

SYNTHESIS OF SOME HIGH-MOLECULAR WEIGHT ESTERS IN SUPERCRITICAL ALCOHOLS

Ayşegül Doğan and E. Sultan Giray*

Department of Chemistry, Faculty of Sciences & Arts, University of Çukurova, Adana,
01330, Turkey esgiray@cu.edu.tr Fax:+90-322 338 6070

Esterification of several carboxylic acids with supercritical alcohols such as 1-propanol, 1-butanol, 1-octanol, isoamylalcohol, ethanol, methanol, and subcritical benzyl alcohol without using any catalyst was studied. A variety of esters were synthesized very effectively using supercritical alcohols as solvent and reagent. Moderate to excellent yields were obtained depending on the nature of the carboxylic acid and the alcohol used. The reaction of acetic acid with lower aliphatic alcohols generally produced higher yields compared with higher aliphatic and aromatic alcohols.

INTRODUCTION

Organic Chemists have significant interest on supercritical fluids because of their unique properties. The physicochemical properties of supercritical fluids, such as diffusivity and polarity, can be continuously controlled by changing their pressure and temperature. This unique property helps them to serve as reaction media in organic synthesis.

Especially, the organic reactions using supercritical carbon dioxide (scCO₂) were extensively studied from the perspective of Green Chemistry[1,2]. Recently, supercritical water (scH₂O) has also been widely used as a reaction solvent. Supercritical water or high-temperature water is a candidate solvent for the conversion of carboxylic acids into their respective amides or esters at high temperature[3-7].

Ghaziaskar et al. investigated the catalytic esterification of 2-ethylhexanoic acid with 2-ethyl-1-hexanol using supercritical carbon dioxide. The effect of pressure, temperature, flow rate and mole ratio of the alcohol with the acid, and the type of catalyst were evaluated. They found that the ester, 2-ethylhexyl 2-ethylhexanoate, was continuously synthesized with 100% selectivity and 40% conversion using zirconium oxide, but the enzymatic catalysis had no significant conversion (3%) due to acid inactivation [8]. The esterification of myristic acid with ethanol was studied using a commercial lipase. Conversions of up to 76% were obtained under solvent-free conditions, whereas conversions of only up to 37 and 4% were obtained under scCO₂ and acetonitrile conditions, respectively [9]. Nagesha *et al.* investigated to optimize the conditions for the maximum yield of fatty acid butyl esters by enzymatic esterification of free fatty acids, which is present in the hydrolyzed soy deodorizer distillate and butanol using an immobilized lipase from *Mucor miehei* (EC 3.1.1.3) under scCO₂ condition [10].

Recently, it was reported that the organic reactions using supercritical fluids not only act as media but also as reagents [11]. Gubin reported the reduction of benzaldehyde to benzyl alcohol using supercritical 2-propanol. It was found to be reactive with some organic compounds and supercritical water[12]. Supercritical alcohols can function as reducing agents

for ketones and aldehydes [13-16]. In literature, the direct addition of alcohol molecules to alkenes or alkynes to form a carbon-carbon bond was reported [17].

High-molecular weight esters can be used as food additives and lubricants, and in cosmetics and pharmaceutical industries. The production of these esters is usually carried out under equilibrium conditions and can be shifted toward the products either by using an excess of the reactants (alcohol or acid) or by the removal of the products (ester or water) from the reaction vessel. The drawback of traditional ester synthesis is the use of a strong acid, sulfuric acid, as a catalyst. Lewis acids may also be used. Also, excess catalyst may cause dehydration of alcohol and the acids are corrosive and hazardous. It is now reported that a variety of carboxylic acids with supercritical alcohols can synthesize certain industrially important esters without using any catalyst.

MATERIALS AND METHODS

Reactions were carried out in a thick-walled 316 stainless steel reactor (25 mL volume). At first, a certain amount of organic acid (2 mmol) and 1 mmol of alcohol (almost 6 mL) were placed in the reactor, and then the system was purged with high-purity nitrogen. After the temperature inside the reactor had reached the reaction temperature (up to critical temperature of each alcohol), the reactions were carried out for 5 or 30 min. Reaction time was measured from the moment the reaction temperature was reached, and it does not include the time required to reach the reaction temperature or to cool the system (15-20 min each). The pressure during the reaction depends on the substrates. It was found that use of almost 6 ml of the solvent gave acceptable pressures. The conditions used in all the experiments were summarized in Table 1. Once the reactor was heated for the required time, it is placed in a cooling pot and allowed to return to ambient temperature and pressure. Quantitative analysis of the reaction products was carried out using Thermo-Finnigan GC-FID. GC analysis was performed on a nonpolar capillary column [(ZB-5), Alltech, 60 m, film thickness 0.25 mm, I.D. 0.32 mm]. The mobile phase was He gas (12 psi) and the injection volume was 1 ml. The initial temperature was 50° C and the isothermal conditions were maintained for the first 5 min, and then the temperature was increased at a rate of 20° C min⁻¹ up to 300°C. Isothermal conditions were also maintained for the final 5 min. Identification of the products was performed by a Thermo-Finnigan GC-MS by the EI technique (70eV). The products were identified tentatively by matching with GC-MS results of the National Institute of Standards and Technology (NIST) and Wiley 7 mass spectral library data.

RESULTS

Esterification of several organic acids with supercritical alcohols such as 1-propanol **2**, 1-butanol **3**, 1-octanol **4** isoamylalcohol **5**, ethanol **8**, methanol **12**, and subcritical benzyl alcohol **10** were examined in detail. . The critical conditions of the alcohols used in this study are as follows: methanol ($T_c= 513$ K, $P_c= 8,1$ MPa), ethanol ($T_c= 514$ K, $P_c= 6,1$ MPa), propanol ($T_c= 537$ K, $P_c=5,2$ MPa), and benzyl alcohol ($T_c=715$ K, $P_c= 4,3$ MPa).

A series of experiments was performed to optimize the reaction conditions and, in particular, to investigate the role of water/alcohol ratio in the yield. To optimize the reaction conditions, acetic acid was subjected to reaction with numerous alcohols at high temperatures ($\geq 280^\circ\text{C}$) in water with 3:1 and 0:1 water/alcohol ratio. Figure 1 shows the result of esterification of acetic acid **1** with different alcohols. It was found that the amount of alcohol in water was also important for improving the yield of the products. Hence, the ratio of water/alcohol was

changed to 0:1 v/v, and it was found that the supercritical alcohols were very effective in the yield of ester as a solvent and also as an esterification reagent. As the ratio of water was decreased, the yield of ester product was improved and when the reaction was carried out only with supercritical alcohol, 80-100% yield was obtained. The reactions were very fast and completed within approximately 5 min in addition to the time taken by the reactor to cool. It was found that the yield of the ester was strongly dependent on the kind of supercritical alcohol used.

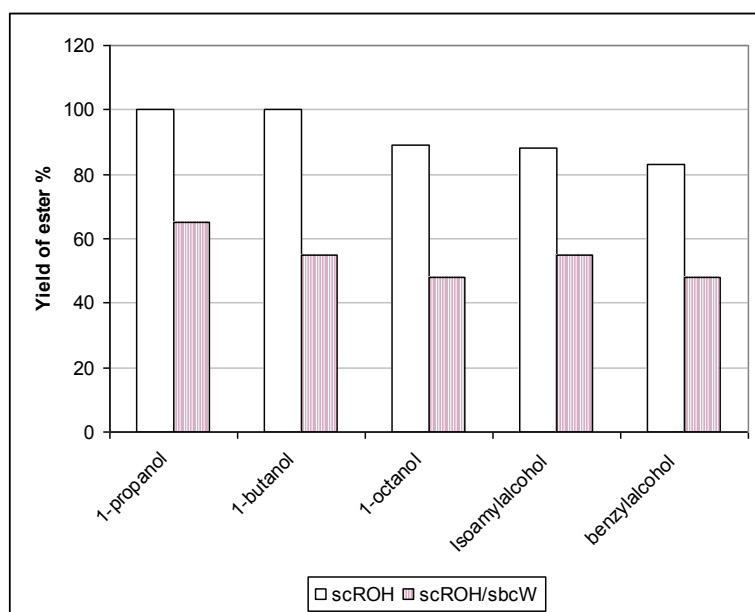


Figure 1. Results obtained from the reaction of acetic acid with different alcohol in sbcW and scROH.

Reactions of acetic acid **1** with 1-propanol **2** and 1-butanol **3** produced the highest yield of ester (100% for both of them), which can be explained by the acidity of the alcohols. More acidic alcohols produce more alkoxide ion and hence this alcohol is responsible for the rapid formation of the corresponding ester, it may be explained that pure alcohol provides more rapid heat transfer than water/alcohol mixture. It is important to note that the presence of an acid catalyst does not alter the equilibrium constants of the reaction, which is a function of temperature only, or change the extent of conversion; it just enhances the rate of the reaction¹³. The stoichiometric ratio of RCOOH/ROH was 2:1. The results of esterification reactions using supercritical alcohols are summarized in Table 1. As could be seen from Table 1, most of the reactions were completed in 5 minutes in addition to the time taken by the reactor to cool. Except the reaction of acetic acid, reaction of butyric acid **7** with ethanol **8** produced the highest yield of ester products among the others.

Table 1 Results obtained with different organic acids and supercritical alcohols.

Entry	Substrate	Alcohol	<i>T</i> (°C)	<i>P</i> (bar)	Time (min)	Product	Yield
1	Acetic acid 1	1-propanol 2	280	68	5	n-Propyl acetate 1a	100
2	Acetic acid 1	1-butanol 3	310	102	5	n-Butyl acetate 1b	100
3	Acetic acid 1	1-octanol 4	280	48	5	Octylacetate 1c	89
4	Acetic acid 1	Isoamylalcohol 5		61		Isoamylacetate 1d	88
5	Acetic acid 1	Benzyl alcohol 6	280	41	5	Benzyl acetate 1e	83
6	Lauric acid 7	Methanol 8	280		5	Methyl laurat 7a	95
7	Stearic acid 9	Methanol 8	280		5	Methyl stearat 9a	95
	Butyric acid 10	Ethanol 11	280	61	5	Ethyl butyrate 7a	100
7	Benzoic acid 12	Benzyl alcohol 13	350	41	30	Benzyl benzoate 12a	58
8	Salicylic acid 14	Methanol 8	280	81	30	Methyl salicylate 14a	30
						Phenol 14b	70
9	Cinnamic acid 15	Methanol 8	280	75	0	Methyl cinnamate 15a	95

In the case of lauric acid **7** and stearic acid **9**, methyl esters of these two organic acid prepared easily in pure methylalcohol in 5 min reaction time. Conversion was almost 100%. During the esterification of benzoic acid **12** and salicylic acid **14**, hydrolysis and decarboxylation reactions were in competition with esterification. It was an expected result because acid-catalyzed decarboxylation was favored by electron-releasing groups like OH. Eckert et al. reported that the benzoate esters can be cleaved to benzoic acid and the corresponding alcohol in near-critical water without the addition of any acidic or basic catalyst²³. Hence, the yield of ester products was lower than that of the others. Reaction of benzoic acid **12** with benzyl alcohol **13** produced benzyl benzoate **12a** with 58% yield, whereas the reaction of salicylic acid **14** with supercritical methanol **8** produced methylsalicylate **14a** with 30% yield. The low-ester yield may be explained with the amount of side products. Ether formation between the alcohol molecules, phenol **14b** formation from decarboxylation of salicylic acid **14** and oxidation of salicylic acid **14** to benzaldehyde are possible side reactions that occur when supercritical methanol **8** was used as reagent and reaction solvent. However, the concentrations of these compounds are negligible to that of the ester products.

CONCLUSION

It can be concluded that subcritical alcohols serves as an excellent media and as a reagent for the green esterification of organic acid with very short reaction time. Recently, acid-catalyzed esterification reactions using scCO₂ and scH₂O media were reported. In spite of fairly good yields, this procedure needs purification after the reaction whereas in this study it is not necessary because of 100% conversion of most of the reagents. The unique solvent properties of alcohols under supercritical conditions offer possibilities to improve the reaction rate and facilitate separation by changing the temperature and the pressure. It is expected that more applications will be explored on this interesting reaction medium in the future.

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