

The synthesis of *N*-ethyl-*n*-butylamine by amines disproportionation

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Abstract A synthesis of *N*-ethyl-*n*-butylamine with simple separation method in a fixed-bed reactor using CuO–NiO–PtO/ γ -Al₂O₃ as the catalyst was proposed and investigated. The present catalytic system gave high activity and good selectivity, and the reaction conditions such as temperature and liquid hourly space velocity were optimized. Since no water was generated, the protocol proved to be easy to separate, and *N*-ethyl-*n*-butylamine was collected at 110 °C by distillation. The yield and the purity were 60.7 and 99.5 %, respectively.

Keywords *N*-Ethyl-*n*-butylamine · Disproportionation · Fixed-bed reactor · Catalyst

Introduction

N-Ethyl-*n*-butylamine is an important pesticide and pharmaceutical intermediate, which can be used for the synthesis of herbicides, such as pebulate and benfluralin

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[1], and the synthesis of nervous system drugs, such as milnacipran [2]. There are many methods for the synthesis of *N*-ethyl-*n*-butylamine, and the most commonly used method is *N*-alkylation of amine with aryl/alkyl halides [3, 4]. However, the use of aryl/alkyl halides is unfriendly to the environment, and this procedure generates large amounts of inorganic salts as byproducts [5]. The relatively green method for the synthesis of *N*-ethyl-*n*-butylamine is the catalytic amination of alcohols [6–8], generally by using the Cu, Ni, and Co catalysts. However, this method generates water as a byproduct, which will reduce the activity of the catalyst and may form azeotrope with the raw material alcohol and the product amine, thus rendering the purification of the target product difficult.

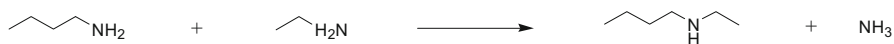
The process for the amines disproportionation is a class of common side reactions in the synthesis of aliphatic amines. Some researchers have studied the amines disproportionation phenomenon in a number of systems, trying to suppress the disproportionation to improve the selectivity of primary products; however, the results showed that preventing the amines disproportionation reactions from the source was very difficult, and only possible by reducing the activity of the catalyst to reduce the amines disproportionation [7, 9, 10]. The research of the amines disproportionation reaction as the main reaction is small and the cross-disproportionation of a variety of aliphatic amines to synthesize asymmetric amines, such as the synthesis of *N*-ethyl-*n*-butylamine from ethylamine and butylamine, is even rarer. An earlier study of the conversion between methylamine, dimethylamine, and trimethylamine was carried out, and the result showed either methylamine or dimethylamine as the raw material, and a mixture of methylamine, dimethylamine, and trimethylamine was found [11, 12]. The catalysts of the amines disproportionation are mainly metal or supported metal catalysts, and one having high catalytic activity and acidic centers would be favorable to the amines disproportionation reaction. Many transition metals have been used in the amines disproportionation reaction, such as Ni, Cu, Co, Ru, Pt, or Pd [7], among which Ni has high catalytic activity [8, 13–15]. The acidic centers of catalyst are often provided by the support, and the performance of the catalyst alters with changing the catalyst's acidity. A specific study on the role of the support on the properties of Cu–Cr catalysts has been reported [16], and the result showed that the performance varied in the following order, $\text{SiO}_2\text{--Al}_2\text{O}_3 \approx \text{Al}_2\text{O}_3 > \text{SiO}_2 \approx \text{graphite} \approx \text{ZnO}$.

In this paper, we report on the synthesis of *N*-ethyl-*n*-butylamine from ethylamine and butylamine with CuO–NiO–PtO/ γ -Al₂O₃ catalyst in a fixed-bed reactor. A report on a photocatalytic process of *N*-alkylation of different amines by using microreactors with immobilized Pt-free TiO₂ as well as Pt-loaded TiO₂ can be found in the literature [17]. The *N*-ethylation process of butylamine was examined in the ethanol solvent with immobilized Pt-loaded TiO₂ and found to yield only 36 %. There was another report [18] on the synthesis of *N*-ethyl-*n*-butylamine, and the yield of the reaction of butylamine and ethanol catalyzed by Ni–Sn/Al₂O₃ was only 42 %. The yield of *N*-ethyl-*n*-butylamine in this paper is significantly higher than the results in the literature. The synthesis of *N*-ethyl-*n*-butylamine from ethylamine and butylamine has an important advantage: the reaction does not generate water, which solved the fundamental problem of removing the water from the reaction mixture, and no azeotrope in the reaction mixture made the separation process simple.

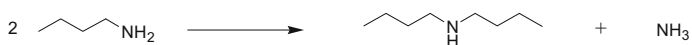
Result and discussions

The synthesis of *N*-ethyl-*n*-butylamine was catalyzed by CuO–NiO–PtO/ γ -Al₂O₃ through the disproportionation. Starting with ethylamine and butylamine, a mixture of *N*-ethyl-*n*-butylamine, ethylamine, diethylamine, butylamine, dibutylamine, *N*, *N*-diethylbutylamine and some other heavy constituents resulted through the reactions.

The reaction formula of the synthesis of *N*-ethyl-*n*-butylamine is as follows:



The reaction formula of main byproducts is as follows:



The reaction formula of minor byproducts is as follows:



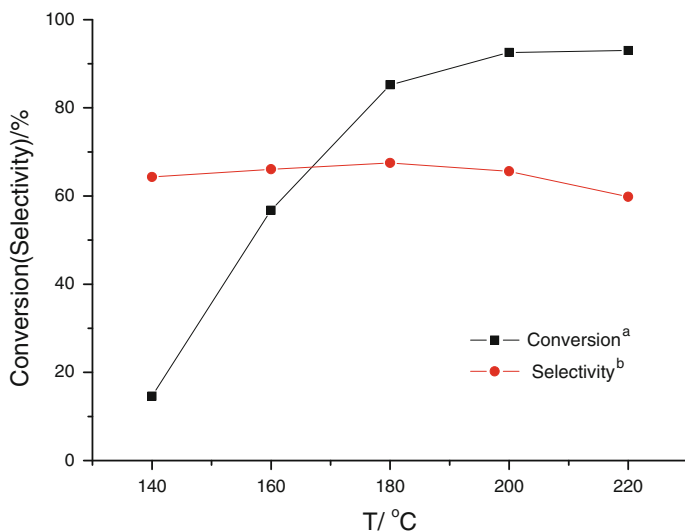


Fig. 1 The influence of temperature on the reaction

The existence of subsidiary reaction brought some byproducts. However, these byproducts have a certain commercial value; for example, although the demand of *N,N*-diethylbutylamine and *N,N*-dibutylethylamine is low, the value is high, and this system exactly meets this requirement.

The reaction of ethylamine with butylamine was carried out over CuO–NiO–PtO/ γ -Al₂O₃ in the temperature range of 140–220 °C. Figure 1 shows the influence of temperature on the reaction at a 2:1 mol ratio of ethylamine to butylamine, 0.2 h⁻¹ liquid hourly space velocity (LHSV), and 0.8 MPa. The conversion of butylamine increased markedly as the temperature increased and reached a maximum at 200 °C, while the selectivity of *N*-ethyl-*n*-butylamine decreased at over 180 °C. In the research, 200 °C produced the maximum yield of *N*-ethyl-*n*-butylamine. During the research, the yield of diethylamine, dibutylamine, and *N*-ethyl-*n*-butylamine showed a significant increase from 140 to 180 °C. When the temperature varied from 180 to 200 °C, the increased conversion of butylamine mainly contributed to the increase of *N,N*-diethylbutylamine and *N,N*-dibutylethylamine, which resulted in the decline of the selectivity. In addition, when the temperature was beyond 200 °C, the conversion changed slightly, while the selectivity had a relatively evident decrease.

(a) The conversion of butylamine.

(b)
$$\text{Selectivity} = \frac{\text{moles of product}}{\text{moles of butylamine converted}}$$

The reaction is also strongly influenced by the LHSV, because low LHSV prolongs the contact time with the catalyst, promoting further reactions. On the other hand, at high LHSV, the contact time is too short to convert the raw materials completely. The results of the influence of LHSV on the reaction are shown in Fig. 2. The conversion of butylamine decreased markedly as LHSV increased,

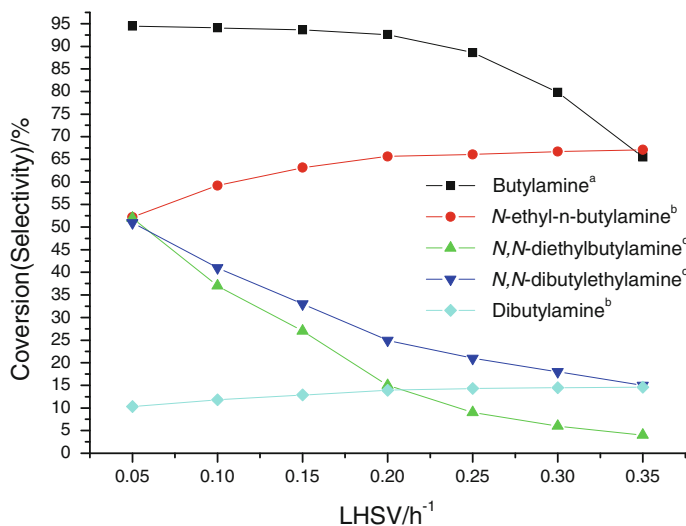


Fig. 2 The influence of LHSV on the reaction

especially beyond 0.2 h^{-1} . When the contact time was short, it was favorable for generating *N*-ethyl-*n*-butylamine and dibutylamine, while at the long contact time, it was favorable for getting *N,N*-diethylbutylamine and *N,N*-dibutylethylamine. In the research, LHSV of 0.2 h^{-1} resulted in the highest yield of *N*-ethyl-*n*-butylamine.

- The conversion of butylamine.
- The selectivity of *N*-ethyl-*n*-butylamine and dibutylamine.
- Ten times the selectivity of *N,N*-diethylbutylamine and *N,N*-dibutylethylamine.

Moreover, the influence of catalyst at the optimum condition (ethylamine and butylamine at a 2:1 mol ratio, $200 \text{ }^\circ\text{C}$ temperature, 0.2 h^{-1} LHSV, and 0.8 MPa pressure.) was also explored and the results are summarized in Table 1. Catalytic activity of CuO–alumina was low, while NiO–alumina showed high disproportionation activity but poor selectivity due to further reaction and due to deamination [19]. In addition, copper proved to be an unstable catalyst and needed different

Table 1 The effect of different catalyst on the reaction

Catalyst ^a	Butylamine conversion (%)	<i>N</i> -Ethyl- <i>n</i> -butylamine selectivity (%)
CuO/ γ -Al ₂ O ₃	21.5	26.4
CuO–NiO/ γ -Al ₂ O ₃	87.6	56.5
CuO–NiO–PtO/ γ -Al ₂ O ₃	92.6	65.6
NiO/ γ -Al ₂ O ₃	98.2	15.2

^a The supported metal content of CuO/ γ -Al₂O₃, NiO/ γ -Al₂O₃ and CuO–NiO/ γ -Al₂O₃ was equal to the CuO–NiO–PtO/ γ -Al₂O₃ catalyst, and the proportion of copper and nickel in the CuO–NiO/ γ -Al₂O₃ catalyst was also equal to the proportion in the CuO–NiO–PtO/ γ -Al₂O₃ catalyst

additives to stabilize the copper catalyst. Therefore, CuO–NiO–PtO/ γ -Al₂O₃ was selected as the catalyst. The ratio of copper and nickel was also investigated, and too low a nickel content made the catalytic activity poor, while too high a nickel content lowered the selectivity. Platinum was added to improve the catalytic activity and selectivity.

Conclusions

In conclusion, an easy separation method for the synthesis of *N*-ethyl-*n*-butylamine from ethylamine and butylamine by amine disproportionation was examined in a fixed-bed reactor in the presence of CuO–NiO–PtO/ γ -Al₂O₃ as the catalyst. During the research, the optimum temperature and LHSV were investigated. Moreover, the catalyst was also explored and CuO–NiO–PtO/ γ -Al₂O₃ we selected gave high activity and good selectivity.

Experimental

The CuO–NiO–PtO/ γ -Al₂O₃ catalyst was prepared using an impregnation method at fixed Cu/Ni/Pt ratio, and concrete steps are as follows:

- The carrier γ -Al₂O₃ ($S_{\text{BET}} = 200\text{--}220 \text{ m}^2 \text{ g}^{-1}$, $\Phi = 2\text{--}3 \text{ mm}$) was calcined for 3 h at 450 °C and for 5 h at 650 °C in muffle furnace.
- The calcined γ -Al₂O₃ was impregnated with water for 36 h, then measured the decrement of water volume to determine the pore volume.
- The solution of copper nitrate, nickel nitrate, and platinum nitrate was prepared to obtain Cu, Ni, and Pt concentrations of 11.2, 8.6, and 0.9 wt%, respectively, and the volume of the solution was two times the total pore volume. Then, the calcined γ -Al₂O₃ from (a) was impregnated with the above-mentioned solution for 36 h, filtrated, and dried at 60 °C for 2 h, and the filtrate was collected at the same time.
- The filtrated catalyst was calcined at 280 °C for 6 h in a muffle furnace, and then cooled.
- After cooling, the catalyst was impregnated with filtrate from (c) for 24 h, then dried at 80 °C.
- Finally, the catalyst was calcined at 450 °C for 6 h, and then cooled to room temperature.

The reaction was performed in a stainless reactor tube filled with the catalyst and surrounded by a jacket filled with a salt bath to control the temperature of the fixed-bed. The total height of the reactor was 60 cm, the effective length was 40 cm, and ceramic rings were placed on the top and at the bottom. The effective radius of the reactor was 15 mm. The fixed-bed reactor is shown in Fig. 3. All reactions were carried out under an atmosphere of hydrogen in a fixed-bed, which was filled with 105 cm³ of the calcinated catalyst, and the catalyst was reduced at 230 °C for 8 h before reaction.

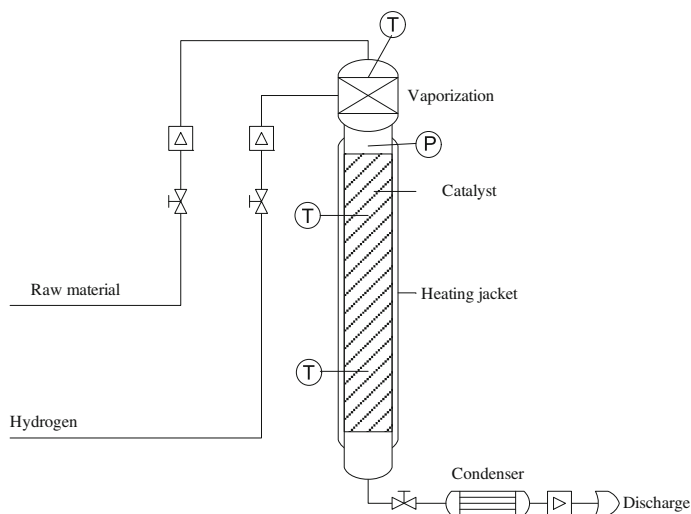


Fig. 3 The fixed-bed reactor

Ethylamine (730 g, 16.2 mol) and butylamine (592 g, 8.1 mol) were evenly mixed in the reservoir and were introduced at the top of the reaction tube via an injection pump. The raw material passed through the catalyst in the fixed-bed at 200 °C, 0.2 h⁻¹ LHSV, and 0.8 MPa pressure, and the gas products were cooled down after passing through the cooling rings at the bottom.

The reaction mixtures were separated by distillation. During the distillation, the heating quantity of the kettle was adjusted to control the steam flow, and the top temperature was monitored to obtain different distillates. *N*-ethyl-*n*-butylamine was collected at 110 °C (497.8 g, 60.7 % yield, and 99.5 % GC purity).

The distillate was analyzed by gas chromatography (Agilent 1790F and SE-30 column) and GC-MS (TRACE GC2000/TRACE MS).

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