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SENSITIVE LIQUID CHROMATOGRAPHIC METHOD FOR THE DETERMINATION OF FORMIC ACID IN AIR SAMPLES

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SUMMARY

A method is described for the determination of formic acid in air samples. Formic acid was collected on activated charcoal, desorbed with *N,N*-dimethylformamide and converted into *p*-bromophenacyl formate. The derivative was analyzed by high-performance liquid chromatography with UV detection (254 nm). The separation was carried out on a reversed-phase C_{18} column with water-acetonitrile (55:45) as eluent. The efficiency of desorption from charcoal and of the esterification was studied, as well the linearity, reproducibility and sensitivity of the method. The method proved sensitive and specific for analysis of low concentrations of formic acid in complex air samples.

INTRODUCTION

Formic acid is used in several industrial processes, *e.g.*, the dyeing and finishing of textiles and paper, the treatment of leather and the manufacture of many chemicals. It is also found among the oxidized thermal degradation products of organic matter, *e.g.*, during the processing of thermoplastics¹.

Formic acid causes irritation of mucous membranes and the skin^{2,3}. Biochemical changes have been observed in rats exposed to sub-acute amounts (20 ppm) of formic acid⁴. Also the neurotoxic potential of formic acid has been investigated using prolonged exposure to the thermal degradation products of polyethylene⁵.

The current threshold limit value for formic acid is 5 ppm (9 mg/m³) (American Conference of Governmental Industrial Hygienists), a concentration which is difficult to determine with many common methods. The determination of low concentrations of formic acid is especially troublesome for mixtures of acidic compounds and for air samples containing thermo-oxidized degradation products of plastics¹.

The usual methods for the determination of formic acid, *e.g.*, potentiometric titration with sodium hydroxide and reactions with oxidizing or reducing agents, are insensitive to low concentrations of formic acid in the air. Gas chromatography after collection in sodium hydroxide solution and esterification constitutes a more sensitive method, but the detection limit is too high and personal sampling with bubblers is

inconvenient⁶. Ion chromatography with a detection limit of 0.5 $\mu\text{g/ml}$ is a sensitive method for formic acid but the instrumentation is not readily available⁷.

In this paper, we describe a high-performance liquid chromatographic (HPLC) method for the determination of formic acid as its *p*-bromophenacyl ester⁸ from air impurities collected on activated charcoal.

MATERIALS AND METHODS

N,N-dimethylformamide, used for the elution of formic acid from charcoal, was of spectrophotometric grade (EGA-Chemie, G.F.R.). The reagents for esterification, *p*-bromophenacyl bromide (pure A.R.; Koch-Light, Great Britain) and N,N-diisopropylethylamine (ICN Pharmaceuticals, U.S.A.), were used without further purification. Formic acid was obtained from E. Merck (G.F.R.). Sodium ¹⁴C]formate (52 mCi/mmol in ethanol-water, 7:3) was purchased from NEN Chemicals (Great Britain). The coconut charcoal used for sampling was from Chemviron (Great Britain). It was purified by washing with water and heating under nitrogen at 350°C overnight, and sieved to contain particles of 0.4–0.8 mm in diameter.

Sampling

The charcoal tubes were prepared in our laboratory. A glass tube (15 cm \times 4 mm I.D.) was packed with 200 mg of activated charcoal and capped with small plugs of glass wool. The flow resistance was found to be 1.1 ± 0.1 kPa. Air samples (18 l) were collected with a Sipin personal sampling pump (Model SP 15; Anatole J. Sipin, U.S.A.) at a flow-rate of 0.2 l/min.

Derivatization

After sampling, the charcoal tubes were emptied into screw-capped tubes containing 2 ml of N,N-dimethylformamide (DMF). The tubes were subjected to ultrasonication for 20 min and the solutions filtered through a 0.5- μm Fluoropore filter (FHP 01300; Millipore, U.S.A.). A 20- μl volume of 0.1 M *p*-bromophenacyl bromide in DMF and 1 μl of N,N-diisopropylethylamine were added to the filtrate. The molar concentration of the bromide was calculated to be about twice and the concentration of the amine catalyst about four times that of acids in the sample. The reaction mixture was heated at 60°C for 2 h and then kept at room temperature overnight.

Chromatographic procedure

Liquid chromatography was conducted with a Varian 5000 liquid chromatograph equipped with a UV detector (254 nm) and a Rheodyne 7125 injector. Separation was carried out with a μ Bondapak C₁₈ column (15 cm \times 3.9 mm I.D.). The analytical column was protected by a guard column packed with Bondapak C₁₈/Corasil. The flow-rate of the eluent, acetonitrile-water (45:55), was 1.5 ml/min. The injection volume was 10 μl .

Studies on the efficiency of desorption and esterification

The efficiency of desorption of formic acid with DMF as eluent was studied at three different concentrations of formic acid: 3.1, 7.6 and 15.3 $\mu\text{g/ml}$ DMF. Each of

these standard solutions contained 100 mg/ml charcoal. Blanks without charcoal were made at the same concentrations. A 10- μ l volume of radioactive formate solution (52 mCi/mmol solution diluted 1:100) was added to the standards and they were ultrasonicated for 20 min. An aliquot of 0.5 ml was removed from each solution to a tube containing 3.5 ml of scintillation liquid and the radioactivities were measured with a liquid scintillation counter.

The possibility of leakage through the charcoal tube was also tested. Two charcoal tubes were connected with PTFE tubing and 15.3 μ g of formic acid were injected into the first tube. Air (0.2 l/min) was pumped through the tubes for 1.5 h. A dilution of this order corresponds to 0.37 ppm (cm^3/m^3) of formic acid in an air sample of 18 l, concentration level higher than that commonly found in air samples collected from worksites during the processing of plastics. The tubes were analyzed separately.

The formation of the ester derivative of formic acid was studied with labelled formate. Three different concentrations of the acid (3.1, 7.6 and 15.3 μ g/ml DMF) were used. The bromophenacyl formate peak was collected after HPLC separation (injection volume 20 μ l). A 10-ml volume of scintillation liquid was added and the radioactivity was measured.

RESULTS AND DISCUSSION

When the adsorption efficiency of the charcoal was tested from the point of view of leakage, no carry-over from the first tube to the second was observed at the concentration level used. The adsorption efficiency of Amberlite XAD-2 and Tenax-GC was also tested. These adsorbents proved inefficient as retainers of formic acid.

The desorption by DMF of charcoal-bound formic acid was $54 \pm 3\%$ ($\bar{x} \pm$ S.D., $n = 12$). Thus DMF, in spite of its high solvent strength, only partially desorbed the acid from the charcoal. Water would have been a better desorbent⁹ but its use was precluded by the inhibitory effect of water on the derivative formation¹⁰. The reproducibility of the recovery was quite good, with a coefficient of variation of 0.055. Ultrasonication increased the desorption efficiency, especially at the lowest concentration level, and resulted in the same per cent recovery at each of the three concentrations studied. The extent of derivatization was 100% when studied with [¹⁴C]formate.

The reproducibility of the determinations of formic acid was tested with six samples at a formic acid concentration of 7.6 μ g/ml of eluent. The coefficient of variation was 0.06. Fig. 1 displays a typical chromatogram for an analysis of atmospheric formic acid, and Fig. 2 a typical calibration curve for the *p*-bromophenacyl ester of formic acid. Linearity is good (correlation coefficient 0.999), but the curve has a non-zero intercept. This is due to impurities in the chemicals and the charcoal (despite purification of the latter). This deviation, however, remained stable within a batch of reagents.

The sensitivity of this method is facilitated by the high absorbance of the *p*-bromophenacyl chromophore in the UV region. The molar extinction coefficient has been reported to be $1.8 \cdot 10^4$ l/mol \cdot cm at 254 nm ($\lambda_{\text{max}} = 260$ nm)⁸. The detection limit is approximately 0.5 μ g/ml, corresponding to a formic acid concentration of 0.03 ppm (cm^3/m^3) in an air sample of 18 l. The detection limit could be lowered by further

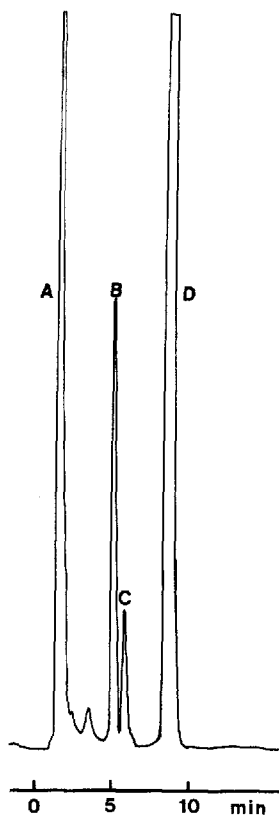


Fig. 1. Typical chromatogram from an atmospheric formic acid sample. Peaks: A = DMF; B = *p*-bromophenacyl ester of formic acid; C = acetic ester; D = *p*-bromophenacyl bromide.

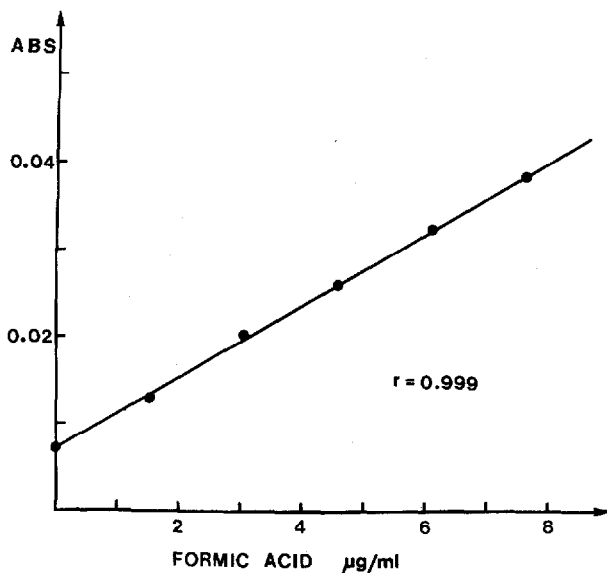


Fig. 2. Calibration curve for the determination of formic acid.

purification of the reagents, the solvent and the adsorption material but this is obviously difficult.

The method has been successfully adapted to measure low concentrations of formic acid in complex air samples, *e.g.*, samples from the workroom air of a plastic processing industry¹ as well as from the atmosphere when exposing animals to the thermal degradation products of plastics (*e.g.*, ref. 11). Good reproducibilities have been obtained and the storage of sampling tubes for up to 3 weeks in a refrigerator does not affect the recovery of formic acid.

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