catalyst had a better selectivity and activity than 5% Pd/C. When the weight ratio of NaOH to *o*-nitrochlorobenzene reached 0.65 and concentration of NaOH increased up to 25 wt%, there was a better selectivity and the reaction time became shorter in the hydrogenation of *o*-nitrochlorobenzene. 1,4-Dihydronaphthoquinone as a co-catalyst was useful to reduce dehalogenation and formation of *o*-chloroaniline. NMR spectroscopy confirmed the chemical structures of 2.2'-dichlorohydrazobenzene and 3.3'-dichlorobenzidine finally.

References

1. Bechamp. A. *Annales de Chimie (Paris)* **1824**, *42*, 186.
2. Yu. Z.; Liao. S.; Xu. Y.; Yang. B.; Yu. D. *J. Mol. Catal. A* **1997**, *120*, 247.
3. Freifelder. M. *Practical Catalytic Hydrogenation*; Wiley: New York. 1967.
4. Rylander. P. N. *Catalystic Hydrogenation in Organic Syntheses*; Academic Press: New York. 1979.
5. Haber. Z. F. *Electrochem.* **1898**, *4*, 56.
6. Smith. G. V.; Song. R.; Gasior. M.; Malz. R. E. *Catalysis Organic Reactions*; Marcel Dekker: New York, 1994.
7. Blaser. H. U.; Studer. M. *Appl. Catal.* **1999**, *189*, 191.
8. March. J. *Advanced Organic Chemistry*, 4th ed.; John Wiley & Sons: New York. 1994.
9. Vollheim. G.; Troger. K. J.; Lippert. G. *US patent* **1975**, 3.897,499.
10. Coq. B.; Tijani. A.; Figueras. F. *J. Mol. Catal.* **1992**, *71*, 317.
11. Habig. K.; Baessler. K.; Warning. K. *US patent* **1993**, 5,208.376.
12. Harald. E.; Gleinnig. K. *US patent* **1978**, 4,075.198.
13. Cordier. G.; Grosselin. J. M.; Bailliard. R. M. *Catalysis Organic Reactions*; Marcel Dekker: New York, 1998.
14. Yang. X.; Liu. H.; Zhong. H. *J. Mol. Catal. A* **1999**, *147*, 55.
15. Yu. Z.; Liao. S.; Xu. Y.; Yang. B.; Yu. D. *J. Chem. Soc. Chem. Commun.* **1995**, 1155.