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Kinetic Study of Synthesizing 1-(3-Phenylpropyl)-pyrrolidine-2,5-dione under Solid−Liquid Phase-Transfer Catalysis

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Abstract:

The synthesis of 1-(3-phenylpropyl)-pyrrolidine-2,5-dione (SUC-R) was successfully carried out from the reaction of succinimide (SUC-H) with 1-bromo-3-phenylpropane (RBr) in a small amount of KOH and organic solvent solid–liquid phase medium under phase-transfer catalysis (PTC) almost water-free conditions. The main purpose of this work was to determine the reaction conditions by examining the kinetic behavior, reaction mechanism, activation energy, and the related parameters in the solid–liquid PTC reaction. A rational mechanism for the reaction is proposed according to the experimental evidence. The reaction follows a pseudo-first-order rate law. A rate expression was developed to describe the kinetic behaviors from which the apparent rate constant (k_{app}) of the organic-phase reaction was obtained via experimental data. Kinetics of the reaction, including the effects of agitation speed, amount of water, amount of potassium hydroxide, temperature, amount of tetraoctylammonium bromide (TOAB), volume of cyclohexanone, quarternary ammonium salts, and organic solvents on the conversion of RBr and the apparent rate constant (k_{app}) were investigated in detail. Rational explanations for the resulting phenomena are provided.

Introduction

Phase-transfer catalysis (PTC), a technique to bring the reactants in two mutually insoluble phases by adding a phase transfer agent, has been developed for synthesizing organic chemicals and is widely applied in a variety of industries.[1–3] In general, PTC can be divided into two major classes: liquid–liquid two-phase PTC (abbreviated as LL-PTC)[4–12] and solid–liquid two-phase PTC (abbreviated as SL-PTC).[13,14] In the case of SL-PTC without an aqueous phase (under an anhydrous condition), the nucleophile is in a solid form, and reactant stays in the organic phase. At present, PTC has been successful in C-, N-, O-, and S-alkylations involving SN_2 type reactions in a variety of industries.

Imide derivatives are types of organic compounds with numerous applications in biology,[15,16] as well as synthetic[17] and polymer[18] chemistry. In recent years, the mode of operations reported in the literature for the synthesis of these derivative compounds includes: *N*-alkylation of maleimide using alcohol promoted by PPh_3/DIAD in THF;[19]the reactions of potassium phthalimide and succinimide with *N*-substituted-2,2,2-trifluoroacetimidoyl chlorides using active methylene or Grignard's reagents prompted in THF;[20] the application of ionic liquids to synthesize imide derivatives[21] successfully; the reaction of potassium salt of phthalimide to carboxamides;[22] and the reaction of potassium salt of phthalimide with alkyl halide in an organic solvent.[23] However, there have been few papers[14] discussing the reaction of synthesizing imide derivatives under SL-PTC.

In the present work, 1-(3-phenylpropyl)-pyrrolidine-2,5-dione (SUC-R) was synthesized from the reaction of succinimide (SUC-H) with 1-bromo-3-phenylpropane (RBr) in a small amount of KOH and organic solvent solid–liquid-phase

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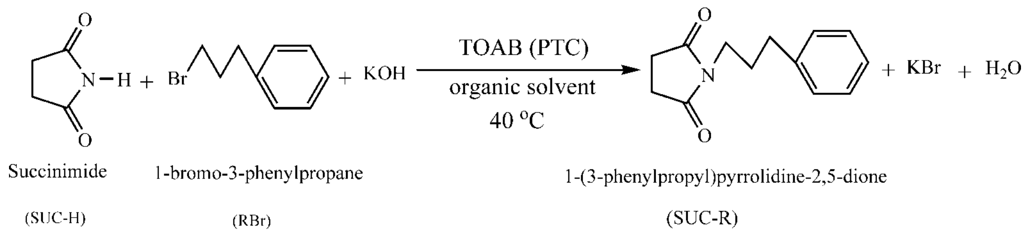
Scheme 1



medium under PTC almost water-free conditions, as shown in Scheme 1. The reaction using SL-PTC is faster than that using LL-PTC. The operating conditions are mild, and a high yield of product is obtained. Thus, the product (succinimide and its derivative) are biologically and industrially useful compounds. Preliminary studies on the kinetics and the effects of various experimental parameters on the rate of SL-PTC reaction were investigated in detail. On the basis of the experimental result, a suitable mechanism is proposed.

Experimental Section

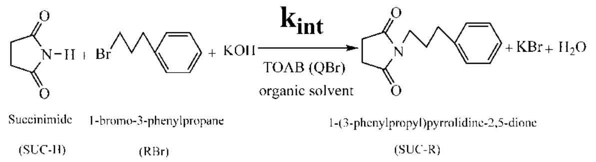
Materials. All reagents, including succinimide (SUC-H), 1-bromo-3-phenylpropane, potassium hydroxide, quaternary ammonium salts: tetraethylammonium bromide (TEAB), tetrabutylammonium bromide (TBAB), tetrabutylammonium chloride (TBAC), tetrabutylammonium iodide (TBAI), tetrabutylammonium hydrogensulfate (TBAHS), tetrahexylammonium bromide (THAB), and tetraoctylammonium bromide (TOAB); organic solvents: chloroform, chlorobenzene, *o*-dichlorobenzene, acetophenone, and cyclohexanone for synthesis were all guaranteed grade (G.R.) chemicals.

Procedures. *(i) Synthesis of 1-(3-Phenylpropyl)pyrrolidine-2,5-dione.* Measured quantities of succinimide (10 g), 1-bromo-3-phenylpropane (10 g) potassium hydroxide (2 g), and TOAB (0.4 g) were dissolved in a 50 mL of acetonitrile at 40 ± 0.1 °C. The mixed (solid–liquid, SL) solution was stirred continuously under agitation speed of 1000 rpm. After 48 h of reaction, the SL solution was separated, and the organic solution was concentrated beforehand in a vacuum evaporator. Then the remaining organic solution with 30 mL of dichloromethane was introduced to an extractor. The organic solution was extracted by a low alkaline solution (1 g KOH/100 mL H_2O) and deionized water (DI) at least five times to remove aqueous reactant and TOAB catalyst. The organic solution was further concentrated by a vacuum evaporator, and a white solid, 1-(3-phenylpropyl)-pyrrolidine-2,5-dione of over 97% purity, was obtained. Finally, the product was identified by mass spectrometry for molecular weight and by NMR (^{1}H NMR and^{13}C NMR) for functional groups and elements for components. The contents of the components experimentally obtained are consistent with the theoretical values.

(ii) Kinetics of the Solid–Liquid Phase-Transfer Catalytic Reaction. The reactor was a 150-mL three-necked round-bottomed Pyrex flask, fitted with agitator, thermometer, sample port, and feed port. Known quantities of succinimide (9.0×10^{-2} mol, as excess reagent), potassium hydroxide (1 g), TOAB (0.4 g, QBr), and 25 mL of cyclohexanone were put into the reactor and stirred at 1200 rpm about 30 min to form the tetraoctylammonium succinimide (SUC-Q) in an organic-phase solution, which was immersed in a well-controlled temperature water bath within ±0.1 °C. Then measured quantities of 1-bromo-3-phenylpropane (6.0×10^{-3} mol, as limiting reagent), and naphthalene (0.3 g, internal standard) were dissolved in 25 mL of cyclohexanone to form the organic solution. The organic solution was added to the reactor and agitated to start the reaction. An aliquot sample (0.2 mL) was withdrawn from the reaction solution and quenched in 6 mL of methanol at each time interval. The sample for analysis was withdrawn from the organic solution after the separation of solid–liquid phase and then analyzed quantitatively by HPLC using the internal standard method. The conditions for analysis on an HPLC (Shimadzu LC-10A, Japan) were: system controller - SCL-10AVP; UV–vis detector - SPD-10AVP; liquid chromatograph - LC-10ATVP; column - C-18 (25 cm × 4.6 mm, 5 μm, applied Supelco Co.); eluent - acetonitrile/deionized water (DI) = 65/35; flow rate = 1.2 mL/min; wavelength = 210 nm with retention time: succinimide = 2.72 min; 1-bromo-3-phenylpropane = 9.55 min; naphthalene = 7.35 min; 1-(3-phenylpropyl)pyrrolidine-2,5-dione = 3.84 min.

Reaction Mechanism and Kinetic Model

For synthesizing an imide compound, the overall reaction of succinimide (SUC-H) and 1-bromo-3-phenylpropane (RBr), which was catalyzed by TOAB (QBr) in the low alkaline of KOH/organic solvent solid–liquid phase medium, can be expressed as eq 1



(1)

In this work, a rational solid–liquid phase reaction mechanism is proposed as

$$\mathrm{SUC-H_{(s)}+KOH_{(s)}\xrightarrow{\text{organic solvent}}SUC-K_{(org)}+H_2O} \quad (2)$$

$$\mathrm{SUC-K_{(org)}+QBr_{(org)}\overset{K_1}{\leftrightarrow}SUC-Q_{(org)}+KBr_{(org)}} \quad (3)$$

$$\mathrm{KBr_{(org)}\overset{K_2}{\leftrightarrow}KBr_{(s)}} \quad (4)$$

$$\mathrm{SUC-Q_{(org)}+RBr_{(org)}\overset{k_{int}}{\rightarrow}SUC-R_{(org)}+QBr_{(org)}} \quad (5)$$

where the species are: KBr, potassium bromide; QBr, tetraoctylammonium bromide (TOAB); RBr, 1-bromo-3-phenylpropane; SUC-H, succinimide; SUC-K, potassium salt of succinimide; SUC-R, 1-(3-phenylpropyl)-pyrrolidine-2,5-dione; SUC-Q, (tetraoctylammonium)succinimide. The subscripts “s”, “org”, “0” represent the characteristics of the species in the solid phase, organic phase, and the initial concentration of the species at time zero, respectively

This reaction mechanism indicates that the active catalyst SUC-Q is produced from the reaction of succinimide (SUC-H), potassium hydroxide, and catalyst QBr in the organic-phase solution. Although no water was added, a trace amount of water was produced during the reaction. The inorganic salt KBr precipitated as a solid form from the organic-phase solution. Then, the active catalyst SUC-Q reacts with organic-phase reactant RBr to produce the desired product SUC-R in the organic-phase solution.

In general, the pseudo-first-order rate law can be used to describe the experimental data when a straight line is obtained by plotting $-\ln([\mathrm{RBr}]_{\mathrm{org}}/[\mathrm{RBr}]_{\mathrm{org},0})$ vs time. Therefore, the rate equation of the intrinsic reaction for eq 5 is given by

$$-\frac{d[\mathrm{RBr}]_{\mathrm{org}}}{dt} = \frac{d[\mathrm{SUC-R}]_{\mathrm{org}}}{dt} = k_{\mathrm{int}}[\mathrm{SUC-Q}]_{\mathrm{org}}[\mathrm{RBr}]_{\mathrm{org}} \quad (6)$$

As shown in eq 3, the reaction is fast and reaches equilibrium in a short time. Thus, the equilibrium constant K_1 is defined as

$$K_1 = \frac{[\mathrm{SUC-Q}]_{\mathrm{org}}[\mathrm{KBr}]_{\mathrm{org}}}{[\mathrm{SUC-K}]_{\mathrm{org}}[\mathrm{QBr}]_{\mathrm{org}}} \quad (7)$$

As stated, the inorganic salt KBr precipitates from the organic solution, and the equilibrium constant K_2 is defined as

$$K_2 = \frac{[\mathrm{KBr}]_{\mathrm{s}}}{[\mathrm{KBr}]_{\mathrm{org}}} \quad (8)$$

The total initial concentration of catalyst Q_0 in organic phase is written as

$$Q_0 = [\mathrm{SUC-Q}]_{\mathrm{org}} + [\mathrm{QBr}]_{\mathrm{org}} \quad (9)$$

The initial conditions of the species are

$$\begin{aligned} &t = 0 \\ &[\mathrm{QBr}]_{\mathrm{org},0} = [\mathrm{SUCQ}]_{\mathrm{org},0} = [\mathrm{SUCK}]_{\mathrm{org},0} = 0 \\ &[\mathrm{QBr}]_{\mathrm{org},0} = Q_0 \\ &[\mathrm{RBr}]_{\mathrm{org}} = [\mathrm{RBr}]_{\mathrm{org},0} \\ &[\mathrm{SUC-R}]_{\mathrm{org},0} = 0 \end{aligned} \quad (10)$$

Solving eqs 7, 8, and 9, the concentration of SUC-Q in organic phase is obtained as

$$[\mathrm{SUC-Q}]_{\mathrm{org}} = Q_0 f_{\mathrm{c}} \quad (11)$$

where f_{c} is defined as

$$f_{\mathrm{c}} = \frac{1}{1 + \frac{1}{K_1 K_2}\frac{[\mathrm{KBr}]_{\mathrm{s}}}{[\mathrm{SUC-K}]_{\mathrm{org}}}} \quad (12)$$

assuming that the concentrations of $[\mathrm{KBr}]_{\mathrm{s}}$ and $[\mathrm{SUC\text{-}K}]_{\mathrm{org}}$ are kept at constant values after the induction period of the reaction. Therefore, as shown in eq 11, $[\mathrm{SUC\text{-}Q}]_{\mathrm{org}}$ stays at a constant value. For this statement, eq 6 can be expressed as

$$-\frac{d[\mathrm{RBr}]_{org}}{dt} = \frac{d[\mathrm{SUC-R}]_{\mathrm{org}}}{dt} = k_{\mathrm{app}}[\mathrm{RBr}]_{\mathrm{org}} \quad (13)$$

where k_{app} is the apparent rate constant and is given as

$$k_{\mathrm{app}} = k_{\mathrm{int}}[\mathrm{SUC-Q}]_{\mathrm{org}} = k_{\mathrm{int}} Q_0 f_{\mathrm{c}} \quad (14)$$

Integrating eq 13 and using eq 10, we thus obtain

$$-\ln(1 - X) = k_{\mathrm{app}} t \quad (15)$$

where X is the conversion of RBr, i.e.,

$$X = 1 - \frac{[\mathrm{RBr}]_{\mathrm{org}}}{[\mathrm{RBr}]_{\mathrm{org},0}} \quad (16)$$

By plotting $-\ln(1 - X)$ versus t, the apparent rate constant k_{app} of the pseudo-first-order rate law from the slope of the straight line is obtained experimentally.

Results and Discussion

In this work, phase-transfer catalysis was successfully employed to synthesize 1-(3-phenylpropyl)-pyrrolidine-2,5-dione (SUC-R) from the reaction of succinimide (SUC-H, as excess reagent) with 1-bromo-3-phenylpropane (RBr, as limiting reagent) in a small amount of KOH and organic solvent solid–liquid phase medium. Under appropriate conditions, a high yield of the product was obtained. The product was successfully separated and purified from the solid–liquid phase reaction solution. From experimental observation, no byproducts were observed during or after the reaction system, indicating that only SUC-R was produced from the reactant RBr by PTC conditions. Therefore, the consumption of the reactant equals the production of product. The effects of the reaction conditions on the conversion (X) of the limited reactant RBr and the apparent rate constant (k_{app}) are discussed below.

(a) Effect of the Agitation Speed. For a solid–liquid phase reaction system, stirring agitation increases the kinetic energy of the system and tends to speed up the reaction until a limiting factor is reached. After this the reaction rate is not affected by increasing stirring rates. Thus, the effect of the agitation speed on the conversion and the reaction rate was studied in the range of 0−1200 rpm. As shown in Figure 1, the experimental data of the reaction kinetics follows the pseudo-first-order rate law and passes the origin point of a straight line for each experimental run. The apparent rate constants (k_{app}) were obtained

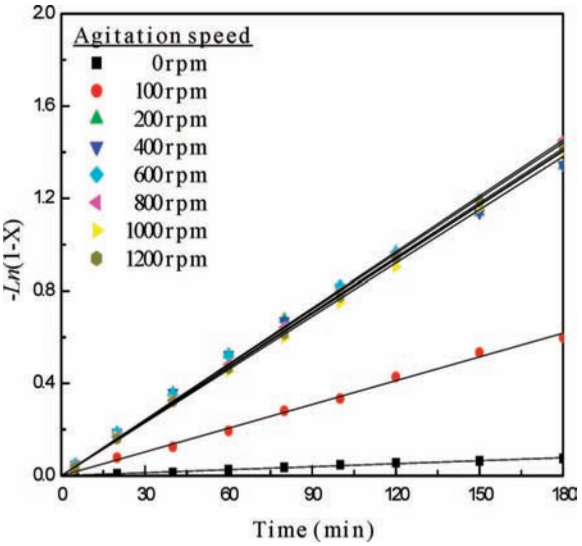


Figure 1. **Plot of $-\ln(1 - X)$ of 1-bromo-3-phenylpropane versus time with various agitation speeds; 9.0 × 10^{-2} mol of succinimide, 6.0 × 10^{-3} mol of 1-bromo-3-phenyl-propane, 1 g of KOH, 50 mL of cyclohexanone, 0.3 g of internal standard (naphthalene), 0.4 g of TOAB, 40 °C.**

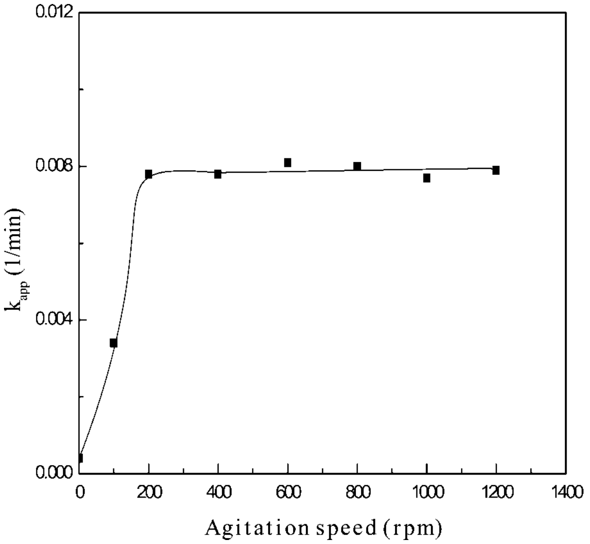


Figure 2. **Plot of the apparent rate constants versus various agitation speeds; 9.0 × 10^{-2} mol of succinimide, 0.006.0 × 10^{-3} mol of 1-bromo-3-phenylpropane, 1 g of KOH, 50 mL of cyclohexanone, 0.3 g of internal standard (naphthalene), 0.4 g of TOAB, 40 °C.**

from the slope of the straight lines. As shown in Figure 2, there was a significant increase in the apparent rate constant k_{app} from 0 to 200 rpm, but it remained at an almost constant value from 200 to 1200 rpm.[2,3,5] This phenomenon indicated less influence of the external mass transfer resistance on the reaction beyond 200 rpm. Thus, the organic-phase reaction is obviously a rate-determining step at 200–1200 rpm. All subsequent reactions were set at 1200 rpm to assess the effect of various factors on the rate of reaction.

(b) Effect of the Amount of Water. Generally, there is not even a trace amount of water added to the SL-PTC. However, in this work, a small amount of water (less than 1 mL) was added to the reaction solution in order to examine how the reaction rate and the conversion were affected by the amount of water.[2,3,6,13] The effect of the amount of water on the apparent rate constant (k_{app}) was studied in range of 0−1 mL with 1 g of KOH. As shown in Figure 3, the reaction rate and the conversion of RBr decreases with increased amount of water. Therefore, as shown in Figure 4, the apparent rate constant is decreased with the increase in the amount of water. This phenomenon indicates that: (i) the concentration of KOH is decreased with the increase in the amount of water. Thus, the concentration of active catalyst SUC-$Q_{(org)}$ is also decreased with the increase in the amount of water, which is unfavorable for the reaction. (ii) The hydration effect of active catalyst SUC-$Q_{(org)}$ is increased by increasing the amount of water, which is unfavorable for the reaction. In order to enhance the apparent rate constant, it is favorable for the reaction to use less water

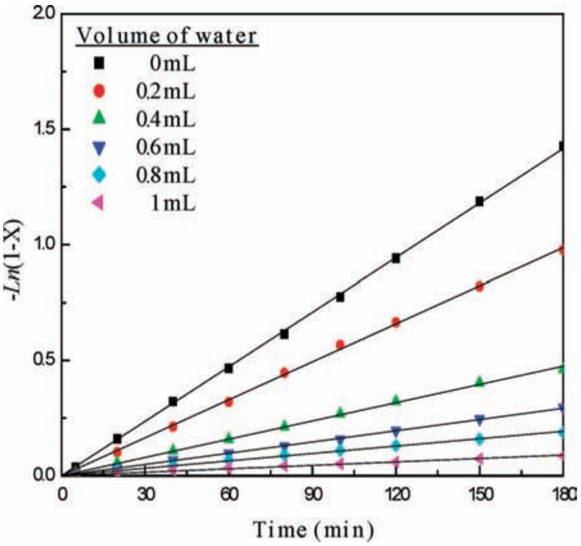


Figure 3. **Plot of $-\ln(1 - X)$ of 1-bromo-3-phenylpropane versus time with various volumes of water; 9.0 × 10^{-2} mol of succinimide, 6.0 × 10^{-3} mol of 1-bromo-3-phenylpropane, 1 g of KOH, 50 mL of cyclohexanone, 0.3 g of internal standard (naphthalene), 0.4 g of TOAB, 40 °C, 1200 rpm.**

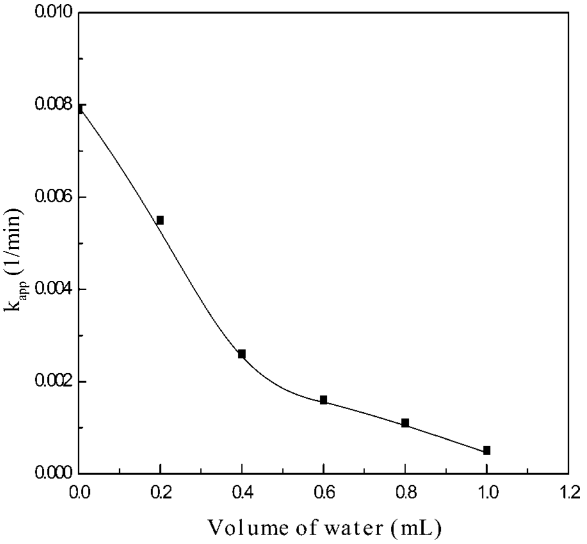


Figure 4. **Plot of the apparent rate constants versus various volumes of water; 9.0 × 10^{-2} mol of succinimide, 6.0 × 10^{-3} mol of 1-bromo-3-phenylpropane, 1 g of KOH, 50 mL of cyclohexanone, 0.3 g of internal standard (naphthalene), 0.4 g of TOAB, 40 °C, 1200 rpm.**

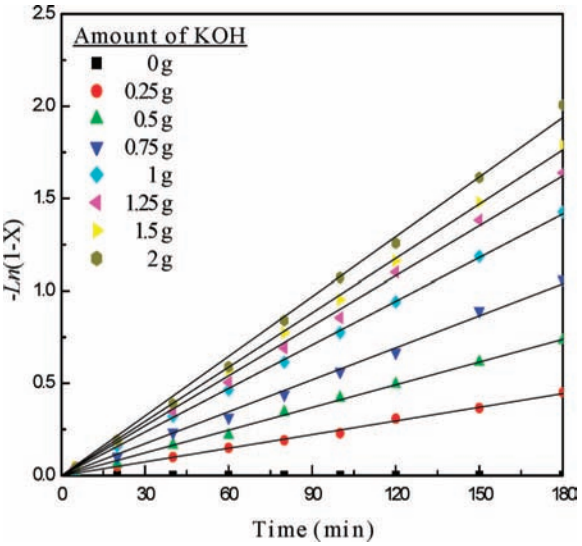


Figure 5. **Plot of $-\ln(1 - X)$ of 1-bromo-3-phenylpropane versus time with various amounts of KOH; 9.0×10^{-2} mol of succinimide, 6.0×10^{-3} mol of 1-bromo-3-phenylpropane, 50 mL of cyclohexanone, 0.3 g of internal standard (naphthalene), 0.4 g of TOAB, 40 °C, 1200 rpm.**

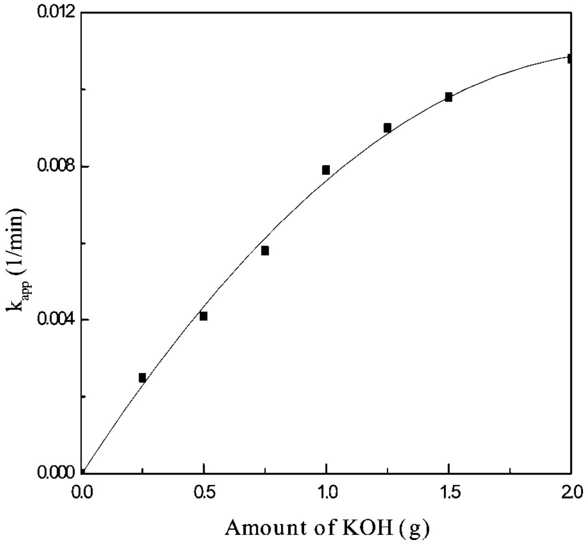


Figure 6. **Plot of the apparent rate constants versus various amounts of KOH; 9.0×10^{-2} mol of succinimide, 6.0×10^{-3} mol of 1-bromo-3-phenylpropane, 50 mL of cyclohexanone, 0.3 g of internal standard (naphthalene), 0.4 g of TOAB, 40 °C, 1200 rpm.**

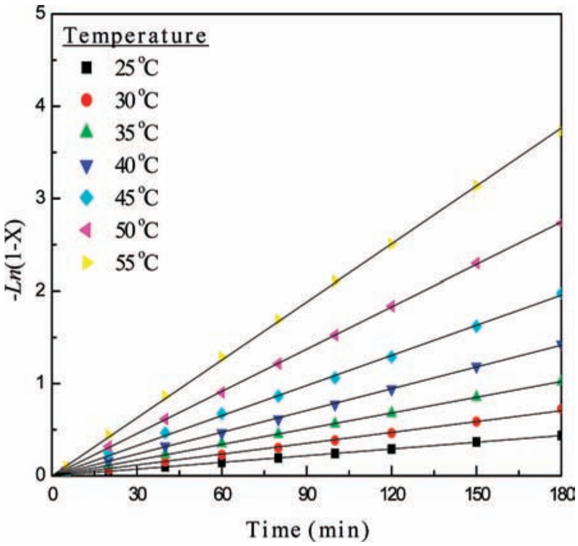


Figure 7. **Plot of $-\ln(1 - X)$ of 1-bromo-3-phenylpropane versus time with various temperatures; 9.0×10^{-2} mol of succinimide, 6.0×10^{-3} mol of 1-bromo-3-phenyl-propane, 1 g of KOH, 50 mL of cyclohexanone, 0.3 g of internal standard (naphthalene), 0.4 g of TOAB, 1200 rpm.**

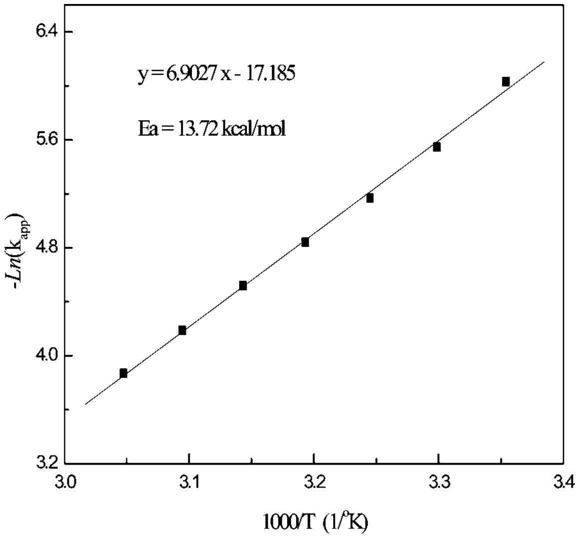
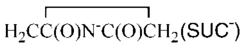


Figure 8. **Arrhenius plot for $-\ln(k_{app})$ versus $1/T$; 9.0×10^{-2} mol of succinimide, 6.0×10^{-3} mol of 1-bromo-3-phenylpropane, 1 g of KOH, 50 mL of cyclohexanone, 0.3 g of internal standard (naphthalene), 0.4 g of TOAB, 1200 rpm.**

or be in an anhydrous condition although water is produced from reaction. Thus, that is the reason why the reaction system was carried out in a solid–liquid solution in this work.

(c) Effect of the Amount of KOH. The effect of the amounts of KOH on the apparent rate constant (k_{app}) was studied in the range of 0–2 g with an anhydrous condition. As shown in Figure 5, the reaction rate is increased with increasing amount of KOH. As shown in Figure 6, the apparent rate constant is dramatically increased with increased amount of KOH. In the absence of KOH, no reaction is observed after 3 h of reaction.[5–7] Nevertheless, the conversion is dramatically increased to 36.26% after 3 h of reaction when a small quantity of KOH (0.25 g) is added to the reaction solution. This phenomenon indicates that increased KOH concentration enhances the production of the active species



$H_2CC(O)N^-C(O)CH_2(SUC^-)$

Thus, the concentration of active catalyst SUC-Q_{org} is increased by increasing the amount of KOH, which is favorable for the reaction.

(d) Effect of Temperature. The effect of the temperature on the reaction was studied in the range of 25–55 °C. The results are shown in Figure 7. It is clear that the reaction rate and the conversion are both increased with increased temperature.[2,3,8,9,13] As shown in Figure 8, the apparent rate constant is increased linearly with the increase in temperature, and the activation energy (E_a) is 13.72 kcal/mol from the slope of the Arrhenius plot of $-\ln(k_{app})$ versus $1/T$. The value of apparent activation

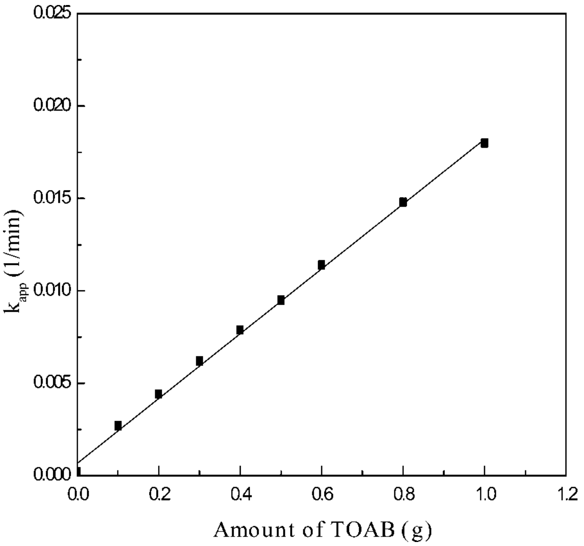


Figure 9. **Plot of the apparent rate constants versus various amounts of TOAB; 9.0×10^{-2} mol of succinimide, 6.0×10^{-3} mol of 1-bromo-3-phenylpropane, 1 g of KOH, 50 mL of cyclohexanone, 0.3 g of internal standard (naphthalene), 40 °C, 1200 rpm.**

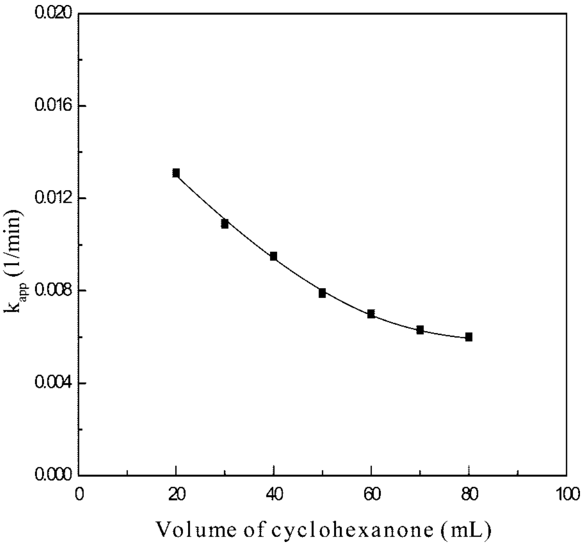


Figure 10. **Plot of the apparent rate constants versus various volumes of cyclo-hexanone; 9.0×10^{-2} mol of succinimide, 6.0×10^{-3} mol of 1-bromo-3-phenylpropane, 1 g of KOH, 0.3 g of internal standard (naphthalene), 0.4 g of TOAB, 40 °C, 1200 rpm.**

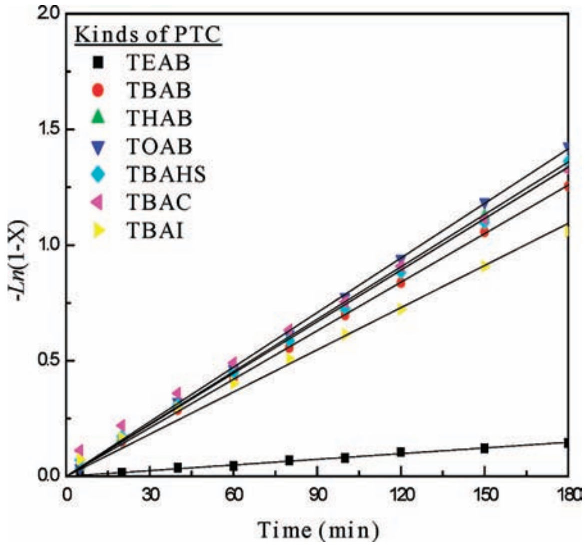


Figure 11. **Plot of $-\ln(1 - X)$ of 1-bromo-3-phenylpropane versus time with various phase-transfer catalysts; 9.0×10^{-2} mol of succinimide, 6.0×10^{-3} mol of 1-bromo-3-phenylpropane, 1 g of KOH, 0.3 g of internal standard (naphthalene), 7.3×10^{-4} mol of PTCs, 40 °C, 1200 rpm.**

energy shows that the solid–liquid reaction is under organic-phase reaction control with agitation speed of 1200 rpm.

(e) Effect of the Amount of TOAB Catalyst. The effect of the amount of TOAB catalyst on the reaction was studied in the range of 0–1 g. As shown in Figure 9, the apparent rate constant is increased linearly with the increase in the amount of TOAB catalyst. In the absence of TOAB catalyst, a conversion of 4.16% is observed after 3 h of reaction. However, the conversion is dramatically increased to 38.50% after 3 h of reaction when a small quantity of TOAB catalyst (0.1 g) is added to the reaction solution. The concentration of quaternary ammonium cation (Q^+) in organic-phase solution, which affects the concentration of the active catalyst SUC-Q, is increased with increased amount of TOAB catalyst. Thus, the apparent rate constant is highly dependent on the amount of TOAB catalyst.[2,3,6,13] In addition, the experimental results are consistent with the theoretical derivation given by eq 15.

(f) Effect of the Volume of Cyclohexanone (Organic Solvent). The effect of the volume of cyclohexanone on the apparent rate constant was studied in the range of 20–80 mL. As shown in Figure 10, the apparent rate constant is decreased with increased volume of cyclohexanone. This phenomenon indicates that a dilute concentration of the reactants and active catalyst $SUC\text{-}Q_{(org)}$ are decreased with the increase in the volume of cyclohexanone. In order to enhance the apparent rate constant, decreasing the volume of cyclohexanone is favorable for the reaction.[2,3,13]

(g) Effect of the Quaternary Ammonium Salts. In this work, seven quaternary ammonium salts were selected for the solid–liquid reaction at 40 and 1200 rpm. As shown in Figure 11, and Table 1, the reactivity order of these seven catalysts are: TOAB > THAB $\doteq$ TBAHS $\doteq$ TBAC > TBAB > TBAI > TEAB. Comparing the experimental results for TOAB, THAB, TBAB, and TEAB, it can clearly be seen that the reactivity of quaternary salt increases with the increase in the total carbon number of the alkyl group of the cation.[2,3] This phenomenon indicates that a large total carbon number increases hydrophobic properties of the SL-PTC. Furthermore, Table 1 depicts the apparent rate constant for these seven catalysts in which TOAB contributes high reactivity.

(h) Effect of the Organic Solvents. According to solid–liquid PTC reaction systems, the solvent affects the intrinsic reaction of the reactant. This implies that various solvents have different reaction rates. In this work, five organic solvents were applied to investigate the effect of their polarities and dielectric constants (ϵ) on the S-L PTC system. As shown in Figure 12 and Table 2, the reactivity order of these five solvents are: cyclohexanone > acetophenone > *o*-dichlorobenzene > chlorobenzene > chloroform It is clearly found that the apparent rate constant increases with thedielectric constantof the solvents

Table 1. Effect of phase-transfer catalysts on the apparent rate constants[a]

phase transfer catalysts	apparent rate constants
TEAB	0.8
TBAB	7
THAB	7.4
TOAB	7.9
TBAHS	7.4
TBAC	7.5
TBAI	6.1

[a] Reaction conditions: 9.0×10^{-2} mol of succinimide, 6.0×10^{-3} mol of 1-bromo-3-phenylpropane, 1 g of KOH, 0.3 g of internal standard (naphthalene), 7.3×10^{-4} mol of PTCs, 40 °C, 1200 rpm.

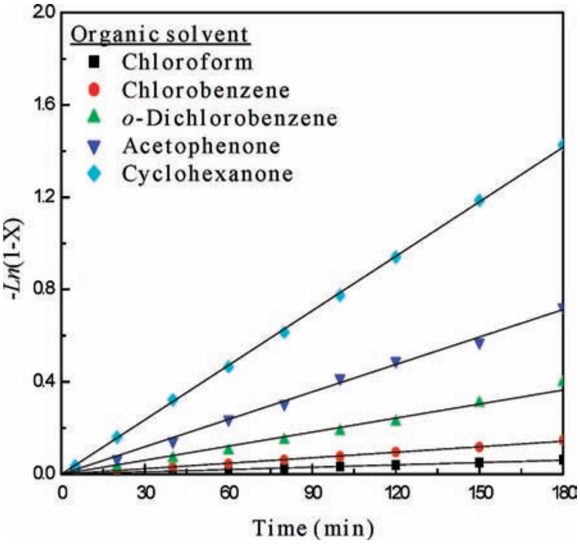


Figure 12. Plot of $-\ln(1 - X)$ of 1-bromo-3-phenylpropane versus time with various organic solvents; 9.0×10^{-2} mol of succinimide, 6.0×10^{-3} mol of 1-bromo-3-phenyl-propane, 1 g of KOH, 50 mL of organic solvent, 0.3 g of internal standard (naphthalene), 0.4 g of TOAB, 40 °C, 1200 rpm.

but does not increase with the polarity.[2,3,6,13] In order to enhance the apparent rate constant, using a high dielectric constant solvent (cyclohexanone) is favorable for the reaction. In addition, the degradation of any organic solvent was not observed during or after the reaction.

Table 2. Effect of the organic solvents on the apparent rate constants[a]

organic solvents	dielectric constant ϵ	polarity	apparent rate constant k_{app} ($\times 10^{-3}$ min^{-1})
chloroform	4.8	4.1	0.3
chlorobenzene	5.6	2.7	0.8
o-dichlorobenzene	9.93	–	2
acetophenone	17.4	4.8	4
cyclohexanone	18.3	4.7	7.9

[a] Reaction conditions: 9.0×10^{-2} mol of succinimide, 6.0×10^{-3} mol of 1-bromo-3-phenyl-propane, 1 g of KOH, 50 mL of organic solvent, 0.3 g of internal standard (naphthalene), 0.4 g of TOAB, 40 °C, 1200 rpm.

Conclusion

In this work, the synthesis of 1-(3-phenylpropyl)-pyrrolidine-2,5-dione (SUCR), which is a biologically and industrially useful imide derivative, was successfully carried out from the reaction of succinimide (SUC-H) with 1-bromo-3-phenylpropane (RBr) in a small amount of KOH and organic solvent under solid–liquid phase-transfer catalytic (SL-PTC) almost water-free conditions. The reaction mechanism and the apparent rate constants were obtained from the experimental results. When the agitation speed exceeds 200 rpm, the mass transfer resistance at the solid–liquid interface can be ignored. The overall reaction can be described by pseudo-first-order kinetics, and the apparent activation energy in cyclohexanone of 13.72 kcal/mol was obtained. The reaction rate is increased by increasing the amount of KOH and TOAB. Nevertheless, the reaction rate is decreased by increasing the volume of water and cyclohexanone. A high dielectric constant organic solvent, such as cyclohexanone, enhances the reaction to obtain a high conversion of RBr. A high reactivity is obtained by choosing TOAB as the phase-transfer catalyst.

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