The Horner-Wadsworth-Emmons Reaction of Diethyl (1-Methylthioalk-3-Enyl)phosphonates

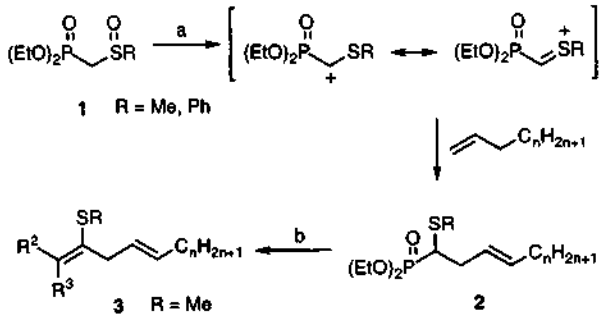
Taek Hyeon Kim*, Hyeong-Geun Lee, and Dae Young Kim†

Department of Fine Chemical Technology, Chonnam National University, Kwangju 500-757, Korea
†Department of Chemistry, Soonchunhyang University, Onyang P. O. Box 97, Chungnam 336-600, Korea
Received October 15, 1996

Phosphonates substituted with an electron-withdrawing group are powerful reagents for forming carbon-carbon double bonds by the Horner-Wadsworth-Emmons (HWE) reaction because they provide control of olefin regio- and stereoselectivity.[1] (1-Methylthio)methylphosphonate is converted into the corresponding vinyl sulfide under the HWE reaction conditions.[2] Vinyl sulfides, convenient precursors to aldehydes and ketones upon hydrolysis, are important reagents for the homologation of aldehydes and ketones.[2,3]

During our studies on the total synthesis of a sex pheromone, (4*E*,7*Z*)-4,7-tridecadienyl acetate, we found the HWE reaction product of a α-sulfonyl γ,δ-unsaturated phosphonate was transformed into 1,4-dienes upon desulfonylation process.[4] In the present study we wish to report the HWE reactions of various phosphonates **2** with carbonyl compounds to develop a general synthetic method to 2-(substituted-sulfenyl)-1,4-dienes **3**, vinyl sulfides (Scheme 1).

The starting materials, α-sulfinylmethanephosphonates **1**, were prepared by the oxidation of the corresponding α-sulfenylmethanephosphonate with sodium metaperiodate.[5] We used trifluoroacetic anhydride (TFAA) in trifluoroactic acid (TFA) as an activator of the Pummerer reaction, as previously reported by Ishibashi and co-workers,[6] to provide γ, δ-unsaturated phosphonate **2**. The Pummerer reaction of sulfinylmethanephosphonate **1** with various 1-alkenes was successfully carried out. The results are summarized in Table 1. The reaction procedure is as follows: TFAA (1.2 mmol) was added to a solution of methylsulfinylmethanephosphonate (0.26 g, 1.2 mmol) in TFA (4 mL) under nitrogen atmosphere in an ice bath. 1-Pentene (1.2 mmol) was added slowly to the mixture with a syringe. The reaction mixture was stirred for 0.8 hour at room temperature, then quenched by adding water and extracted with chloroform. The extract was dried, filtered and evaporated. The residual oil was chromatographed on silica gel, using ethyl acetate. Using this procedure, a variety of desired phosphonates **2** were prepared in good yields under mild reaction conditions.[7]



Scheme 1. *Reagents and conditions*: (a) TFAA, TFA, rt; (b) n-BuLi, carbonyl compounds, − 78 °C~50 °C.

Horner-Wadsworth-Emmons (HWE) Reaction. The treatment of lithiated anions of phosphonates **2** with carbonyl compounds successfully led to the desired 1,4-diene system in 43-69% yields. As seen in Table 2, the reactions were carried out with aromatic as well as aliphatic aldehydes. Attempted reaction with cyclohexanone was also successful. In most cases, the HWE reaction of **2** with aldehydes proceeded with an *E* and *Z* isomer mixture. The configurations and ratios of *E* and *Z* isomers were determined by the additive increment method of Pascual[8] and NMR data. The chemical shifts of the vinylic protons were diagnostic. For an example, using the additive increment method, the vinylic proton in **3a-*E*** will appear at δ 6.10, while the spectrum of **3a-*Z*** will show this proton at δ 6.33. The vinylic proton of **3a** spectrum appeared at δ 6.12 and 6.40 in 61 : 39 ratio, respectively. Therefore, the major isomer was assigned with *E* configuration. In conclusion, the HWE reaction of **2** with carbonyl compounds offers a con-

Table 1. Preparation of Diethyl (1-R-thioalk-3-enyl)phosphonates **2**

Run	n	Yield (%)[a]	*E*/*Z* ratio[b]	^{31}P NMR[c]
2a	R=Me 2	95	80/20	+25.9
2b	3	88	81/19	+26.3
2c	4	90	81/19	+26.3
2d	5	95	77/23	+26.7
2e	R=Ph 2	62	76/24	+25.4
2f	3	57	86/14	+25.6
2g	4	58	73/27	+25.6
2h	5	61	68/32	+25.9

[a] Isolated yields are based on phosphonates. [b] The ratios of *E* and *Z* isomers were determined by GC/MS. [c] The conversion of positive ^{31}P NMR signals to low field from H_3PO_4 is used.

Table 2. Preparation of 2-(Substituted-methylsulfenyl)-1,4-dienes **3**

	n	Carbonyl cpds	Yields	*E*/*Z*[a]
3a	2	Benzaldehyde	69	61/39
3b	2	Cyclohexanone	62	-
3c	2	Hexanal	58	57/43
3d	3	Bezaldehyde	68	62/38
3e	3	Heptanal	58	[b]
3f	3	Cyclohexanone	65	-
3g	4	Benzaldehyde	60	63/37
3h	4	Hexanal	43	55/45

[a] The ratios of *E* and *Z* isomers were determined by NMR. [b] Not determined.

venient process for the conversion of carbonyl compounds to homologous functionalized vinyl sulfides **3**.[9]

The experimental procedure for the preparation of **3a** is as follows: 1.6 M n-Butyllithium (3.5 mL) in hexane was added to a solution of diethyl 1-methylthiohex-3-enylphosphonate **2a** (1.30 g, 4.7 mmol) in tetrahydrofuran at −78 °C under nitrogen. To the reaction mixture, after being stirred for 4-6 hrs, was added a tetrahydrofuran solution of benzaldehyde (0.47 g, 4.7 mmol). The reaction mixture was stirred for 1 hr at −78 °C and for further 15-20 hrs at 50 °C, treated with water and saturated aqueous ammonium chloride, extracted with ether, dried, and concentrated. The crude product was chromatographed on silica gel.

Acknowledgment. This research was partially supported by the Chonnam National University Research Foundation (1995).

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7. Compound **2a**. ^{1}H NMR ($CDCl_3$) 0.85 (t, *J*=7.3 Hz, 3H), 1.20 (t, *J*=7.1 Hz, 6H), 1.95-2.05 (m, 2H), 2.08 (*E*-isomer) and 2.09 (s, 3H, *Z*-isomer), 2.25-2.72 (m, 2H+1H), 4.00-4.15 (m, 4H), 5.25-5.50 (m, 2H); IR ($CDCl_3$) 2980 (s), 1255 (P=O, s), 1060-1030 (vs), 965; Mass (m/e, %) 61 (100), 81 (99), 152 (26), 198 (25), 266 (MW, 5).
Compound **2b**. ^{1}H NMR ($CDCl_3$) 0.93 (t, *J*=6.7 Hz, 3H), 1.32-1.45 (m, 2H), 1.33 (t, *J*=7.3 Hz, 6H), 2.05-2.15 (m, 2H), 2.23 (*E*-isomer) and 2.24 (s, *Z*-isomer, 3H), 2.40-2.83 (m, 2H+1H), 4.10-4.24 (m, 4H), 5.43-5.60 (m, 2H); IR ($CDCl_3$) 2940, 1260 (P=O, s), 1055-1030 (vs), 970; Mass (m/e, %) 61 (24), 81 (21), 95 (33), 152 (100), 198 (43), 280 (10).
Compound **2c**. ^{1}H NMR ($CDCl_3$) 0.68 (t, *J*=6.8 Hz, 3H), 1.10-1.30 (m, 4H), 1.13 (t, *J*=7.2 Hz, 6H), 1.90-2.15 (m, 2H), 2.00 (*E*-isomer) and 2.01 (s, *Z*-isomer, 3H), 2.15-2.62 (m, 2H+1H), 3.90-4.04 (m, 4H), 5.20-5.40 (m, 2H); IR ($CDCl_3$) 2940, 1260 (P=O, s), 1060-1025 (vs), 970.
Compound **2d**. ^{1}H NMR ($CDCl_3$) 0.82 (t, *J*=6.9 Hz, 3H), 1.12-1.32 (m, 6H), 1.27 (t, *J*=7.4 Hz, 6H), 1.98-2.15 (m, 2H), 2.16 (*E*-isomer) and 2.17 (s, *Z*-isomer, 3H), 2.30-2.75 (m, 2H+1H), 4.02-4.17 (m, 4H), 5.35-5.50 (m, 2H); IR ($CDCl_3$) 2940, 1260 (P=O, s), 1060-1030 (vs), 965; Mass (m/e, %) 61 (37), 152 (34), 198 (100), 261 (25), 308 (14).
Compound **2e**. ^{1}H NMR ($CDCl_3$) 0.92 (t, *J*=6.9 Hz, 3H), 1.25 (t, *J*=7.4 Hz, 6H), 1.80-2.10 (m, 2H), 2.20-2.80 (m, 2H), 2.90-3.42 (m, 1H), 4.08-4.22 (m, 4H), 5.35-5.60 (m, 2H), 7.10-7.50 (m, 5H); IR ($CDCl_3$) 2980, 1260 (P=O, s), 1060-1035 (vs), 965.
Compound **2f**. ^{1}H NMR ($CDCl_3$) 0.87 (t, *J*=6.9 Hz, 3H), 1.32-1.45 (m, 2H), 1.28 (t, *J*=7.3 Hz, 6H), 1.80-2.10 (m, 2H), 2.20-2.80 (m, 2H), 2.95-3.51 (m, 1H), 4.08-4.22 (m, 4H), 5.38-5.60 (m, 2H), 7.10-7.58 (m, 5H); IR ($CDCl_3$) 2940, 1260 (P=O, s), 1055-1030 (vs).
Compound **2g**. ^{1}H NMR ($CDCl_3$) 0.85 (t, *J*=6.5 Hz, 3H), 1.10-1.30 (m, 4H), 1.26 (t, *J*=7.0 Hz, 6H), 1.80-2.10 (m, 2H), 2.20-2.75 (m, 2H), 2.95-3.31 (m, 1H), 4.05-4.20 (m, 4H), 5.37-5.50 (m, 2H), 7.07-7.50 (m, 5H); IR ($CDCl_3$) 2940, 1260 (P=O, s), 1060-1030 (vs); Mass (m/e, %) 109 (40), 123 (54), 191 (36), 203 (54), 247 (82), 260 (100), 356 (MW, 9).
Compound **2h**. ^{1}H NMR ($CDCl_3$) 0.84 (t, *J*=6.8 Hz, 3H), 1.12-1.32 (m, 6H), 1.25 (t, *J*=7.2 Hz, 6H), 1.75-2.10 (m, 2H), 2.25-2.75 (m, 2H), 3.04-3.31 (m, 1H), 4.03-4.17 (m, 4H), 5.35-5.36 (m, 2H), 7.06-7.50 (m, 5H); IR ($CDCl_3$) 2940, 1260 (P=O, s), 1055-1030 (vs), 960; Mass (m/e, %) 77 (38), 81 (9), 91 (55.6), 109 (82), 123 (100), 203 (40), 260 (83), 370 (MW, 9).
8. Pascual, C.; Meier, J.; Simon, W. *Helv. Chim. Acta* **1966**, *49*, 164.
9. Compound **3a**. ^{1}H NMR ($CDCl_3$) 0.99 (t, *J*=6.9 Hz, 3H), 2.00-2.12 (m, 2H), 2.27 (*Z*-isomer) and 2.35 (s, *E*-isomer, 3H), 3.10-3.21 (m, 2H), 5.48-5.68 (m, 2H), 6.19 (*E*-isomer; 61%) and 6.48 (s, 1H, Z-isomer; 39%), 7.17-7.50 (m, 5H); Mass (m/e, %) 91 (60), 115 (100), 134 (44., 155 (38), 218 (MW, 31).
Compound **3b**. ^{1}H NMR ($CDCl_3$) 0.97 (t, *J*=7.6 Hz, 3H), 1.54 (bs, 6H), 1.97-2.10 (m, 2H), 2.16 (s, 3H), 2.15-2.21 (m, 2H), 2.50 (bs, 2H), 3.04 and 3.09 (bd, *J*=5.4, 5.9 Hz, 2H), 5.28-5.64 (m, 2H).
Compound **3c**. ^{1}H NMR ($CDCl_3$) 0.89 (t, *J*=6.9 Hz, 3H), 0.99 (t, *J*=8.0 Hz, 3H), 1.30 (bs, 6H), 1.99-2.11 (m, 4H), 2.20 (s, 3H), 2.91-2.99 (m, 2H), 5.08-5.16 (*E*-isomer; 57%) and 5.36-5.56 (m, 2H+1H, *Z*-isomer; 43%).
Compound **3d**. ^{1}H NMR ($CDCl_3$) 0.98 (t, *J*=6.8 Hz, 3H), 1.21-1.75 (m, 2H), 2.00-2.21 (m, 2H), 2.22 (*Z*-isomer) and 2.33 (s, 3H, *E*-isomer), 3.08-3.25 (m, 2H), 5.41-5.65 (m, 2H), 6.10 (*E*-isomer; 62%) and 6.40 (s, 1H, *Z*-isomer; 38%), 7.19-7.50 (m, 5H); IR ($CDCl_3$) 2949 (vs), 2870, 1615; Mass (m/e, %) 91 (74), 115 (100), 128 (33), 155 (37), 232 (MW, 36).
Compound **3e**. ^{1}H NMR ($CDCl_3$) 0.90 (t, *J*=6.9 Hz, 6H), 1.33 (bs, 10H), 1.85-2.32 (m, 4H), 2.20 (s, 3H), 2.90-2.99 (m, 2H), 5.32-5.58 (m, 3H); Mass (m/e, %) 79 (55), 85 (55), 91 (33), 113 (100), 225 (46), 240 (MW, 13).
Compound **3f**. ^{1}H NMR ($CDCl_3$) 0.92 (t, *J*=7.2 Hz, 3H), 1.10-1.38 (m, 2H), 1.40-1.72 (bs, 6H), 1.80-2.80 (m, 6H), 2.15 (s, 3H), 2.95-3.10 (m, 2H), 5.25-5.49 (m, 2H); IR ($CDCl_3$) 2920 (vs), 1450, 970; Mass (m/e, %) 91 (100), 95 (49), 209 (81), 224 (MW, 36).
Compound **3g**. ^{1}H NMR ($CDCl_3$) 0.85 (t, *J*=6.9 Hz, 3H), 1.10-1.45 (m, 4H), 1.85-2.10 (m, 2H), 2.06 (*Z*-isomer) and 2.13 (s, 3H, *E*-isomer), 2.87-3.10 (m, 2H), 5.28-5.50

(m, 2H), 6.00 (*E*-isomer; 63%) and 6.30 (s, 1H, *Z*-isomer; 37%), 6.95-7.40 (m, 5H); IR ($CDCl_3$) 2940 (vs), 1610, 1440, 970; Mass (m/e, %) 91 (73), 115 (100), 128 (32), 134 (44), 155 (39), 246 (MW, 30).

Compound **3h**. ^{1}H NMR ($CDCl_3$) 0.88 (t, J=6.2 Hz, 6H), 1.29 (bs, 10H), 1.97-2.19 (m, 4H), 2.19 (s, 3H), 2.90-2.98 (m, 2H), 5.11-5.16 (*E*-isomer; 55%) and 5.33-5.55 (m, 2H+1H, *Z*-isomer; 45%).

Supercritical Fluid Chromatographic Separations of Pesticides Employing Methanol Modified CO_2 Mobile Phase

Dongjin Pyo*, Dongjin Park, and Hohyun Kim

Department of Chemistry, Kangwon National University, Kangweondo 200-092, Korea
Received October 16, 1996

During its relatively short existence, supercritical fluid chromatography (SFC) has become an attractive alternative to GC and LC in certain industrially important applications. SFC gives the advantage of high efficiency and fast analysis time for the analysis of non-volatile or thermally labile mixtures. Some applications of SFC to the separation of pesticides are featured in this paper, along with representative chromatograms. Pesticide analysis has received much attention because of the environmental impact of pesticides and fungicides and the need to monitor their levels and those of their metabolites in complex sample matrices such as foods. GC often is the analytical method of choice because of the availability of sensitive, selective detectors (FPD, NPD, ECD). However, difficulties arise when the solutes cannot be analyzed by GC because of thermal instability. HPLC is not helpful either, because such compounds cannot be detected easily at trace levels by a UV detector or one of the other HPLC detectors. In these cases, SFC is an alternative to GC or HPLC for the analysis of pesticides. The SFC analysis of some polar pesticides using mass spectrometry as a detector has previously been reported.[1] Thermally labile carbamate pesticides were also separated by capillary SFC.[2]

The ability to analyze moderately polar compounds with supercritical CO_2 is demonstrated in this paper; however, modifiers must be used. One of the most difficult problems with SFC is how polar substrates can be analyzed. Using the classification scheme of eluents by Synder,[3] carbon dioxide shows a polarity similar to that of hexane. The solvent power of the eluents used in SFC may be enhanced by adding a second eluent, the so-called 'modifier' to the basic mobile phase. Separations are often performed by SFC where the composition of the mobile phase is changed during the run or by adding a modifier before the chromatographic run is started. The influence on the retention behaviour of adding a modifier depends on the nature of the substrate, the stationary phase, and on the modifier itself. Yonker *et al.*,[4] report that at CO_2/methanol mixture at 50 °C UV absorbance maxima shifts for 2-nitroanisole. When dealing with the use of modifiers, it should be mentioned that some problems arise. First, a binary mixture of eluents can contaminate the instrument. The modifier remaining in a injector, tubing, expecially pump can be eluted slowly during the next run. This may affect the time to achieve chemical equilibrium and cause a corrosion at the pump. Second, many modifiers can diffuse in the laboratory and contaminate the air in the laboratory. To overcome these problems, we designed a new method which is shown in Figure

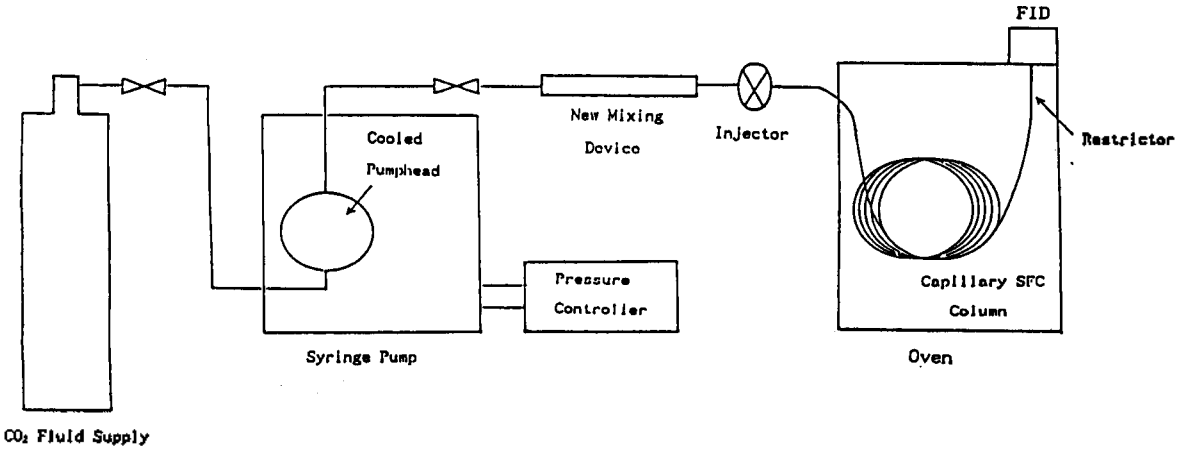

Figure 1. Schematic diagram of the apparatus used for adding a polar modifier to the supercritical fluid mobile phase.

venient process for the conversion of carbonyl compounds to homologous functionalized vinyl sulfides **3**.[9]

The experimental procedure for the preparation of **3a** is as follows: 1.6 M n-Butyllithium (3.5 mL) in hexane was added to a solution of diethyl 1-methylthiohex-3-enylphosphonate **2a** (1.30 g, 4.7 mmol) in tetrahydrofuran at −78 °C under nitrogen. To the reaction mixture, after being stirred for 4-6 hrs, was added a tetrahydrofuran solution of benzaldehyde (0.47 g, 4.7 mmol). The reaction mixture was stirred for 1 hr at −78 °C and for further 15-20 hrs at 50 °C, treated with water and saturated aqueous ammonium chloride, extracted with ether, dried, and concentrated. The crude product was chromatographed on silica gel.

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7. Compound **2a**. ^{1}H NMR ($CDCl_3$) 0.85 (t, *J*=7.3 Hz, 3H), 1.20 (t, *J*=7.1 Hz, 6H), 1.95-2.05 (m, 2H), 2.08 (*E*-isomer) and 2.09 (s, 3H, *Z*-isomer), 2.25-2.72 (m, 2H+1H), 4.00-4.15 (m, 4H), 5.25-5.50 (m, 2H); IR ($CDCl_3$) 2980 (s), 1255 (P=O, s), 1060-1030 (vs), 965; Mass (m/e, %) 61 (100), 81 (99), 152 (26), 198 (25), 266 (MW, 5).
Compound **2b**. ^{1}H NMR ($CDCl_3$) 0.93 (t, *J*=6.7 Hz, 3H), 1.32-1.45 (m, 2H), 1.33 (t, *J*=7.3 Hz, 6H), 2.05-2.15 (m, 2H), 2.23 (*E*-isomer) and 2.24 (s, *Z*-isomer, 3H), 2.40-2.83 (m, 2H+1H), 4.10-4.24 (m, 4H), 5.43-5.60 (m, 2H); IR ($CDCl_3$) 2940, 1260 (P=O, s), 1055-1030 (vs), 970; Mass (m/e, %) 61 (24), 81 (21), 95 (33), 152 (100), 198 (43), 280 (10).
Compound **2c**. ^{1}H NMR ($CDCl_3$) 0.68 (t, *J*=6.8 Hz, 3H), 1.10-1.30 (m, 4H), 1.13 (t, *J*=7.2 Hz, 6H), 1.90-2.15 (m, 2H), 2.00 (*E*-isomer) and 2.01 (s, *Z*-isomer, 3H), 2.15-2.62 (m, 2H+1H), 3.90-4.04 (m, 4H), 5.20-5.40 (m, 2H); IR ($CDCl_3$) 2940, 1260 (P=O, s), 1060-1025 (vs), 970.
Compound **2d**. ^{1}H NMR ($CDCl_3$) 0.82 (t, *J*=6.9 Hz, 3H), 1.12-1.32 (m, 6H), 1.27 (t, *J*=7.4 Hz, 6H), 1.98-2.15 (m, 2H), 2.16 (*E*-isomer) and 2.17 (s, *Z*-isomer, 3H), 2.30-2.75 (m, 2H+1H), 4.02-4.17 (m, 4H), 5.35-5.50 (m, 2H); IR ($CDCl_3$) 2940, 1260 (P=O, s), 1060-1030 (vs), 965; Mass (m/e, %) 61 (37), 152 (34), 198 (100), 261 (25), 308 (14).
Compound **2e**. ^{1}H NMR ($CDCl_3$) 0.92 (t, *J*=6.9 Hz, 3H), 1.25 (t, *J*=7.4 Hz, 6H), 1.80-2.10 (m, 2H), 2.20-2.80 (m, 2H), 2.90-3.42 (m, 1H), 4.08-4.22 (m, 4H), 5.35-5.60 (m, 2H), 7.10-7.50 (m, 5H); IR ($CDCl_3$) 2980, 1260 (P=O, s), 1060-1035 (vs), 965.
Compound **2f**. ^{1}H NMR ($CDCl_3$) 0.87 (t, *J*=6.9 Hz, 3H), 1.32-1.45 (m, 2H), 1.28 (t, *J*=7.3 Hz, 6H), 1.80-2.10 (m, 2H), 2.20-2.80 (m, 2H), 2.95-3.51 (m, 1H), 4.08-4.22 (m, 4H), 5.38-5.60 (m, 2H), 7.10-7.58 (m, 5H); IR ($CDCl_3$) 2940, 1260 (P=O, s), 1055-1030 (vs).
Compound **2g**. ^{1}H NMR ($CDCl_3$) 0.85 (t, *J*=6.5 Hz, 3H), 1.10-1.30 (m, 4H), 1.26 (t, *J*=7.0 Hz, 6H), 1.80-2.10 (m, 2H), 2.20-2.75 (m, 2H), 2.95-3.31 (m, 1H), 4.05-4.20 (m, 4H), 5.37-5.50 (m, 2H), 7.07-7.50 (m, 5H); IR ($CDCl_3$) 2940, 1260 (P=O, s), 1060-1030 (vs); Mass (m/e, %) 109 (40), 123 (54), 191 (36), 203 (54), 247 (82), 260 (100), 356 (MW, 9).
Compound **2h**. ^{1}H NMR ($CDCl_3$) 0.84 (t, *J*=6.8 Hz, 3H), 1.12-1.32 (m, 6H), 1.25 (t, *J*=7.2 Hz, 6H), 1.75-2.10 (m, 2H), 2.25-2.75 (m, 2H), 3.04-3.31 (m, 1H), 4.03-4.17 (m, 4H), 5.35-5.36 (m, 2H), 7.06-7.50 (m, 5H); IR ($CDCl_3$) 2940, 1260 (P=O, s), 1055-1030 (vs), 960; Mass (m/e, %) 77 (38), 81 (9), 91 (55.6), 109 (82), 123 (100), 203 (40), 260 (83), 370 (MW, 9).
8. Pascual, C.; Meier, J.; Simon, W. *Helv. Chim. Acta* **1966**, *49*, 164.
9. Compound **3a**. ^{1}H NMR ($CDCl_3$) 0.99 (t, *J*=6.9 Hz, 3H), 2.00-2.12 (m, 2H), 2.27 (*Z*-isomer) and 2.35 (s, *E*-isomer, 3H), 3.10-3.21 (m, 2H), 5.48-5.68 (m, 2H), 6.19 (*E*-isomer; 61%) and 6.48 (s, 1H, Z-isomer; 39%), 7.17-7.50 (m, 5H); Mass (m/e, %) 91 (60), 115 (100), 134 (44., 155 (38), 218 (MW, 31).
Compound **3b**. ^{1}H NMR ($CDCl_3$) 0.97 (t, *J*=7.6 Hz, 3H), 1.54 (bs, 6H), 1.97-2.10 (m, 2H), 2.16 (s, 3H), 2.15-2.21 (m, 2H), 2.50 (bs, 2H), 3.04 and 3.09 (bd, *J*=5.4, 5.9 Hz, 2H), 5.28-5.64 (m, 2H).
Compound **3c**. ^{1}H NMR ($CDCl_3$) 0.89 (t, *J*=6.9 Hz, 3H), 0.99 (t, *J*=8.0 Hz, 3H), 1.30 (bs, 6H), 1.99-2.11 (m, 4H), 2.20 (s, 3H), 2.91-2.99 (m, 2H), 5.08-5.16 (*E*-isomer; 57%) and 5.36-5.56 (m, 2H+1H, *Z*-isomer; 43%).
Compound **3d**. ^{1}H NMR ($CDCl_3$) 0.98 (t, *J*=6.8 Hz, 3H), 1.21-1.75 (m, 2H), 2.00-2.21 (m, 2H), 2.22 (*Z*-isomer) and 2.33 (s, 3H, *E*-isomer), 3.08-3.25 (m, 2H), 5.41-5.65 (m, 2H), 6.10 (*E*-isomer; 62%) and 6.40 (s, 1H, *Z*-isomer; 38%), 7.19-7.50 (m, 5H); IR ($CDCl_3$) 2949 (vs), 2870, 1615; Mass (m/e, %) 91 (74), 115 (100), 128 (33), 155 (37), 232 (MW, 36).
Compound **3e**. ^{1}H NMR ($CDCl_3$) 0.90 (t, *J*=6.9 Hz, 6H), 1.33 (bs, 10H), 1.85-2.32 (m, 4H), 2.20 (s, 3H), 2.90-2.99 (m, 2H), 5.32-5.58 (m, 3H); Mass (m/e, %) 79 (55), 85 (55), 91 (33), 113 (100), 225 (46), 240 (MW, 13).
Compound **3f**. ^{1}H NMR ($CDCl_3$) 0.92 (t, *J*=7.2 Hz, 3H), 1.10-1.38 (m, 2H), 1.40-1.72 (bs, 6H), 1.80-2.80 (m, 6H), 2.15 (s, 3H), 2.95-3.10 (m, 2H), 5.25-5.49 (m, 2H); IR ($CDCl_3$) 2920 (vs), 1450, 970; Mass (m/e, %) 91 (100), 95 (49), 209 (81), 224 (MW, 36).
Compound **3g**. ^{1}H NMR ($CDCl_3$) 0.85 (t, *J*=6.9 Hz, 3H), 1.10-1.45 (m, 4H), 1.85-2.10 (m, 2H), 2.06 (*Z*-isomer) and 2.13 (s, 3H, *E*-isomer), 2.87-3.10 (m, 2H), 5.28-5.50

(m, 2H), 6.00 (*E*-isomer; 63%) and 6.30 (s, 1H, *Z*-isomer; 37%), 6.95-7.40 (m, 5H); IR ($CDCl_3$) 2940 (vs), 1610, 1440, 970; Mass (m/e, %) 91 (73), 115 (100), 128 (32), 134 (44), 155 (39), 246 (MW, 30).

Compound **3h**. ^{1}H NMR ($CDCl_3$) 0.88 (t, J=6.2 Hz, 6H), 1.29 (bs, 10H), 1.97-2.19 (m, 4H), 2.19 (s, 3H), 2.90-2.98 (m, 2H), 5.11-5.16 (*E*-isomer; 55%) and 5.33-5.55 (m, 2H+1H, *Z*-isomer; 45%).

Supercritical Fluid Chromatographic Separations of Pesticides Employing Methanol Modified CO_2 Mobile Phase

Dongjin Pyo*, Dongjin Park, and Hohyun Kim

Department of Chemistry, Kangwon National University, Kangweondo 200-092, Korea
Received October 16, 1996

During its relatively short existence, supercritical fluid chromatography (SFC) has become an attractive alternative to GC and LC in certain industrially important applications. SFC gives the advantage of high efficiency and fast analysis time for the analysis of non-volatile or thermally labile mixtures. Some applications of SFC to the separation of pesticides are featured in this paper, along with representative chromatograms. Pesticide analysis has received much attention because of the environmental impact of pesticides and fungicides and the need to monitor their levels and those of their metabolites in complex sample matrices such as foods. GC often is the analytical method of choice because of the availability of sensitive, selective detectors (FPD, NPD, ECD). However, difficulties arise when the solutes cannot be analyzed by GC because of thermal instability. HPLC is not helpful either, because such compounds cannot be detected easily at trace levels by a UV detector or one of the other HPLC detectors. In these cases, SFC is an alternative to GC or HPLC for the analysis of pesticides. The SFC analysis of some polar pesticides using mass spectrometry as a detector has previously been reported.[1] Thermally labile carbamate pesticides were also separated by capillary SFC.[2]

The ability to analyze moderately polar compounds with supercritical CO_2 is demonstrated in this paper; however, modifiers must be used. One of the most difficult problems with SFC is how polar substrates can be analyzed. Using the classification scheme of eluents by Synder,[3] carbon dioxide shows a polarity similar to that of hexane. The solvent power of the eluents used in SFC may be enhanced by adding a second eluent, the so-called 'modifier' to the basic mobile phase. Separations are often performed by SFC where the composition of the mobile phase is changed during the run or by adding a modifier before the chromatographic run is started. The influence on the retention behaviour of adding a modifier depends on the nature of the substrate, the stationary phase, and on the modifier itself. Yonker *et al.*,[4] report that at CO_2/methanol mixture at 50 °C UV absorbance maxima shifts for 2-nitroanisole. When dealing with the use of modifiers, it should be mentioned that some problems arise. First, a binary mixture of eluents can contaminate the instrument. The modifier remaining in a injector, tubing, expecially pump can be eluted slowly during the next run. This may affect the time to achieve chemical equilibrium and cause a corrosion at the pump. Second, many modifiers can diffuse in the laboratory and contaminate the air in the laboratory. To overcome these problems, we designed a new method which is shown in Figure

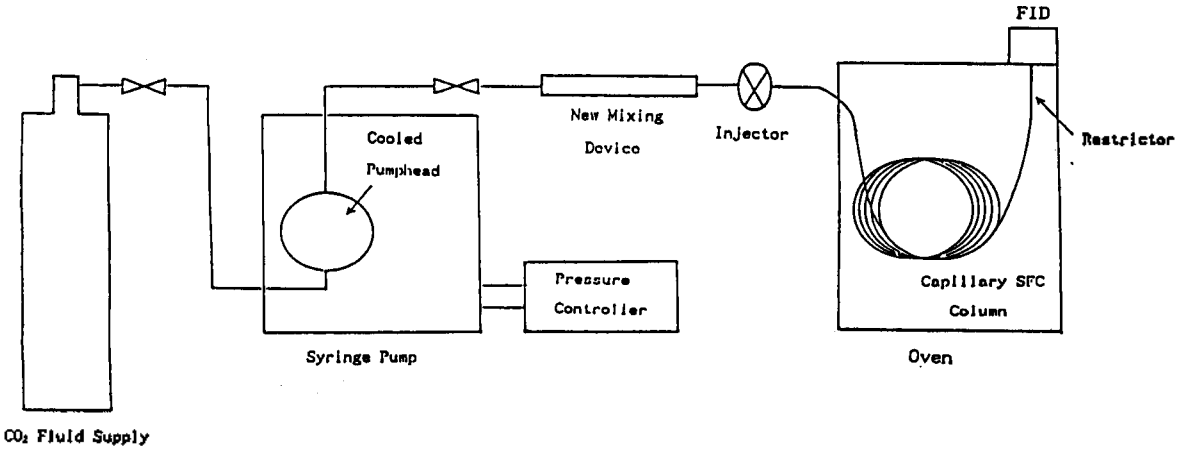

Figure 1. Schematic diagram of the apparatus used for adding a polar modifier to the supercritical fluid mobile phase.