Alcohols from Ozonolysis Products of Unsaturated Fatty Esters[1]

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ABSTRACT

1-Nonanol and alkyl 9-hydroxynonanoates were more readily prepared by hydrogenation of the respective isolated aldehydes than by direct hydrogenation of products from reductive ozonolysis of oleate esters. Hydrogenation with nickel catalysts and aprotic solvents reduced the isolated aldehydes in good yield with a minimum of side reactions. Although the noble metal catalyst and hydroxylic solvent systems frequently used in similar reductions were also effective, they required a promoter that fortuitously catalyzed hydrolysis of acetals that formed during hydrogenation. Direct hydrogenation of the ozonolysis products resulted in side reactions and a mixture of products difficult to separate.

INTRODUCTION

Omega-hydroxyalkanoic acids and their esters have value as intermediates for both laboratory and industrial use. Of this compound class, 9-hydroxynonanoic acid is a member that has little tendency to form cyclic lactones and is readily available by cleavage of unsaturated fatty acids having a double bond in the 9-position. The cleavage may be accomplished most easily through reductive ozonolysis of methyl oleate.

Methyl 9-hydroxynonanoate has been prepared previously by catalytic hydrogenation of isolated methyl azelaaldehydate (methyl 9-oxononanoate) in 95% ethanol with platinum oxide catalyst and ferrous sulfate promoter in 80-90% yields (1), by a two stage hydrogenation with nickel of methyl oleate ozonolysis products formed either in naphtha (2) or in methanol or 1-butanol (3), and by sodium borohydride reduction of oleic acid ozonolysis products formed in chloroform (4). Purity of some reported products may be questionable, inasmuch as complete analytical data are lacking, particularly in early work when modern techniques, such as gas chromatography, were not available.

Generally, hydroxylic solvents are preferred to nonparticipating solvents for preparation of either aldehydes or alcohols by reductive ozonolysis (5). Such solvents participate in the ozonolysis reaction to give mixtures of alkoxy hydroperoxides in good yields instead of ozonides. Also, reduction of the ozonolysis products by chemical reducing agents is preferred to catalytic hydrogenation. Although it is simpler to operate and requires the cheapest reducing agent, catalytic hydrogenation invariably produces up to 25% of by-product ester.

We report here our attempts with several different catalyst and solvent systems to prepare 1-nonanol and methyl 9-hydroxynonanoate in high yield and purity.

EXPERIMENTAL PROCEDURES

Materials

Methyl oleate was prepared from Pamolyn 100 oleic acid (Hercules, Wilmington, DE) and contained 92.5% oleic, 2.3% linoleic, 2.3% conjugated dienoic, and 2.9% saturated acids. Methyl esters of soybean fatty acids were prepared by transesterification of soybean oil and contained 11.6% palmitate, 4.8% stearate, 27.8% oleate, 49.3% linoleate, and 6.5% linolenate esters. Platinum oxide (Adam's catalyst) and 5% ruthenium on carbon were purchased from Matheson, Coleman & Bell (Norwood, OH); No. 28 Raney active nickel catalyst in water, from W.R. Grace & Co., Catalyst Division (South Pittsburg, TN); Girdler G-69 50% nickel powder, reduced and stabilized, from Girdler Catalysts, Chemical Products Division, Chemetron Corporation (Louisville, KY); and 58% nickel on Kieselguhr, 60-65% nickel reduced, in 1/8 in. pellets, from Harshaw Chemical Co. (Cleveland, OH).

Apparatus

The Magne-Dash autoclaves were made by Autoclave Engineers (Erie, PA); the low pressure, catalytic hydrogenation apparatus, by Parr Instrument Co (Moline, IL).

Analysis

Gas liquid chromatographic (GLC) analyses were performed first in an F&M Model 500 gas chromatograph with thermal conductivity detector and later in a Hewlett-Packard Model 5700A chromatograph with a flame ionization detector. Analyses for alcohols were performed either isothermally at 125 or 175 C or programmed from 150 to 250 C with SE-30 or OV-101 on Chromosorb W(HP) in a 4 ft x 1/8 in. stainless steel column at 30-40 ml/min helium flow. These packings gave effective peak separations for the various aldehyde, acetal, ester, and alcohol components in the reaction products.

Hydrogenation of Alkoxy Hydroperoxides to Alcohols

Butanol/acetic acid solvent: 1. Platinum oxide catalyst. Methyl oleate (45.8 g, 0.15 mol C-9 double bond) in 1-butanol (93 g, 1.26 mol) and glacial acetic acid (75 g, 1.26 mol) was ozonized 67 min at 6-8 C with an ozone-containing oxygen stream delivering 2.2 mmol ozone per min. The solution was transferred to a 500 ml Magne-Dash autoclave that had been chilled in ice, 0.5 g PtO_2 was added, and hydrogenation was carried out at 3500 psig. The temperature rose from 12 to 25 C and was then maintained at 25 C. After 2¼ hr, GLC indicated 22.6% methyl 9-oxononanoate and 57.8% methyl 9-hydroxynonanoate in that portion of the chromatogram devoted to the bifunctional or high boiling components. An additional 0.2 g PtO_2 was added, and hydrogenation was continued for another 2¼ hr (Table I, run 1). The product was filtered and flash distilled under vacuum to recover 52.83 g of volatiles and 2.65 g residue. Redistillation through a 1 x 6 in. Vigreux column gave a fraction (92.4% 1-nonanol, 18.18 g, 76% yield) boiling 26-75 C/0.05 torr, and a fraction (91.8% methyl 9-hydroxynonanoate, 17.78 g, 58% yield) boiling 82-89 C/0.05 torr. The latter fraction contained 3.1% 1,1-dibutoxynonane. The residue weighed 6.65 g and was identified as the dibutyl acetal of methyl 9-oxononanoate.

Residue analysis: Calculated for $C_{18}H_{36}O_4$: C, 68.31; H, 11.47. Found: C, 68.48; H, 11.51.

A similar run but at 27-51 C produced methyl 9-hydroxynonanoate in 63% yield and methyl 9-acetoxynonanoate in 20% yield (run 2).

A similar run with soybean methyl esters with hydrogenation at 0-38 C produced a mixture of alcohols and their

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TABLE I

Effect of Substrate, Solvent, and Temperature on Hydrogenated Product Composition

Run[a]	Solvent	Temperature[b] (C)	Catalyst	Product composition (% by wt)			Yield of alcohol (%)
				Aldehyde	Alcohol	Other (type of compound)	
Alkoxy hydroperoxide substrate							
1	1-Butanol/acetic acid	12-25	PtO_2	2.9	84.4	3.1 (acetal)	58
2	1-Butanol/acetic acid	27-51	PtO_2	---	63.0	20.0 (acetoxy ester)	63
3	1-Butanol/acetic acid	29, 60	Ni	77.4	5.0	10.9 (unknown)	43
4	1-Propanol/acetic acid	25	PtO_2	15.0	82.0	3.0 (acetal)	71
5	Methanol	25	PtO_2	71.1	---	17.2 (diester) 6.4 (acetal)	0
6	Methanol	25, 200	Ni	---	71.0	25.0 (diester)	71
7	Methanol	50, 100	Ru	37.5	3.0	16.2 (diester) 43.4 (acetal)	31
8[c]	Ethanol	13, 100	Ni	---	0.0	35.4 (diester) 26.2 (acetal)	0
Aldehyde substrate							
9[d]	Tetrahydrofuran/H_2O	100	Ni	---	98.9	1.1 (unknown)	85
10[d]	Ethyl acetate	100	Ni	---	95.7	4.3 (unknown)	86
11[d]	Ethyl acetate/H_2O	25, 100	Ru	---	100	---	83
12[e]	Heptane	100	Ni	---	99.2	0.8 (unknown)	95
13[d]	Heptane	100	Ni	---	90.0	10.0 (unknown)	83
14[d]	Heptane	100	Ni	---	100.0	---	83

[a] Except where noted, the starting material was methyl oleate.

[b] Two temperatures separated by a comma indicate a two-stage hydrogenation.

[c] Soybean methyl esters composed the substrate.

[d] 9-Oxononanoate ester.

[e] Nonanal.

acetates. Redistillation of the more volatile half from flash distilled product through a 8 mm x 60 cm concentric tube column gave 1-hexanol (87% purity, 83% yield) boiling 47-71 C/13 torr; a fraction, containing 1,3-propanediol (17.2%) and 1-nonanol (54.1%), boiling 71-81 C/0.4 torr; and a residue containing 1,3-propanediol (16.3%) and 1-nonanol (71.7%). Yield of 1,3-propanediol was 83% and of 1-nonanol, 81%.

2. Nickel catalyst. Hydrogenation of similar methyl oleate ozonolysis products with moist Raney nickel at 24-29 C and 300 psig for 1 hr followed by a 1 hr period at 60 C and 300 psig produced methyl 9-oxononanoate in 77% purity and 43% yield (run 3).

Propanol/acetic acid solvent: 1. Platinum oxide catalyst. Methyl oleate (29.1 g, 0.1 mol C_9 double bond) in 1-propanol (48 g, 0.8 mol) and glacial acetic acid (48 g, 0.8 mol) was ozonized at 8-12 C. The solution was transferred to a 500 ml Parr bottle chilled in ice, 0.1 g of PtO_2 was added, and hydrogenation was carried out in a Parr shaker at room temperature and 15 psig until hydrogen uptake stopped after 2½ hr. GLC indicated 65.1% methyl 9-oxononanoate, 0% methyl 9-hydroxynonanoate, and 41.3% dipropyl acetal of methyl 9-oxononanoate of the high boiling compounds. Hydrogenation was continued at 50 psig after addition of 0.4 ml of 0.1 M $SnCl_2 \cdot 2H_2O$ in 1-propanol, and after 1½ hr GLC indicated 1.6% methyl 9-oxononanoate, 57.1% hydroxy ester, and 41.3% acetal ester. Hydrogenation was continued at 50 psig after addition of 10 ml H_2O, 0.4 ml of $SnCl_2$ solution, and 0.1 g PtO_2, and after 4 hr GLC indicated 15.0% aldehyde ester, 82.0% hydroxy ester, and 3.0% acetal ester. After hydrogenation for an additional 3½ hr, isolation of the product gave the hydroxy ester in 71% yield and 90% purity as a fraction boiling 89-95 C/0.03 torr (run 4).

Methanol solvent: 1. Platinum oxide catalyst. Methyl oleate (50.0 g, 0.172 mol C-9 double bond) in methanol (109 g, 3.4 mol) was ozonized at 5-8 C. The solution was transferred to a 500 ml Parr hydrogenation bottle, 0.1 g PtO_2 was added, and hydrogenation was conducted at room temperature and 15 psig. After 2 hr, a product (25.41 g) was isolated as a fraction boiling 91-96 C/0.12 torr and having the composition: methyl 9-oxononanoate, 71.1% (59% yield); dimethyl azelate, 17.2% (12% yield); and methyl 9,9-dimethoxynonanoate, 6.4% (6.4% yield) (run 5).

2. Nickel catalyst. In a similar experiment with moist Raney nickel catalyst, hydrogenation was carried out initially at room temperature, then up to 200 C and at 2500 psig. After 1 hr, the product was isolated and found to contain hydroxy ester in 71% yield and azelate ester in 25% yield (run 6).

3. Ruthenium catalyst. Methyl oleate (32.7 g, 0.1 mol C-9 double bond) in methanol (96 g, 3.0 mol) was ozonized 45 min at -5 to 3 C. The product solution was transferred to a 250 ml rocker autoclave. Water (13 ml) and 5% ruthenium on charcoal (0.3 g) were added. Hydrogenation was conducted at 500 psig and 50 C for 1 hr, then at 100 C for 2½ hr, with a total pressure drop of 167 psi recorded. The solution contained no peroxidic material, but GLC showed much aldehyde left. More Ru/C (0.3 g) was added, and hydrogenation was continued at 100 C and 650 psig for an additional 2 hr. After filtration and removal of solvent, the product was distilled through a 1 x 6 in. Vigreux column at reduced pressure. The fraction (16.44 g), boiling 73-93 C at 0.02-0.03 torr, contained methyl 9-oxononanoate (37.5%, 33.1% yield), methyl 9-hydroxynonanoate (3.0%, 2.6% yield), dimethyl azelate (16.2%, 12.3% yield), and methyl dimethoxynonanoate (43.4%, 30.7% yield) (run 7). Identity of the last named compound was confirmed by mass chromatography and mass spectroscopy (6).

Ethanol solvent: 1. Nickel catalyst. Soybean methyl esters (100.0 g, 0.2738 mol of available C-9 bifunctional compounds) in absolute ethanol (200 g) were ozonized 3½ hr at 5-10 C. The solution was transferred to a 1 liter Magne-Dash autoclave chilled in ice and equipped with a cooling coil. Raney nickel catalyst (10 g) was added, and hydrogenation was carried out for 2 hr at 4-13 C and 300 psig hydrogen and then for 8 hr at 100 C and 1200 psig pressure. At the end of the first low temperature stage, the peroxide test was strong. The absence of peroxygen compounds was confirmed only after 3 hr at the second high temperature stage. Analysis of the product by GLC indi-

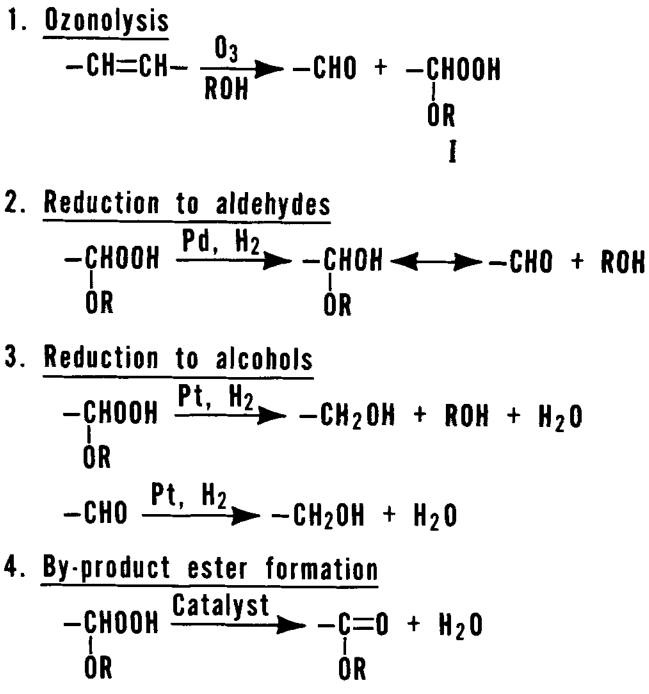

FIG. 1. Formation and reactions of alkoxy hydroperoxides produced by ozonolysis of unsaturated fatty esters.

cated the following composition for the high boiling components: methyl 9-hydroxynonanoate (0%), ethyl methyl azelate (35.4%), methyl 9,9-diethoxynonanoate (26.2%), methyl palmitate (26.2%), and methyl stearate (12.2%) (run 8).

Hydrogenation of Isolated Aldehydes

Tetrahydrofuran solvent: Nickel catalyst. Ethyl 9-oxononanoate (96.8%, 100.0 g, 0.5 mol) in tetrahydrofuran (100 ml) containing 5 ml water and 5.75 g moist Raney nickel catalyst was hydrogenated in a 500 ml Magne-Dash autoclave. Reaction was 90% complete after 4 hr at 500 psig and 100-110 C, and 100% complete after 1½ hr more at 900 psig and 100 C. After removal of catalyst and solvent, distillation gave 98.9% pure ethyl 9-hydroxynonanoate (82.67 g, 84.6% yield) (run 9).

Ethyl acetate solvent: 1. Nickel catalyst. Ethyl 9-oxononanoate (99+%, 50.0 g, 0.25 mol) in ethyl acetate (100 ml) with 2.3 g of Raney nickel catalyst (washed with ethanol, then ethyl acetate) was hydrogenated in a 500 ml Magne-Dash autoclave. Reaction was 68% complete after 7¼ hr at 100 C and 500 psig and essentially complete after 8-3/4 hr at 120 C and 500 psig. The brown solution was filtered, desolventized, and flash distilled to yield ethyl 9-hydroxynonanoate (95-110 C/0.01 torr, 45.1 g, 95.7% purity, 85.6% yield) (run 10).

2. Ruthenium catalyst. Ethyl 9-oxononanoate (99+%, 20.0 g, 0.1 mol) in a mixture of 70 ml ethyl acetate and 30 ml water with 0.5 g 5% ruthenium on charcoal was hydrogenated in glass Parr shaker. Reaction was 34% complete after 7 hr at room temperature. The mixture was transferred to a 250 ml rocker bomb, and the reaction was 98.9% complete after 2 hr at 100 C and 500 psig and 100% complete after an additional 2 hr. There was obtained 16.83 g of pure ethyl 9-hydroxynonanoate boiling 91-96 C/0.03 torr in 83% yield (run 11).

Heptane solvent: 1. Nickel catalyst. Nonanal (95.5%, 42.7 g, 0.286 mol) in heptane (125 ml) with 2.0 g of Raney nickel catalyst (washed with tetrahydrofuran, then heptane) was hydrogenated in a 500 ml Magne-Dash autoclave. Reaction was complete after 1 hr at 100 C and 375 psig. Cooling was necessary at first to maintain the temperature at 100 C. Distillation produced 39.58 g (94.9% yield) of product, boiling at 74-76 C/1.8 torr, having a purity of 99.2% by GLC (run 12).

Methyl 9-oxononanoate (91.9%, 30.39 g, 0.15 mol) in heptane (125 ml) with 2.25 g Raney nickel catalyst was hydrogenated in a 500 ml Magne-Dash autoclave. Reaction was 79% complete after 1 hr at 75 C and 375 psig; it was 99% complete after 4 hr at 100 C and 375 psig. From the heterogeneous reaction product was isolated by distillation 26.1 g of product boiling 87-93 C/0.02 torr and having a purity of 90% by GLC. Yield of methyl 9-hydroxynonanoate was 83% (run 13).

Isopropyl 9-oxononanoate (99.5%, 21.4 g, 0.1 mol) in heptane (100 ml) with 10.7 g of 50% nickel powder (Girdler G-69) was hydrogenated in a 250 ml rocker autoclave. Reaction was complete after 2 hr at 100 C and 500 psig. Flash distillation produced 17.93 g of pure isopropyl 9-hydroxynonanoate, boiling at 96-106 C/0.02 torr, for a yield of 83%. A similar run but with 21 g 58% nickel on Kieselguhr (Harshaw Ni 0104) gave an 83% yield of pure hydroxy ester (run 14).

Methyl 9-Acetoxynonanoate

Methyl 9-hydroxynonanoate (4.6 g, 24.5 mmol), acetic anhydride (2.5 ml, 26.2 mmol), and 4 drops of H_2SO_4 were heated for 2 hr at 80 C. The solution was cooled and neutralized with aqueous sodium carbonate. Extraction with ether followed by evaporation of the ether produced 5.5 g residue (94.7% methyl 9-acetoxynonanoate by GLC, 98% yield). Distillation gave a fraction analyzing 99+% by GLC.

Analysis calculated for $C_{12}H_{22}O_4$: C, 62.60; H, 9.64. Found: C, 62.93; H, 9.74. $n_D^{20} = 1.4358$, $d_4^{20} = 0.984$, $M_D = 61.2$ (Theor., 60.94).

RESULTS AND DISCUSSION

Substrate (whether alkoxy hydroperoxide or aldehyde), solvent, temperature, and catalyst all had important effects on the preparation of 1-nonanol and alkyl 9-hydroxynonanoates (Table I). Substrate had the single greatest effect on product yield and purity.

Hydrogenation of Alkoxy Hydroperoxides

By-product ester is encountered whenever alkoxy hydroperoxides, formed during reductive ozonolysis of methyl oleate in hydroxylic solvents, are hydrogenated to prepare methyl 9-oxononanoate (5) (Fig. 1). One method that overcomes this problem involves an equimolar solvent mixture of an alcohol and a carboxylic acid during ozonolysis and subsequent hydrogenation (7). Another reportedly successful approach has involved temperature control and two stages during hydrogenation (2,3). For example, White, King, and O'Brien (3) hydrogenated first at 0.15 C then at 35-50 C with platinum catalyst.

Applying the alcohol/acid solvent system and platinum catalyst to making methyl 9-hydroxynonanoate was only partially successful. Although this solvent system indeed prevented ester formation, at least two other by-products formed. If hydrogenation was carried out much above room temperature, considerable amounts of methyl 9-acetoxynonanoate were present (run 2). Of course, the acetate can be hydrolyzed and reesterified to methyl 9-hydroxynonanoate, but preparation then becomes more cumbersome. If hydrogenation was carried out below room temperature, the reaction was incomplete and much of the aldehydes were converted to acetals. When 1-butanol and acetic acid were used, the dibutyl acetals of methyl 9-oxononanoate and nonanal were present in large quantities (run 1). Under the conditions used, the dibutyl acetal of methyl 9-oxononanoate was insufficiently volatile to be detected by GLC or to be distilled. When 1-propanol and acetic acid were used, however, the dipropyl acetal was sufficiently volatile to be detected by GLC and to be distilled.

Pressure had the expected effect on reaction time. Hydrogenation at 3500 psig of hydrogen proceeded to completion in 5 hr (run 2), but at 50 psig, hydrogenation was complete only after ca. 12 hr (run 4). Low pressure hydrogenation was carried out in a Parr bottle with platinum oxide catalyst and with stannous chloride promoter. The stannous chloride aided hydrolysis of acetals, as well as serving as a promoter for the catalyst.

Raney nickel in the 1-butanol/acetic acid solvent system at 300 psig produced mainly methyl 9-oxononanoate in poor yield (run 3). We judge palladium to be superior to nickel for the hydrogenation of alkoxy hydroperoxides to aldehydes (5). Palladium, however, has insufficient activity to reduce aldehydes to alcohols.

When methanol was the only solvent, dimethyl azelate was a major by-product regardless of the catalyst used—whether platinum oxide, Raney nickel, or ruthenium on charcoal (runs 5-7). Temperature had little effect on by-product ester formation in our work.

Fractional distillation was not an effective means of separating dimethyl azelate from the hydroxy ester. However, fractional extraction similar to that described by Bush and Densen (8) did achieve separation. With equal volumes of 70% aqueous ethanol and pentane-hexane, a product originally containing 73% methyl 9-hydroxynonanoate was concentrated to 80% in the first extract and to 87% in the second extract.

Hydrogenation of Aldehydes

Isolated aldehydes gave much cleaner products upon hydrogenation to the alcohol than did the mixture of alkoxyhydroperoxides and aldehydes formed by ozonolysis. However, purity of the product alcohol depended upon purity of the starting aldehyde. Purity presents no problem inasmuch as we had reported earlier several methods for making high purity alkyl 9-oxononanoates (9).

Both nickel (runs 9, 10, 12-14) and ruthenium (run 11) were excellent catalysts. Nickel was used in several different forms (Raney nickel, nickel powder, nickel on Kieselguhr), and all were equally effective. Ruthenium was used in the presence of water, which apparently is required to make the catalyst effective (10,11).

Heptane (runs 12-14) and tetrahydrofuran (run 9) were effective solvents and somewhat superior to ethyl acetate; ethyl acetate seemed to slow hydrogenation rates and is subject to hydrolysis and other reactions. Heptane produced 1-nonanol from nonanal in high yield (run 12). Yields were somewhat lower with methyl 9-oxononanoate, a result which probably could be ascribed to mechanical losses in handling the two-phase reaction product, methyl 9-hydroxynonanoate being only partially soluble in heptane. Tetrahydrofuran worked best with water present. Hydrogenation with this solvent without water gave lower yields of distilled product and larger amounts of distillation residues.

Yields of hydroxy ester ranged from 83 to 85%. 1-Nonanol was isolated in 95% yield from hydrogenation of the aldehyde in heptane. The difference in yields between the mono- and bifunctional compounds might indicate loss due to self-condensation of hydroxy ester during distillation.

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