Lactonization of Hydroxy Ester over Hydrous Zirconium(IV) Oxide Modified by Trimethylsilyl Chloride

Hideyuki KUNO,* Makoto SHIBAGAKI, Kyoko TAKAHASHI, and Hajime MATSUSHITA
Life Science Research Laboratory, Japan Tobacco Inc., 6-2 Umegaoka, Midori-ku, Yokohama, Kanagawa 227

(Received November 10, 1992)

Synopsis. The lactonization of hydroxy esters was performed over hydrous zirconium(IV) oxide modified by trimethylsilyl chloride. In the case of both primary and secondary hydroxy esters, lactones were obtained in high yield. In addition, it was elucidated that modified-hydrous zirconium(IV) oxide is superior to hydrous zirconium(IV) oxide regarding selectivity in lactonization.

It is very difficult to synthesize lactones which contain a medium ring (7—10 member ring) from the hydroxy ester. Recently, we reported that 7-heptanolide and 8-octanolide were obtained over hydrous zirconium(IV) oxide (HZO).[1)] However, this method did not give satisfactory yields of lactones, since dehydration occurs easily. It is thought that this dehydration occurs at acid sites on the surface of the hydrous zirconium(IV) oxide.

It has been reported that the strength of the acid sites on metal oxides can be controlled by the addition of other metal ions.[2)] In the case of binary metal oxides, it is known that the strength of the acid sites is dependent on the average electronegativities of the metal ions of binary oxides.[3)] On the other hand, a modification of metal oxides by silicon compounds provides an alternative method for controlling the acid sites. In previous studies,[4,5)] selective reactions were achieved over a catalysts modified by a silicon compound used as a coupling reagent.

In this study, the lactonization of hydroxy esters was carried out over hydrous zirconium(IV) oxide modified by trimethylsilyl chloride (TMS-modified HZO). This resulted in the hydroxy esters being efficiently converted to the corresponding lactones. In particular, it is noteworthy that the medium-ring lactones, 7-heptanolide and 8-octanolide, were obtained in high yield. In addition, the secondary hydroxy esters could be efficiently converted to the corresponding lactones. Further, since this modified catalyst is solid, separation from products is easy, as is recycling.

Experimental

Preparation of Trimethylsilyl (TMS)-Modified Catalyst. Hydrous zirconium(IV) oxide[6)] (10 g) was immersed in a hexane solution (20 ml) of trimethylsilyl chloride (10 g) overnight at room temperature. A solid, the catalyst coupled with trimethylsilyl chloride, was filtered off, washed with hexane and acetone, and then dried under reduced pressure.

Lactonization. The reaction was carried out in a glass flow reactor with a fixed-bed catalyst [for instance, the flow rate of the nitrogen carrier gas was 60 cm^3 min^{-1}; 1.0 g of a 24—60 mesh catalyst was used at a reaction temperature of 275°C]. A solution of hydroxy ester (12.0 mM) and a hydrocarbon as an internal standard in toluene was fed using a microfeeder into the reactor (5 cm^3 h^{-1}). The products were analyzed by GLC (a capillary column DB-1 30 m and PEG 20 M 25 m) and GC-MS (Shimadzu QP1100EX) after a steady state conditions had been reached.

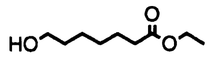
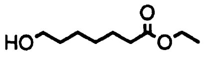
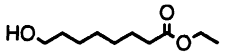
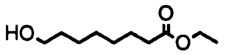
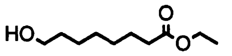
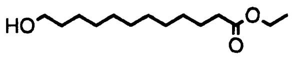
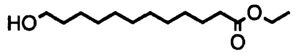
Results and Discussion

Lactonization of Primary Hydroxy Ester. In this investigation the lactonization of various primary hydroxy esters was carried out over both TMS-modified and non-modified catalysts. These results are shown in Table 1. It was found that all of the primary hydroxy esters were efficiently converted to the corresponding lactones over a TMS-modified catalyst. In particular, it is noteworthy that medium-ring (8—10 member ring) lactones can be obtained in high yield. Further, it is obvious that TMS-modified HZO is superior to non-modified HZO as a catalyst for lactonization. In the lactonization of ethyl 7-hydroxyheptanoate over the HZO catalyst, the selectivity and yield were 41 and 35%, respectively. However, 7-heptanolide was obtained from ethyl 7-hydroxyheptanoate in 83% selectivity and 77% yield over a TMS-modified HZO catalyst. This tendency was also observed in the synthesis of 8-octanolide and other lactones. From these results it was found that the side reactions, for instance dehydration, polymerization and decarboxylation, were inhibited by using TMS-modified HZO. It is considered that the active sites of the side reactions are decreased, since the hydroxy group on the surface of HZO is covered by trimethylsilyl chloride.

Effect of the Reaction Temperature. In order to elucidate the dependence on the reaction temperature, lactonizations of ethyl 6-hydroxyhexanoate and ethyl 6-hydroxydecanoate were carried out at various reaction temperatures in this catalyst system. These results are shown in Table 2. In the range of 150 to 300°C, the yield of 6-hexanolide increased with increasing temperature. On the other hand, in the 150—300°C range, the selectivity and yield were greatest at 200°C for the lactonization of ethyl 6-hydroxydecanoate. The difference in these two cases resulted from the degree of dehydration occurring as a side reaction.

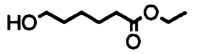
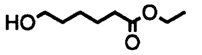
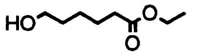
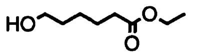
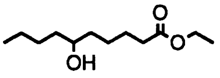
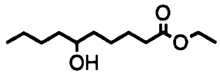
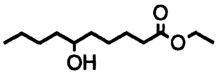
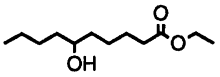
Lactonization of Secondary Hydroxy Ester. The lactonization of various secondary hydroxy esters was carried out over TMS-modified HZO and non-modified HZO; the results are given in Table 3. It was found that the secondary hydroxy esters were efficiently con-

Table 1. Lactonizations of Primary Hydroxy Esters

Catalyst	Reactant	Cat./g	Temp/°C	Conv./%	Sel./%	Yield/%
TMS–Zr		1.0	250	92	83	77
Zr		0.5	250	86	41	35
TMS–Zr		1.0	250	78	87	67
TMS–Zr		1.0	275	91	69	63
Zr		0.5	275	73	48	36
TMS–Zr		1.0	250	8.4	100	8.4
Zr		0.5	275	8.3	92	7.6

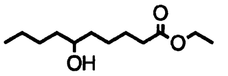
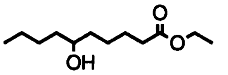
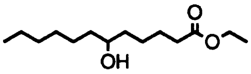
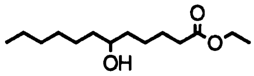
Zr: Hydrous zirconium(IV) oxide, TMS–Zr: hydrous zirconium(IV) oxide modified by trimethylsilyl chloride. Conditions: reactant, 0.06 mmol h^{-1}; toluene, 5 cm^3 h^{-1}.

Table 2. Effect of the Reaction Temperature

Substrate	Cat./g	Temp/°C	Conv./%	Sel./%	Yield/%
	0.5	150	6.1	100	6.1
	0.5	200	58	100	58
	0.5	250	91	100	91
	0.5	300	93	100	93
	1.0	150	25	60	15
	1.0	200	51	81	41
	1.0	250	55	58	32
	1.0	300	85	28	24

Catalyst: hydrous zirconium (IV) oxide modified by trimethylsilyl chloride. Conditions: reactant, 0.06 mmol h^{-1}; toluene, 5 cm^3 h^{-1}.

Table 3. Lactonizations of Secondary Hydroxy Esters

Catalyst	Substrate	Temp/°C	Conv./%	Sel./%	Yield/%
TMS–Zr		200	51	81	41
Zr		275	86	43	36
TMS–Zr		250	58	90	52
Zr		250	57	41	23

Zr: Hydrous zirconium(IV) oxide, TMS–Zr: Hydrous zirconium(IV) oxide modified by trimethylsilyl chloride. Conditions: Catalyst, 1.0 g; reactant, 0.06 mmol h^{-1}, toluene, 5 cm^3 h^{-1}

verted to the corresponding lactones over TMS-modified HZO. On the other hand, the dehydration of hydroxy ester occurred as the main reaction over HZO. It was found that the selectivities were different between TMS-modified HZO and non-modified HZO in lactonization of these secondary hydroxy esters.

References

1) H. Kuno, M. Shibagaki, K. Takahashi, I. Honda, and H. Matsushita, *Chem. Lett.*, **1992**, 571.

2) G. Connell and J. A. Dumesic, *J. Catal.*, **102**, 216 (1988).

3) K. Shibata, T. Kiyoura, J. Kitagawa, T. Sumiyoshi, and K. Tanabe, *Bull. Chem. Soc. Jpn.*, **46**, 2985 (1973).

4) H. Kuno, K. Takahashi, M. Shibagaki, and H. Matsushita, *Bull. Chem. Soc. Jpn.*, **63**, 3320 (1990).

5) H. Kuno, M. Shibagaki, K. Takahashi, I. Honda, and H. Matsushita, *Bull. Chem. Soc. Jpn.*, **64**, 2508 (1991).

6) M. Shibagaki, K. Takahashi, H. Kuno, and H. Matsushita, *Bull. Chem. Soc. Jpn.*, **63**, 258 (1990).