

Research note

Phase-transfer catalysis for synthesis of Ethyl 2-(4-Nitrophenoxy)Acetate under sonication- kinetic aspects

P. Abimannan, V. Rajendran*

Pachaiyappa's College for Men, Kanchipuram, Tamil Nadu, India – 631 501

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ABSTRACT

Ultrasound assisted phase-transfer catalyzed preparation of ethyl 2-(4-nitrophenoxy)acetate from the corresponding p-nitrophenol and ethyl 2-bromoacetate using the mild solid base, anhydrous potassium carbonate, under very mild conditions is reported. The solid-liquid reactions were performed in a batch reactor equipped with reflux condenser, and ultrasonic irradiations were introduced using an ultrasonic bath operating at a frequency of 28 kHz with a power rating of 300 W. The reaction was carried out at 50°C under pseudo-first order conditions and was monitored by gas chromatography (GC). From the experimental data, a rate expression had been developed to explain the kinetic behavior of the reaction from which the apparent rate constant (k_{app}) of the organic phase was attained. The effects of different operating parameters such as stirring rate, temperature, catalyst loading and kind of Phase-transfer catalysts, base variation and quantity of water, and kind of solvents have been investigated to maximize the yield of synthesis of ethyl 2-(4-nitrophenoxy)acetate.

1. Introduction

The development of catalytic processes that afford an easy separation of the reaction mixture, easy removal of the catalyst is one of the main aims of chemical research and the chemical industry today [1]. These characteristics are reflected in phase-transfer catalysis (PTC). Particularly, PTC methods conducted in a solid-liquid system (SL-PTC) have aroused considerable interest in recent years [2]. Compared to liquid-liquid PTC (LL-PTC), the phase-transfer

catalyst for SL-PTC can easily improve the reaction rate or conversion or yield. The milder conditions of performing the reaction, the lack of side reactions, lesser corrosion caused to the environment, can be reckoned among the advantages of the system of the SL-PTC. Furthermore, in solid-liquid PTC the mild bases such as potassium carbonate and sodium carbonate are used and carbonates can be applied in a solid state, particularly in cases when reactants are sensitive to the presence of water in the reactive systems; they dry

*Corresponding author: 1967sssr@gmail.com

more easily than the solid NaOH [3].

Researchers have published several reports on the use of ultrasound as a process intensification tool for numerous catalytic reactions as well as in homogeneous and in heterogeneous reactions and it has proved to be a clean tool for improving yields and decreasing reaction time [4]. Research has been carried out in the area of cavitation for synthesizing different organic materials since the discovery that ultrasound could play a role in generating cavitation in a medium. Cavitation is the phenomenon of sequential formation, growth and collapse of millions of microscopic vapor bubbles in the liquid. The collapse or implosion of these cavities creates highly localized temperatures of roughly 5000–10000 K and a pressure of about 1000–2000 atm and results in short-lived, localized hot-spot in cold fluid [5,6]. The chemical and physical effects of ultrasound in a fluid medium were first systematically reported by Suslick [7], who stated that the chemical effects of ultrasound are not derived from a direct coupling of the acoustic field with chemical species on a molecular level. Instead, sonochemistry and sonoluminescence derive principally from acoustic cavitation, the formation, growth, and implosive collapse of bubbles in liquids irradiated with high-intensity ultrasound. The chemical effects of ultrasound have been well-explained as a consequence of localized hot spots created during bubble collapse [5]. Nowadays, ultrasound in the heterogeneous PTC reactions has garnered much more attention. The combination of phase-transfer catalysis and sonication results in a better technique than either of the

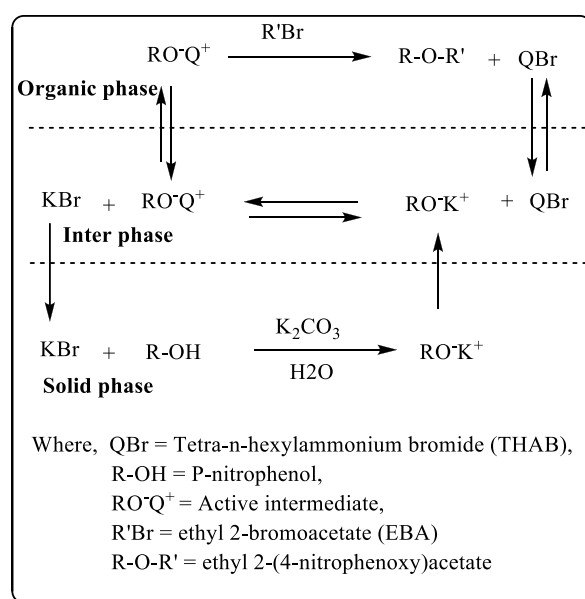
techniques alone [8-11]. The interfacial mechanism of the solid-liquid PTC system is represented in the scheme 1 [12-16].

We report herein the application of the mild solid base, potassium carbonate, in the solid-liquid phase-transfer catalyzed synthesis of ethyl 2-(4-nitrophenoxy)acetate under sonication. The kinetic aspect such as stirring rate, temperature, catalyst loading and kind of Phase-transfer catalysts, base variation and quantity of water and kind of solvents on the conversion of ethyl 2-bromoacetate is well studied.

2. Experimental

2.1. Catalysts, chemicals and solvents

All the reagents, including, p-nitrophenol and ethyl 2-bromoacetate (SD Fine Chemicals, Mumbai, India), biphenyl (Aldrich), tetra-n-butylammonium iodide (TBAI), tetra-n-butylammonium bromide (TBAB), tetra-n-butylammonium hydrogen sulfate (TBAHS), tetra-n-hexylammonium bromide (THAB) and tetra-n-butylammonium chloride (TBAC)



Scheme 1. proposed mechanism for the present reaction system.

were obtained from Fischer scientific, Fluka, Merck and Aldrich. Solvents and other reagents for synthesis were guaranteed grade (GR) chemicals and were used without further purification.

2.2. Instrumentation

Gas chromatography was carried out using a GC-Varian 3700 model. Ultrasonic water bath, Equitron, Media Instrument Manufacturing Company, Chennai, India-600 004.

2.3. Ultrasonic process equipment

Ultrasonic energy is transmitted to the process vessel through the liquid medium, usually water in the tank. For safety purposes, the sonochemical reactor consisted of a two layer stainless steel body. The sonochemical reactor configuration used in the present work is basically an ultrasonic bath. The internal dimension of the ultrasonic cleaner tank is 48cm×28cm×20cm with liquid holding capacity of 5 L. Two types of ultrasound frequencies were used in these experiments, which are 28 kHz and 40 kHz with each output as 300 W. Both ultrasounds are separately produced through a flat transducer mounted at the bottom of the sonicator. The reactor was a 250 mL three-necked Pyrex round-bottom flask. This reaction vessel was supported at the centre of the ultrasonic cleaning bath 2cm above from the position of the transducer to obtain the maximum ultrasound energy. All the experimental parameters were done at 28 kHz with output power of 300W.

2.4. Kinetics of etherification reaction

The reaction was conducted on a 250 mL

three-necked Pyrex round-bottom flask, this permits agitating the solution, inserting the water condenser to recover organic reactant, and taking samples and feeding the reactants. This reaction vessel was supported at the centre of the sonicator. Known quantities of chlorobenzene (30 mL), potassium carbonate (3 g in 0.5 mL water) and 0.2 g biphenyl (IS-internal standard) were introduced into the reactor. Then, 3 g of p-nitrophenol and 0.6 g of ethyl 2-bromoacetate, 0.2 g of THAB were introduced to the reactor to start the reaction. The reaction mixture was stirred at 800 rpm. The phase separation was almost immediate on stopping the stirring process. Samples were collected from the organic layer at regular time intervals and 0.5 mL of chlorobenzene was added to vials to dilute the solution. The kinetics was followed by estimating the amount of ethyl 2-bromoacetate (limiting reagent) that disappeared and was measured by a gas Chromatography (GC-Varian 3700 model). The analyzing conditions were as follows: Column, 30m×0.525mm i.d. capillary column containing 100% poly(dimethyl siloxanen); injection temperature, 250°C; FID detector (300°C). Yields were determined from standard curve using biphenyl as an internal standard. The kinetic experiments of etherification were carried out under pseudo first order conditions, taking excess of p-nitrophenol and potassium carbonate under the combined effect of sonication (28 kHz, 300W) and phase-transfer catalyst. The k_{app} values were obtained by plotting $-\ln(1-X)$ versus time.

3. Results and discussion

3.1. Effects of stirring speed

Kinetics studies have been performed at 0–1000 rpm. The pseudo-first order rate constant was obtained from plot of $-\ln(1-x)$ versus time. Calculated rate constants are shown in Fig. 1. The rate of the reaction is increased up to stirring rate 200 rpm, after that it remains almost constant. The data clearly indicates that mixing speed within the interval under examination (200-1000 rpm) does not affect the rate of ethyl 2-(4-nitrophenoxy)acetate formation. On the basis of experimental observation, the reaction is still enhanced by ultrasonic irradiation even when the reaction is not agitated by the stirrer. Combination of ultrasound and stirring produce an enhanced rate of reaction, it is mainly believed that the interfacial area between two phases is affected both by the agitation speed and by the use of ultrasound which are responsible for the enhancement of the kinetics by harsh mixing, enhancement of mass transfer, especially in solid-liquid

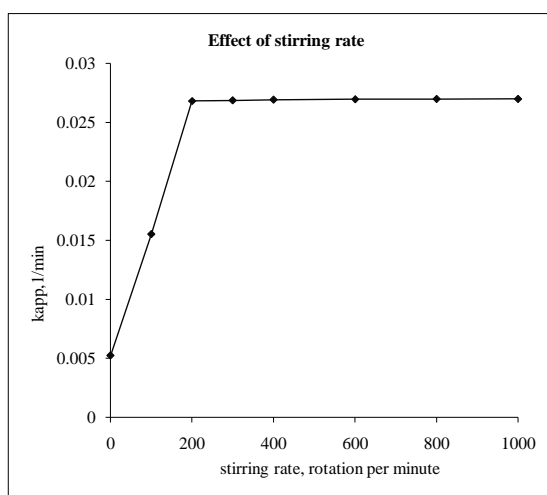


Figure 1. Effect of various stirring speed on the rate of reaction: 3 g of K_2CO_3 , 0.5 mL H_2O , 0.2 g of biphenyl (internal standard), 3 g of p-nitrophenol, 0.6 g of ethyl 2-bromoacetate, 0.2 g of THAB, 30 mL of chlorobenzene, $50^\circ C$, 28 kHz, 300 W.

systems, hence high erosion of the solid particles occurs and the surface area is increased. The reaction was carried out in silent condition (stirring only) to compare the influence of ultrasound. The influence of stirring and ultrasound irradiation shows enhanced rate. The rate constant (k_{app}) 26.82×10^{-3} , 1/min and 12.23×10^{-3} , 1/min corresponds to the ultrasound + stirring and stirring only. All model measurements were carried out with mechanical stirring at 800 rpm.

3.2. Effect of amount of THAB loading and different PTCs

The conversion of ethyl 2-bromoacetate was very little in the absence of THAB in the reaction mixture. However, the reaction had been increased by adding a tiny quantity of the THAB catalyst. The enhanced rates or conversion are obtained due to the rise in the maximum number of catalytically active sites. The % conversion of ethyl 2-bromoacetate for various amount of THAB catalyst loaded is shown in Fig. 2(a). The conversion of ethyl 2-bromoacetate is gradually increased to 55.3%, 68.5% and 80% for 0.1 g, 0.15 g and 0.2 g for loading of THAB respectively. For loading of 0.3 g of THAB, the conversion reaches 85.3% in 50 min and remains for prolonging the time for 60 min. Therefore we decided that the fittest value of the THAB catalyst loaded for this reaction system is 0.2 g.

Five different phase-transfer catalysts were employed to explore their efficacy for this reaction. The catalysts tested were tetra-n-butylammonium iodide (TBAI), tetra-n-butylammonium bromide (TBAB), tetra-n-butylammonium hydrogen sulfate (TBAHS), tetra-n-hexylammonium

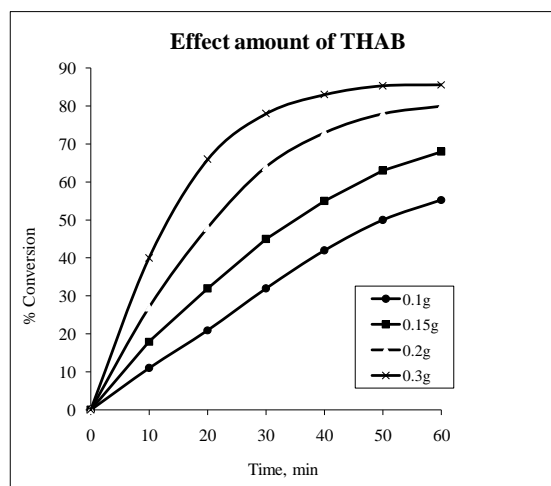


Figure 2 (a). Effect of amount of THAB on the conversion: 3 g of K_2CO_3 , 0.5 mL H_2O , 0.2 g of biphenyl (internal standard), 3 g of p-nitrophenol, 0.6 g of ethyl 2-bromoacetate, 30 mL of chlorobenzene, 800 rpm, 28 kHz, 300 W.

bromide (THAB) and tetra-n-butylammonium chloride (TBAC). The kinetic profile of the reaction is obtained by plotting $-\ln(1-x)$ versus time (Fig. 2(b)). The order of catalytic reactivity of PTC's is $THAB > TBAB > TBAI \sim TBAHS > TBAC$ [12]. This indicates that

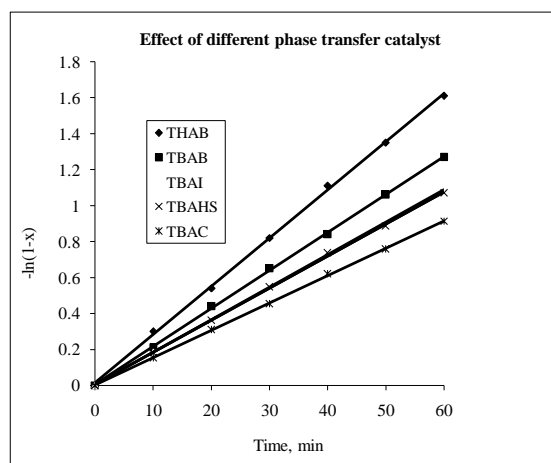


Figure 2(b). Effect of different phase transfer catalyst on the conversion: 3 g of K_2CO_3 , 0.5 mL H_2O , 0.2 g of biphenyl (internal standard), 3g of p-nitrophenol, 0.6 g of ethyl 2-bromoacetate, 0.2 g of PTCs, 30 mL of chlorobenzene, 800 rpm, 28 kHz, 300 W.

a more lipophilic quaternary cation more easily solvates the solid reactant anion, thus a faster initial reaction rate was obtained. Moreover, the deactivation of TBAI catalyst was greater than that of others. This may be due to larger ionic size of iodide reducing the solubility of ROQ in chlorobenzene. The production of NaI from the reaction of NaBr with TBAI may also retard the formation and concentration of ROQ in the organic phase, thus reducing the reaction rate.

3.3. Effect of temperature

To study the effect of temperature for reaction between p-nitrophenol and ethyl 2-bromoacetate, the temperature was varied from $40^\circ C$ to $70^\circ C$ keeping constant reaction conditions under ultrasound irradiation (Fig. 3). The conversion of ethyl 2-bromoacetate was observed to increase with increase in reaction temperature along with ultrasonication [8]. This is due to the number of reactant molecules which possess higher activated

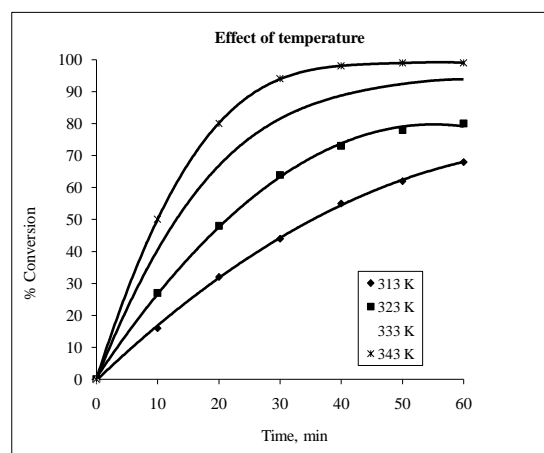


Figure 3. Effect of various temperatures on the rate of reaction: 3 g of K_2CO_3 , 0.5 mL H_2O , 0.2 g of biphenyl (internal standard), 3 g of p-nitrophenol, 0.6 g of ethyl 2-bromoacetate, 0.2 g of THAB, 30 mL of chlorobenzene, 800 rpm, 28 kHz, 300 W.

energy at a higher temperature and thus the ultrasonic wave easily passes through the reactor and increases the collision between the reactants. The Arrhenius plot was made to determine the energy of activation as 41.86 kJ/mol (Fig. 4). This value also demonstrates that the reaction is kinetically controlled.

3.4. Effect of different solvents

According to solid-liquid PTC reaction systems, intrinsic reactions including the rate constants and conversion are highly affected by the organic solvents. Various solvents have different reaction rates. In this work, five organic solvents were used to investigate the effect of their polarities and dielectric constants (ϵ) on the SL-PTC and ultrasonication system. The pseudo-first order rate constant was obtained from plot of $-\ln(1-x)$ versus time. As in Table 1, Entry No. 1, the order of reactivity of these five solvents is: *o*-dichlorobenzene > chlorobenzene > anisole > toluene > hexane. It was clearly found that the apparent rate constant increased with the dielectric

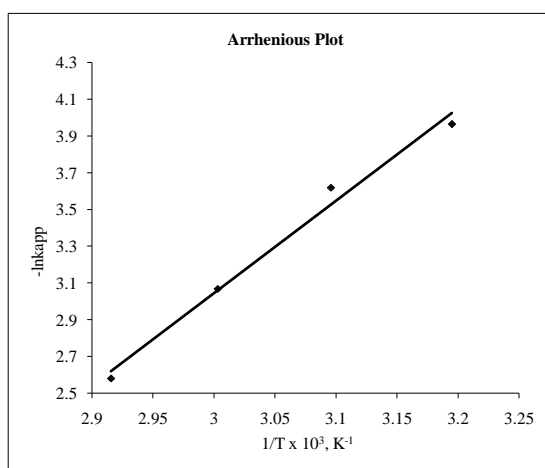


Figure 4. Arrhenius plot: 3 g of K_2CO_3 , 0.5 mL H_2O , 0.2 g of biphenyl (internal standard), 3 g of *p*-nitrophenol, 0.6 g of ethyl 2-bromoacetate, 0.2 g of THAB, 30 mL of chlorobenzene, 800 rpm, 28 kHz, 300 W.

Table 1

Effect of various kinetic parameters on the reaction rate.

Entry No.	Kind of variations	$K_{app} \times 10^3$, 1/min
1.	Kind of solvents (Dielectric constant)	
	Chlorobenzene (5.6)	26.82
	<i>O</i> -dichlorobenzene (9.93)	30.12
	Toluene (2.4)	20.02
	Hexane (1.89)	12.52
	Anisole (4.3)	22.43
2.	Various K_2CO_3 concentration	
	1 g in 0.5 mL H_2O	16.76
	2 g in 0.5 mL H_2O	20.54
	3 g in 0.2 mL H_2O	12.24
	3 g in 0.5 mL H_2O	26.82
	3 g in 1 mL H_2O	24.43
	3 g in 2 mL H_2O	20.54
	3 g in 3 mL H_2O	16.65
3 g in 5 mL H_2O	14.22	

Reaction condition: 3 g of K_2CO_3 , 0.5 mL H_2O , 0.2 g of biphenyl (internal standard), 3 g of *p*-nitrophenol, 0.6 g of ethyl 2-bromoacetate, 0.2 g of THAB, 30 mL of chlorobenzene, 800 rpm, 50°C, 28 kHz, 300 W.

constant of the solvents but did not increase with the polarity. In order to enhance the apparent rate constant, using a high dielectric constant solvent is favorable for the reaction. In addition, no degradation of any organic solvent was observed during or after the reaction. The results are also shown in Table 1, Entry No.1. It was clearly observed that the apparent rate constant increases with the dielectric constant of the solvents but does not increase with the polarity.

3.5. Effect of various potassium carbonate concentrations

The rate of reaction is tremendously affected by a concentration of the alkaline potassium carbonate. The rate of etherification of *p*-nitrophenol was strongly dependent on the strength of the potassium carbonate concentrations. Kinetic experiments were carried out by

employing 1 to 3 g of K_2CO_3 (0.5 mL water constant) under otherwise similar reaction conditions. The pseudo-first order rate constant was obtained from plot of $-\ln(1-x)$ versus time. The conversion or rate of reaction was tremendously increased with increase in basicity (Table 1, Entry No.2). The main reason is that on increasing the alkaline concentration, the amount of production of anion (RO^-) is increased and the distribution of active catalyst (ROQ) increases, too. From the Table 1, Entry No.2, the conversion or reaction rate increased linearly in the alkali concentration. The water has an indirect influence on the basicity of potassium carbonate and the hydration of the ion-pair. In order to increase the apparent rate constant (k_{app}), it is desirable that the reaction use less water or be in an anhydrous condition, although water is produced from reaction. Thus, that is the reason why the reaction was carried out in a solid-liquid solution in this work [14]. The volume of water is changed from 0-5 mL, keeping 3 g base as constant, the reaction rate first increased and then decreased as the volume increased.

4. Conclusions

The solid-liquid reaction was successfully carried out in the presence of tetra-n-hexylammonium bromide and ultrasonication to produce the desired product namely 2-(4-nitrophenoxy) acetate from p-nitrophenol and ethyl 2-bromoacetate.

The higher selectivity and rate of reaction was obtained under sonication and PTC.

The apparent reaction rates were observed to obey the pseudo-first order

kinetics.

The reaction mechanism and the apparent rate constants were obtained from the experimental results.

The apparent rate constants are found to be directly dependent on each kinetic variable, such as, concentration of PTC, amount of potassium carbonate, stirring speed and temperature. However it decreases with increase in the volume of water.

Energy of activation was calculated from the Arrhenius plot.

The combination of ultrasound and PTC resulted in better efficacy as compared to the individual operations.

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