A Simple Method for the Analysis of a Homologous Series of Alcohols using Gas Chromatography

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Gas chromatography has been a useful means for the analysis of complex mixtures of reasonably volatile compounds, and many analyses of lower fatty alcohols are available.

This report will present a study concerning the gas chromatographic analysis of an alcohol mixture which is produced by Ziegler's process.(1-4) This mixture consists of the normal even carbon-numbered alcohols ranging from C_6 through C_{22}. As the mixture contains components with high boiling points, gas chromatographic separation must be made at quite a high temperature. Therefore, the stationary liquid should be virtually nonvolatile at a column temperature of 200—250°C, and, at the same time, the liquid must be stable against thermal decomposition at such a high temperature. From these considerations, acetate-washed grease,(5) Apiezon grease(6,7) or Reoplex(8,9) was expected to be appropriate for this purpose.

On chromatograms, free alcohols usually give rise to asymmetric peaks; they have a drawn-out "trail," a shape obviously unfavorable to their sharp separation and to the quantitative analysis of the components with lower concentrations. The tailing of peaks may be attributed to the polarity of the solid support and to the association of alcohol molecules.(10) Hence, in order to avoid these unfavorable aspects, it was recommended that the alcohols, prior to analysis, be converted to their acetates, which show no tailing and are more stable against the thermal decomposition than the original alcohols. Furthermore, the acetates of C_6 and higher alcohols have lower melting points than those of the corresponding alcohols, and a mixture of them is more easily injected into the instrument.

It thus becomes important to convert the individual alcohol in the sample mixture quantitatively to its acetates. However, by the ordinary acetylation method, for example, by the use of acetic anhydride or acetyl chloride, it was found that the distribution of the acetates obtained does not correspond to that of the starting alcohol mixture, mainly because of the difference in the solubility of each acetate into an aqueous solution, which is formed by the washing of the reaction mixture with water after the acetylation process in order to remove the catalysts and excess reagents from the acetates produced.

This paper will report on an attempt to

TABLE I. ANALYTICAL CONDITION AND RETENTION TIMES

Analytical condition		Retention time, min.	
Stationary liquid	Silicone greanse (high vacuum)	n-$C_6H_{13}OAc$	1.4
Solid support	Aqua-regia-treated	n-$C_8H_{17}OAc$	2.2
	Chromosorb (35—60 mesh)	n-$C_{10}H_{21}OAc$	3.9
Liquid : Solid	20 : 80 (wt.)	n-$C_{12}H_{25}OAc$	7.3
Column length	225 cm. (I. D. 5 mm.)	n-$C_{14}H_{29}OAc$	14.9
Column temp.	220°C	n-$C_{16}H_{33}OAc$	27.9
Carrier gas	He	n-$C_{18}H_{37}OAc$	44.7
Flow rate	66 ml./min.	n-$C_{20}H_{41}OAc$	100
		n-$C_{22}H_{45}OAc$	180

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1) K. Ziegler, F. Krupp and K. Zosel, *Angew. Chem.*, **67**, 425 (1955).

2) K. Ziegler, French Pat. 1134907 (Apr. 19, 1957).

3) K. Ziegler, British Pat. 804335 (Nov. 12, 1958).

4) K. Ziegler, U. S. Pat. 2892858 (June 30, 1959).

5) F. R. Cropper and A. Heywood, *Nature*, **174**, 1063 (1954).

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7) A. Ofner, W. Kimel, A. Holmgren and F. Forrester, *Helv. chim. Acta*, **42**, 2577 (1959).

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10) Anon, Prices (Bromborough) Ltd., Tech. Publication No. 6; "Gas chromatography Abstracts," Butterworths, London (1960), p. 412.

TABLE II. ANALYTICAL RESULTS (REPEATABILITY OF GAS CHROMATOGRAPHY ITSELF)

Compt.	Calcd. X_o wt.%	Found, X_i 1	2	3	4	5	Av. $\overline{X}_i$	Mean error[a)]	Dev. from Calcd.[b)]	Rel. Dev.[c)]
n-$C_6H_{13}OAc$	4.6	4.7	4.3	4.5	5.9	5.1	4.9	0.4	+0.3	6.5
n-$C_8H_{17}OAc$	4.7	5.4	4.3	5.5	6.3	5.7	5.4	0.4	+0.7	14.8
n-$C_{10}H_{21}OAc$	11.2	10.9	11.7	11.3	12.4	11.8	11.5	0.4	+0.3	2.7
n-$C_{12}H_{25}OAc$	11.3	11.6	11.4	12.4	12.4	12.1	12.1	0.3	+0.8	7.1
n-$C_{14}H_{29}OAc$	22.3	23.1	23.8	22.7	23.2	22.6	22.9	0.4	+0.6	2.7
n-$C_{16}H_{33}OAc$	22.6	20.5	20.5	21.0	19.8	21.1	20.6	0.4	−2.0	8.9
n-$C_{18}H_{37}OAc$	23.3	23.8	24.0	22.6	20.0	21.6	22.6	1.1	−0.7	3.0

a) $\dfrac{\Sigma|\overline{X}_i - X_i|}{n}$ b) $\overline{X}_i - X_o$ c) $\dfrac{\overline{X}_i - X_o}{X_o} \times 100$

TABLE III. ANALYTICAL RESULTS (REPEATABILITY OF ACETYLATION-GAS CHROMATOGRAPHY)

Compt.	Calcd. X_o wt.%	Found, X_i 1	2	3	Av. $\overline{X}_i$	Mean error	Dev. from Calcd.	Rel. Dev.
n-$C_6H_{13}OAc$	7.9	7.8	7.1	7.8	7.6	0.3	−0.3	3.8
n-$C_8H_{17}OAc$	17.5	18.3	18.5	17.6	18.1	0.4	+0.6	3.4
n-$C_{10}H_{21}OAc$	15.0	15.4	15.7	15.5	15.5	0.1	+0.5	3.3
n-$C_{12}H_{25}OAc$	20.6	21.3	21.0	20.9	21.1	0.2	+0.5	2.4
n-$C_{14}H_{29}OAc$	26.2	25.6	26.7	25.7	26.0	0.5	−0.2	0.8
n-$C_{16}H_{33}OAc$	12.8	11.6	10.9	12.4	11.6	0.5	−1.2	9.4

find a quantitative analytical method for a homologous series of alcohols through acetylation by the use of ketene gas. It was generated from acetone, along with methane gas, and was passed through a sample volume of an alcohol mixture for a short time in order to acetylate it. The acetate mixture obtained was, without needing any more treatment, immediately subjected to gas chromatographic analysis.

It was confirmed that, by the ketene-acetylation, alcohols were converted to their acetates quantitatively and yet with the same conversion velocity. Consequently, the operation of the analysis was greatly simplified by this acetylation process. The accuracy of this analytical method was found to be satisfactory, as Tables II and III show.

Experimental

Gas Chromatography. — In this work, silicone grease (Dow Corning High Vacuum Silicone Grease) was used as the stationary substrate, while aqua-regia-treated[11)] Chromosorb (Johns-Manville), 35- to 60-mesh size, was used as the solid support. The packing was prepared by adding 80 g. of Chromosorb to 20 g. of silicone grease dissolved in ethyl ether. The solvent was evaporated on a steam-bath, and finally the packing was dried in an air oven at 110°C. The columns were constructed from the packing and stainless steel tubings 0.75, 1.50, 2.25 and 3.00 m. long and 5 mm. in inner diameter, and they were tested at temperatures of 180, 200, 220 and 240°C.

A Shimadzu model GC-1A gas chromatograph equipped with a filament-wire thermal-conductivity cell was used without modification. Helium was used as the carrier gas, and its flow rates were constantly checked with a soap-film flowmeter. In this work the flow rate was controlled at 20, 40 or 66 ml. per minute.

For the standard samples of the higher n-alcohols, C_6 through C_{18}, and of their acetates, commercial alcohols were purchased from the Wako Pure Chemical Co., and purified in our laboratory through their borates and thereafter by the fractional distillation (Podbielniak) of alcohols obtained from the hydrolysis or of their esters acetylated by the ordinary method.

The Apparatus for and Operation of the Ketene Acetylation of an Alcohol Sample. — Figure 1 illustrates a ketene generator and acetylation apparatus. At the start, the cock A is opened and the reactor B (5.5 mm.×60 mm., glass), is charged with 1 ml. of an alcohol mixture. Then the acetone in a 3 l.-flask is gently refluxed, and 50-60 V-AC. is supplied to the 300 W.-nichrome wire, hung in the 3 l.-flask, in order to maintain the dark red color of the wire throughout the acetylation. The vapor of the refluxing acetone comes in contact with the hot wire and undergoes cracking. When the evolution of ketene gas mixture becomes stationary, the cock A is closed and the flow rate of the gas is immediately set at an appropriate rate by controlling the by-pass flow rate (level D) by moving the vessel C up and down according to the reading of the scale differences of an orifice meter E, which has been preliminarily graphed against the flow rate of the ketene gas mixture. When the flow rate is 300 ml. and 600 ml. per hour,

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11) A. Zlatkis, Su-Yu Ling and H. R. Kaufman, *Anal. Chem.*, **31**, 945 (1959).

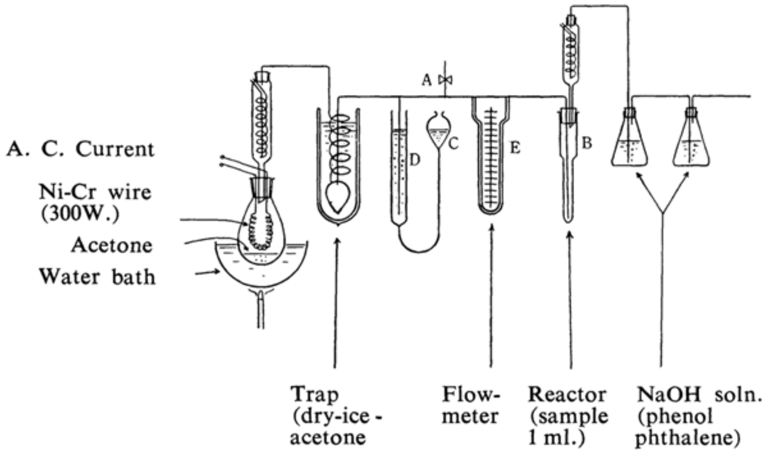

Fig. 1. Keten generator and acetylation apparatus.

it took 2.5 and 1.5 hr. respectively to complete the acetylation of 1 ml. of the alcohol mixture.

Results and Discussion

The Accuracy of the Ketene Acetylation Process.—In order to estimate the loss of the sample during the acetylation process, only the losses of hexyl alcohol and its acetate, which are the most volatile among the compounds under consideration in each series, were investigated. It was found that when flow rate of nitrogen (in place of ketene-metane gas) was 300 ml. per hour, hexylalcohol and its acetate were lost at the rates of 0.7—0.8 mg. and 2.5—3.0 mg. per hour respectively when accompanied by a gas stream. Because, under actual conditions, about 1/4.5 of ketene gas is calculated to be absorbed as a result of the reaction with alcohol, only ca. 0.5 wt.% of the C_6-compounds should be lost during the acetylation process. The loss due to the acetylation of C_8 and higher alcohols, therefore, should be less than 0.5 wt.% respectively, and there should be essentially no difference in composition between the alcohol mixture and the acetate one during the process.

At times during the acetylation process, portions of the sample were taken out and submitted to gas chromatography in order to check the disappearance of alcohols. At the end of the reaction, each peak of the homologous alcohols disappeared completely and simultaneously, and no peaks other than those due to the acetates were produced. It is obvious, therefore, that the conversion of each alcohol to its acetate is perfectly quantitative, and yet that its conversion velocity is the same in all the alcohols concerned.

Gas Chromatographic Analysis. — In the analysis of samples with a very wide boiling range, if complete separation of the lower boiling components is desired the retention times of the higher-boiling components necessarily become too long and, consequently, the peaks of these components become wider. Under such conditions, the limit of detection is undesirably high, and no high accuracy of analysis could be expected. Therefore, the retention time as well as the separation efficiency must be taken into consideration in the determination of analytical conditions. In this work the optimum conditions were selected on the basis of the following evidence; a) analytical time through the retention times of the highest-boiling components, b) separation efficiencies through the height equivalent to a theoretical plate[12] of the components, and c) the stability of the stationary liquid at a high temperature.

As the analytical time is decided by the retention time of the last eluting component, the time of n-$C_{22}H_{45}OAc$ must be restricted within definite limitations. The retention times of n-$C_6H_{13}OAc$ through n-$C_{18}H_{37}OAc$ were measured under various analytical conditions. For a homologous series of organic compounds, it has been shown that a plot of the logarithm of the retention volume or of the time against the number of carbon atoms yields an almost straight line.[13-15] On the basis of the experimental results in this work, it was recognized that a similar relationship is proper for n-$C_6H_{13}OAc$ through n-$C_{18}H_{37}OAc$. By an extrapolation of the line, the retention times of n-$C_{20}H_{41}OAc$ and n-$C_{22}H_{45}OAc$ were presumed

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[12] A. I. M. Keulemans and A. Kwants, "Vapor Phase Chromatography," Butterworths, London (1957), p. 15.
[13] A. T. James and A. J. P. Martin, *Analyst*, **77**, 915 (1952).
[14] A. T. James and A. J. P. Martin, *Biochem. J.*, **50**, 679 (1952).
[15] N. H. Ray, *J. Appl. Chem.*, **4**, 21 (1954).

for each condition. The analytical conditions at which the retention time of n-$C_{22}H_{45}OAc$ becomes longer than 180 min. seemed to be unsuitable for a routine analysis.

The relation between the height equivalent to a theoretical plate (HETP) and the gas flow rate (u) is given by the following equation.[16]

$$\mathrm{HETP} = A + B/u + Cu$$

where A, B and C are constants. Therefore, a plot of the HETP versus u shows a curve with a minimum, at which point the column reaches its highest efficiency. In this work, the values of HETP for 40 and 66 ml. per minute were generally smaller than that for 20 ml. per minute. Therefore, the minimum value seems to be obtained for the flow rate of near 40 or 66 ml. per minute.

At the temperature of 240°C silicone grease was not stable enough for the retention times of the components to decreased in a short time. Therefore, the column temperature should not be maintained at 240°C or over.

In view of these points the analytical conditions shown in Table I were selected for the analysis of n-$C_6H_{13}OAc$ through n-$C_{22}H_{45}OAc$.

A linear relationship was observed between the weight of each component and its peak area.

The Accuracy of the Gas Chromatography (Repeatability).—Table II shows the analytical results of the gas chromatography of a known sample of n-$C_6H_{13}OAc$ - n-$C_{18}H_{37}OAc$. It is clear from these results that the repeatability of this method is fairly good.

The Accuracy (Repeatability) of Acetylation by Ketene Gas by Means of Gas Chromatography.—Table III shows the repeatability of the ketene-acetylation of the known sample of n-$C_6H_{13}OH$ - n-$C_{16}H_{33}OH$ by the use of gas chromatography. It is clear from these results that the repeatability of this method is also fairly good.

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[16] J. J. van Deemter, F. J. Zuiderweg and A. Klinkenberg, *Chem. Eng. Sci.*, 5, 271 (1956).