ORGANIC CONTAMINANTS IN INDOOR AIR AND THEIR RELATION TO OUTDOOR CONTAMINANTS

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INTRODUCTION

Relatively little information exists on the organic contaminants in indoor air, except for some toxic materials in industrial occupational environments. In view of the extended exposures of individuals to indoor air in spaces other than in industry, information on such contaminants is needed before meaningful definitions of the indoor air quality with respect to organic contaminants can be devised. Presently, methods used for the determination of organic contaminants in air fall into two groups:

1. methods used for outdoor air: determination of methane, and all other organics taken together as non-methane hydrocarbons,

2. methods specified by NIOSH for certain harmful substances for which permissible 8-h exposure limits have been defined by OSHA.

The present project was designed to assess the nature and approx. concentrations of organic substances in vapor form which occur in indoor air in typical enclosed spaces. It also sought to determine whether these substances are present in the outside air as well, and thus, are not reducible merely by ventilation.

The project was planned in two phases, the first of which was covered with the development of methodology and initial field trials, while the second dealt with data collection from many sites. This paper presents the results obtained for both phases of this project.

EXPERIMENTAL

Phase I involved the development of techniques to collect, analyze, and identify organic contaminants in air over as wide a molecular carbon number range and over as many functionalities as practical. Requirements of the sampling system include: portability, simplicity, efficiency, sturdiness, reasonable sampling times, and reduction of the sample handling steps. Also, the system should ideally be capable of sensitivities at or below the 1 ppb level. The system used routinely reached a sensitivity level of 0.5 ppb for gas chromatographic/mass spectrometric (GC/MS) analysis.

After a satisfactory collection system was tested in Phase I, and extensive data gathering process was undertaken and formed the major effort on Phase II.

Collector Design

In prior work in our laboratory,[1] Chromosorb 102, a high-surface area styrene-divinylbenzene copolymer was used to collect organic vapors from air. Such materials collect organic vapors with a minimum collection of water vapor. More recently, a new, also highly adsorbent, but much more thermally stable porous organic polymer became available based on 2,6-diphenyl-p-phenylene oxide. The latter was used throughout this program.

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Similarly, mass-spectrometric techniques for identification of compounds have increased in sensitivity as has separation resolution with the advent of glass capillary tubular gas chromatographic columns.

Consequently, the use of smaller air samples became feasible, and smaller amounts of adsorbent in the organic vapor collector could be used. These advances permitted developing collectors from which the organic vapor sample could be transferred into a gas-chromatographic (GC) injection port directly, without the need for a cryogenic collection step as in earlier work.

Fig. 1 shows the collector used in this work. The principal part is a 1/8 in. (3.1 mm) o.d., 0.085 in. (2.16 mm) i.d., stainless steel tube, 8 in. (200 mm) long, packed with approx. 90 mg of 60/80 mesh preconditioned (250°C overnight) porous organic polymer GC 2,6-diphenyl-p-phenylene oxide, kept in place by two Pyrex glass wool plugs. The ends of the principal part are equipped with 1/16-in. (1.6 mm) o.d., 0.030 in. (0.76 mm) i.d., brazed-in stainless steel tubing. One end, L, is 2½ in. (140 mm) long and serves as the sample inlet during sampling and to reach through the GC injection port to the front end of the GC column when connected to a gas-chromatograph. The other end, S, is short, 1 in. (25 mm) and serves to apply suction during sampling and for connection to an alternate carrier gas path during the sample transfer into the gas-chromatograph.

At both ends, the principal 1/8 in. o.d. tubing part carries brazed-in 2 in. (50 mm) long idearms of the same 1/8 in. o.d. stainless steel tubing as the principal part. These sidearms are attached to the principal part by brazing, and their inside openings do not connect to the inside of the collector; they serve as electrical current leads for flash-heating of the collector during the injection of the sample into the GC port. When the collector is connected into the GC port, it is in a horizontal position, and the sidearms extend horizontally sideways. A thin-wire iron-constantan thermocouple is inserted deep into the sidearm farthest from the port, and two current leads are connected to the outer tips of the sidearms by heavy duty aligator clamps.

This system provides for good temperature control during the collector flash-heating cycle. Because of the horizontal position, the electrical resistance heat generation is reasonably uniform along the collector and the sidearms, so that no cold spot occurs where the sidearm joins the principal part. Since the collector is inserted into the GC port up to the attachment of the closest sidearm, the junction point between the 1/8 in. o.d. principal part and the 1/16 in. o.d. extension is already warm before electrical heating starts, and is warmer than the porous polymer charge during the electrical heating cycle. Because of the horizontal position of the collector and sidearms, cold air updrafts are approx. the same both for the collector and the sidearms, and the thermocouple indicates a temperature similar to that of the porous polymer except during the initial warmup when the porous polymer holding part may heat up somewhat more slowly.

In manufacturing the collectors, glass wool plugs and preconditioned porous polymer packing are placed into the collector already equipped with sidearms but without attached 1/16 in. o.d. extensions. The extensions are then brazed-in, with zero-grade nitrogen flow used to protect the inside of the collector from gas fumes. Finally, the collector is then conditioned in a zero-grade helium flow, 30 mL/min, overnight, rapidly cooled, and closed on both ends. Helium is not permitted to flow through the cooled collector except for the short time necessary for cooling; otherwise, the collector would collect impurities even from the zero-grade helium. Collectors can be repeatedly reconditioned.

A closure is shown in blown-up on the right side of Fig. 1. It consists of a commercial Teflon compression gland fitting which has been closed by a stainless steel insert and brazing to form a cap. The end of the collector is inserted as shown. Tightening nut N pushes the stainless steel cylinder C which then compresses the Teflon gland G and seals it around the end of the collector inserted into the gland.

Sample Collection

Sampling consists of pulling air from the shorter small end, S, of the collector, so that the ambient air sample enters through the long end. Fig. 2 is a graph showing the collection efficiency as a function of flow rate. At a 30 mL/min sampling rate, the pressure drop along the collector is approx. 2-3 psi (0.13 to 0.2 atm). Such a pressure drop influences the collection efficiency only slightly. At faster flow rates, the efficiency rapidly deteriorates as shown in Fig. 2.

The collector with the sample is first tightly attached to the new outside line, then its long end is inserted into the GC port (with the GC column cooled to avoid a deterioration of the stationary phase), and sealed by tightening the fitting. Sidearms of the collector are kept in a horizontal position, the thermocouple is inserted into the back sidearm G, and the electrical current leads are attached.

Electrical current to the collector is obtained from two 5v 30A transformer coils H (only one is shown) connected in parallel, so that up to 60A can be drawn continuously, if necessary, to heat the collector. The primary 115v coil is fed through a variable voltage transformer, I, which is in turn controlled by an auxiliary relay K, operated from a pyrometer indicator-controller L, responding to the thermocouple signal. A self-resetting 1-min timer, M, controls the entire circuitry; depressing the timer button initiates the collector heating and at the same time energizes the solenoid valve, directing the carrier gas to flow through the collector. Settings of I determine the rate of heating; the temperature setting on L determines the temperature at which the collector continues to coast until the timer M stops the heating, de-energized the solenoid, and resets, for another heating cycle. A bypass-circuit, not shown, permits a continuous heating of the collector at some selected temperature, with the carrier gas passing through the collector.

A pressure gauge (not shown) in the carrier gas system downstream of the constant flow control valve indicates if the collector/GC part of the system is pneumatically tight.

Typical operation utilizes a 240°C collector heating temperature, which is reached within 20 sec, with some initial overshoot to 280°C. During the remaining 40 sec, the collector coasts around 240°C under carrier gas flow. Tests indicate that at this temperature no significant bleeding of volatiles from 2,6-diphenyl-p-phenylene oxide itself occurs, and a 1 min injection cycle is sufficient to remove all of the sample. This is clearly demonstrated in Fig. 5. The upper trace is an injection as described above of lacquer thinner. The lower trace is a second injection made immediately after the first, from the same collector.

With samples collected and sealed for storage by endcaps, various extraneous impurities seem to accumulate on the outside of the long end of the collector. When such a collector is attached to the GC system, the long end is heated by the port heat and all such impurities are released onto the GC column. To eliminate these artifacts, the collector is first left unheated, but the GC column is rapidly brought to the highest permissible temperature, which is maintained for 15-25 min, to clear the extraneous impurities through the column. The column is then brought back to the starting temperature, the sample injected as outlined above, and the analysis with a programmed temperature rise initiated.

GC/MS System

All samples were analyzed by combined gas chromatography-mass spectrometry under computer control (GC-MS-COMP). Vapors trapped in the porous polymer tubular collectors were transferred directly to the analytical system by thermal desorption. This was achieved by first attaching the collector to the (modified) injection port of the GC, and then rapidly heating it to 250°C while reverse-flushing with helium carrier gas for 60 sec at 30 cm^3/min. Most analyses were performed using OV-101 (50 m x 0.05 mm i.d. SCOT, 15 m x 0.025 mm i.d. WCOT) or SE-30 (50 m x 0.025 mm i.d. WCOT) non-polar capillary columns, but a number of samples were also chromatographed on a 35 m x 0.025 mm i.d. SP-1000 polar column. In all cases, the carrier gas was maintained at a flow rate of 30 cm^3/min and the injector split ratio was adjusted to 10:1. This was found to give an adequate volume of gas through the porous polymer collector during the 60-sec sample-purge cycle. The column was held initially at a temperature of 35°C for 10 min, then programmed at 4°C/min to 210°C.

The total column effluent was passed directly into the ion source of the mass spectrometer, a double focusing instrument, which was operated at low resolution. The ion source of the mass spectrometer consists of a combination standard electron impact source and an electron-impact ionization detector (EID). By operating the EID at a low electron energy, the total ion current signal from the GC, free of the carrier-gas contribution, could be monitored in real-time using an electronic integrator which measured peak areas as well as retention times.

On injection of a sample, the magnet of the mass spectrometer was set to scan repetitively throughout the GC run from m/e 20 to m/e 250 every 2.4 sec. The data were gathered and stored using a data system with disk-based mass storage. At the end of a run, ion abundance data from each scan were numbered and plotted as a function of spectrum scan number using a visual display terminal with hardcopy unit.

Various pumping and metering arrangements were considered, but the use of pumps was finally rejected. The principal reason was that pumps themselves may contaminate air by oil vapors and by vapors from heated paint and insulation; also, most pumps would require the monitoring of pumping rates to assure constant-volume samples. The sampling arrangement that was finally selected is shown in Fig. 3. A polypropylene 2 L conical flask is filled with water and closed with a stopper with two unequal lengths of copper tubing. One tube, A, reaches to the bottom of the flask; its other end is equipped with food-grade flexible plastic tubing, with a similar but smaller in diameter flexible plastic capillary insert, into which the shorter (suction) end of the collector can be plugged. The other tube, B, ends close to the stopper; this tube is equipped with several feet (1-1.5 m) of flexible plastic tubing. In the inverted position, water runs out of the flask through B and into a spare flask, sucking air through the collector. When 2 L of air are sampled, the water level reaches the upper end of B and the water flow and sampling stop.

This arrangement is inexpensive, easy to transport, does not require electrical power for operation, is flexible in placement, and does not contaminate the air by its own emissions. In many cases, the outdoor air sample has to be collected at its entrance into a ventilating system, far from the location of the indoor sample, so that the two collections must be separated. The flask method pumps and meters simultaneously and guarantees reproducible 2 L air samples with little attention.

For collection of outdoor samples in cold weather, calcium chloride was added to the water.

Typical duration for a 2 L sample collection was 40-60 min. Thus, the sample is averaged over a similar period of time.

After sampling, the collectors are closed at both ends with the closure shown in the insert in Fig. 1.

2,6-Diphenyl-p-phenylene oxide is considered a suitable gas-chromatographic stationary phase for separation of all but acidic components. However, in its use as a collector phase, the possibility existed that organic acids still may be satisfactorily released, since the collector contains a relatively short (15 cm) column of porous polymer packing and is very rapidly heated to high temperatures during the sample transfer to the gas-chromatograph. Experiments with heptanoic acid at 1 ppm in air were conducted using the described collector, a 260°C release temperature, and a Carbowax 20 m coated packed column in Teflon-clad stainless steel tubing, which permits direct gas-chromatography of free acids. Excellent heptanoic acid recovery was obtained, indicating that porous polymer collectors are also suitable for collection of organic acid vapors from air.

Sample Transfer to Gas Chromatograph

Fig. 4 shows the electrical and pneumatic circuitry used to transfer samples from collectors to a gas chromatographic injection port.

The following changes were made to adapt the gas chromatograph for operation with the collectors in Fig. 1.

First, the nut used to hold septum discs was removed and replaced with a special attachment shown in the insert at the lower right. The attachment screws onto the port, and a Teflon O-ring, A, seals the attachment to the front end of the threaded part of the injection port. The rest of the attachment is a modified straight through fitting with a Teflon compression plug B. This plug receives the long end of the collector, which is pushed into the port until the sidearm of the collector touches the tightening nut of the attachment.

Second, the carrier gas line to the port is cut between the port and the constant flow valve, which regulates the carrier gas flow in the chromatograph. A 3-way miniature solenoid valve, C, is inserted there. In the de-energized position, this valve admits the regulated carrier gas flow directly to the port, as in the usual GC operation. In the energized position, the carrier gas flow is diverted from the control valve to a new branch, D, of 1/16 in. (1.6 mm) o.d., 0.030 in. (0.76 mm) i.d. stainless steel tubing outside of the gas chromatograph, while the tubing from the solenoid to the port ends at the now-closed direction of the solenoid. The new outside line, on its outer end, is equipped with a brazed-on fitting, E, which carries a compressible Teflon plug. This end is connected to the short end of the collector, F; thus, when the solenoid is energized, the carrier gas flows again to the GC port, but now passes first through the collector.

DISCUSSION OF RESULTS

Over 250 different chemical compounds were identified or tentatively identified in this study. These compounds have been arranged according to compound class in Table 1. Nearly all chemical compound classes are represented with one notable exception; organic acids. The explanation for this is that the acids were probably present in low concentrations if at all due to their high solubility in water. Secondly, the acids are not very volatile and their high polarity would cause them to be held tenaciously by most surfaces in which they come in contact.

The list of alkanes gives an indication of the useful carbon number range of the sampling system. All alkanes from C_3 (propane) to C_{16} (hexadecane) were detected. Earlier investigation of breakthrough volumes indicated that all compounds above C_6 are retained quantitatively. Compounds of C_6 and below provide qualitative information only. Data on the breakthrough volume for a number of compounds is shown in Fig. 9.

Some of the more unusual compounds found were: ketene, a severe pulmonary irritant derived from the thermal decomposition of acetone; acetonitrile, acrylonitrile, butylnitrile, and other nitrogen containing compounds all of which are poisonous; carbon disulfide, a neurotoxin; benzene, trichlorethylene, tetrachloroethylene, styrene, and mono and dichlorobenzene, all suspected carçinogens.

In Table 2 are listed a number of compounds that occurred with relatively high frequency in both indoor and outdoor samples. The numbers listed under the indoor and outdoor headings are percent frequency of occurrence. That is the number of times the compound appeared divided by the means of inside or outside samples. For example, acetone appeared in 51% of the inside samples and in 35% of the outside samples.

The in/out column is the indoor frequency divided by the outdoor frequency. A number close to one indicates a compound that is found equally both indoors and outdoors. A number higher than about 1.5 indicates a compound predominantly found indoors but also found outdoors. A number below one indicates a compound found more often outdoors than indoors.

The compounds found outside as frequently as inside such as toluene, xylene, methylethylketone, tetrachloroethylene, benzene, and low molecular weight alkanes originate from two sources: *(1)* solvents used in manufacturing; *(2)* emissions from automobiles and trucks. Many of these compounds, such as benzene and toluene, are not routinely brought into the home and probably get there via infiltration. Compounds such as tri- and tetrachloroethylene probably are brought into the home on cleaned clothes and also from infiltration. Secondly, these compounds also have a long lifetime in the atmosphere. Tri- and tetrachloroethylene are believed to have lifetimes of at least 1 yr in the troposphere since their reaction with hydroxyl radicals (the primary removal mechanism in the troposphere) is very long.

Compounds such as ethanol, α-pinene, limonene, indole, etc., are produced by the human body, are present in our food, result from having plants indoors, and are used in perfumes and other household products. These compounds, therefore, would be expected, as was found, to be more prevalent indoors than outdoors.

Seventy-two percent of the homes were found to have more compounds inside than outside. The average number of compounds found per house was 31 inside and 14 outside In summer, an average of 37 compounds per home were found, while only 16 per home were found outside. In winter, the number found inside the home dropped to 18, while the number found outside remained more constant at 11 compounds.

Chicago is more heavily industrialized on the south side than on the north or west sides. Dividing the homes into two groups, those with more than fifty compounds reported and those with fewer than fifty compounds reported, it was found that in the former group (eight homes), 62% were on the south side, 25% were on the north side, and 13% were on the west side. In the latter group, 48% were on the south side, 7% were in downtown Chicago, 10% were on the west side, and 35% were on the north side. These distributions should be compared with the overall distribution of 51% on the southside, 32% on the northside, 5% downtown Chicago, and 11% on the west side. This data appears to indicate that, at least to some degree, the contamination in the south side homes may be due to the prevalence of industry in this area, while the homes in the less industrialized north and west sides are experiencing a lower burden of compounds.

The raw GC/MS data were transferred by magnetic tape to an off-line digital computer system. Depending on complexity, some of the files were processed using a sophisticated data-enhancement algorithm to obtain spectra free of background and overlapping components. Identification of the resolved mass spectra was then established using a computer-based search system (Biemann method) or by manual comparison with standard compilations of spectral data.

Sampling Site Selection

Members of ASHRAE Committee TC 2.3 were polled at the beginning of this program and asked what criterion should be used in selecting the sampling sites. Based on the results of this questionnaire, thirty-six homes in the Washington, DC area were added in conjunction with a program at Geomet, Inc. Private homes were selected because people spend about 80% of their time at home and there is a scarcity of data on air quality in homes.

The map in Fig. 6 shows the location of the homes selected for study in the Chicago metropolitan area. These sites were selected to cover as broad a geographical area as possible. The hashed dots indicate homes sampled in summer only. The solid dots represent homes sampled in winter only, and the half solid and hashed dots represent homes sampled both in summer and winter. The two Washington, DC area homes were sampled in winter months.

Each participating owner was asked to fill out a questionnaire, shown in Appendix A. As much data as possible about the home and its occupants that might lead to correlations with the vaporous compounds found were obtained.

Each home was sampled in as reproducible a way as possible. Two samples were taken simultaneously inside and outside. The inside site was selected near a return air duct on the main floor of the house. This was done to try and ensure a representative sample of the air from all parts of the home. The thermostat was set on manual during the analysis to ensure air circulation.

The outside sample was chosen to be upwind of the home and approx. 10 ft away from the foundation.

RESULTS

The Washington, DC area homes were some of the first analyzed and were gas chromatographed (GC) on an SP-1000 column.

The majority of the homes analyzed from the Chicago area were analyzed using an SP-2100, SE-30, or OV-101 GC column. All were open tubular wall coated columns (WCOT) except the SE-30 which was a support coated open tubular column (SCOT). The results of the analysis of the Chicago and Washington, DC homes are presented in Table 1.

An example of a typical analysis of a pair of indoor/outdoor samples is shown in Fig. 7 and 8. In the indoor sample, 118 compounds were found and identified. In the outdoor sample, only 29 compounds were found and identified.

The homes investigated range in age from less than 1 yr to 60 yrs (mean age: 18 ± 16).

The average number of occupants was 3.6 ± 1.3 with the range from 2 to 7. The ages of the occupants ranged from 7 months to 76 yrs. There were three apartments and the rest were detached single-family homes. The average size home was 2000 ± 1000 sq ft with an average of 7 ± 2 rooms on an 0.25 ± 0.18 acre lot. Twenty-eight homes were brick and frame construction, two were high rise concrete, steel, and glass and the rest were wood frame houses. Twenty-one homes had attached garages; the rest were unattached. All homes, but one, were forced air heated with gas as the primary heating source.

Twenty-seven of the homes had basements, and nineteen had attics. Fifteen had been redecorated with approx. half of the homes having new carpeting and/or new furniture. Twelve of the homes had fireplaces and almost all had a washer and dryer. All of the homes, except one, had house plants with the average number being 17. Half of the homes had pets with nineteen dogs (4 small, 10 medium, 5 large), four cats and four other assorted pets (gerbals, frogs, and parakeet) represented. In twenty of the homes at least one smoker was present. Thirty of the homes were airconditioned.

1. People are exposed on a continuing basis to a wide range of organic compounds in ambient air, both indoors and outdoors.

2. The concentrations of these compounds are, on the average, at or below 100 ppb.

3. Transient exposure (of one or more days duration) to compounds at much higher concentrations can occur indoors in situations such as routine redecoration (painting, varnishing), indoor cleaning with various solvents, cooking, etc.

4. The frequency and variety of compounds indoors at or above 1 ppb is greater than outdoors.

5. The indoor contaminants probably arise for the most part from the carpeting, clothing, furniture, and anthropogenic activity in the home; however, no single source was indicated by the data.

6. The data indicated that the location of the home relative to the industrial operations of the community had a slight effect on the number of contaminants found in the homes.

7. The data did not indicate that the level of contamination was seasonally related.

8. The sampling methodologies can be effectively used in general surveys of indoor and outdoor air quality at or above the 1 ppb level.

REFERENCES

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Table 1

COMPOUNDS FOUND ARRANGED INTO COMPOUND CLASSES

ALKANES

n-propane
n-butane
n-pentane
n-hexane
n-heptane
n-octane
n-nonane
n-decane
n-undecane
n-dodecane
n-tridecane
n-tetradecane
n-pentadecane
n-hexadecane

BRANCHED ALKANES

C_4H_{10}
C_5H_{12}
2-methyl pentane
C_6H_{14}
3-methyl pentane
C_7H_{16} (6)
2,4-dimethyl pentane
Dimethylpentane isomer
2-methyl hexane
3-methyl hexane
C_8H_{18} (5)
4-methyl heptane
2,3,3-trimethyl pentane
2-methyl heptane
3-methyl heptane
methylethyl pentane
C_9H_{20} (8)
$C_{10}H_{22}$ (10)
2,2,5,5-tetramethyl hexane
Trimethyl heptane
$C_{11}H_{24}$ (11)
4-methyl decane
$C_{12}H_{26}$ (8)
$C_{13}H_{28}$ (2)
$C_{14}H_{30}$ (2)
$C_{15}H_{32}$ (1)

With one striking exception, in general, there did not appear to be any specific correlation between the compounds and the activity in the home. For example, the two most heavily contaminated homes were different in many of the characteristics of the home. One home was located in Wilmette, a northern suburb near Lake Michigan, and had five occupants including smokers. The home was 20 yrs old, of brick construction, and had not been recently redecorated, but had new furniture. It had an attached garage, a gas stove, fireplace, house plants, a gas drier, and a large dog. The heating plant was was with forced air distribution and was 10 yrs old. The house was fully air conditioned.

The second most burdened home was a 5 yr old western suburban home with two occupants and no smokers. No pets were present. The home had an attached garage, frame construction, house plants, had not been recently redecorated, but contained mostly new furniture. A gas drier and gas heating plant of 5 yrs old, were used with forced air circulation. The house was fully air conditioned.

The similarities between these two homes were the attached garage, presence of new furniture, and gas heating systems.

An analysis of the data on the other homes, looking at these characteristics compared to the burden of compounds found, showed that of the homes in which 50 or more compounds were found, 50% had attached garages, 100% had gas heat, 50% had new furniture and carpeting, and 0% had been recently redecorated.

For the homes in which fewer than fifty compounds were found, 55% had attached garages, 90% had gas heat, 48% had new furnitures, 38% had new carpeting, and 38% had been recently redecorated.

Other correlations were attempted using the characteristics of the homes indicated in the evaluation questionnaire, with similar results. It appears that the number of compounds found in the homes is not related to any of the known attributes of the homes.

In one home that was sampled, the outside of the front door was varnished the day before our field engineer arrived. It was left standing open for a few hours to dry. The next day when the field engineer took the samples, he noted a slight odor of fresh paint or varnish.

The analysis of these indoor samples showed an extremely high number and concentration of compounds. A second sampling visit was scheduled for about 2 wks later. At this time, the indoor sample showed no trace of the high contamination found earlier. This indicates that the transient concentration of compounds resulting from such indoor activities as painting, varnishing, cleaning with solvents, oiling furniture, spraying various materials, such as plant insecticides, deodorants, perfumes, etc., and cooking can become very high, approaching or even exceeding a concentration of 1 ppb.

This study was mainly qualitative. Answering the question of what compounds were present ndoors and what was their relation to outdoor compounds was paramount. However, some semi-quantitative generalizations can be made about the compounds found. Benzene, toluene, and tetrachloroethylene were found to be present in nearly every home and outside sample, and were usually in the highest concentration. All other compounds found and reported were probably present at a concentration of at least 0.5 ppb (the limit of detection of our method). No compound was present at a concentration above 100 ppb.

Finally, it should be noted that for the sampling volume used in this study, i.e., 2 L, a sensitivity of 0.5 ppb was achieved and over 250 compounds were detected. If a 20 L collection had been used, that is an increase in the sensitivity by a factor of 10, then many of the compounds found only in a few homes would have probably been detected in every home. Hundreds of compounds and possibly even thousands of compounds are present in ambient air. The sampling methodologies used here reflect a first attempt at detecting those compounds at or above the 0.5 ppb level.

CONCLUSIONS

In this study, thirty-six homes were sampled in the Chicago metropolitan area. Fifteen were sampled in both summer and winter, resulting in more than fifty separate analyses of indoor and outdoor air. The major conclusions from this study are:

ETHERS

Vinyl ethyl ether
Methoxy vinyl ethyl ether

HETEROCYCLES

C_4H_4O, Furan
C_5H_6O, Methyl furan
C_4H_8O, Tetrahydrofuran
$C_4H_8O_2$, 2-methyl-1,3-dioxlane
$C_4H_8O_2$, p-dioxane

TERPENES

α-pinene
Sabinene
Camphene
β-pinene
Myrene
$C_{10}H_{16}$, terpene (3)
Ocimene
Limonene

CYCLIC ALKANES

Methyl cyclopentane
Cyclopentane
Cyclohexane
Methylcyclohexane
Dimethylcyclohexane (2)
Methylethylcyclopentane
Ethylcyclohexane
Trimethylcyclohexane (2)
Methylethylcyclohexane (2)
Isopropylcyclohexane
Alkylcyclopentane (2)
isobutylcyclohexane
Bicyclodecane

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*Numbers in parenthesis indicate the number of peaks of this compound identified. These are usually isomers of the same chemical formula and not easily identified specifically by GC/MS.

Table 2

FREQUENCY OF OCCURANCE OF SOME OF THE MAJOR COMPOUNDS FOUND IN CHICAGO AREA HOMES

Compound	Indoor	Outdoor	In/Out
Acetone	51	35	1.5
Ethanol	46	9	5.1
Hexane	51	41	1.2
Benzene	91	88	1.0
2-Methylhexane	29	9	3.2
Heptane	46	32	1.4
Toluene	80	85	0.9
Tetrachloroethylene	40	35	1.1
Octane	43	32	1.3
Ethylbenzene	57	32	1.8
m-Xylene	46	56	0.8
p-Xylene	37	32	1.2
Nonane	46	38	1.2
Benzaldehyde	34	15	2.3
α-Pinene	37	6	6.2
β-Pinene	11	6	1.8
Acetophenone	17	9	1.9
Decane	29	18	1.6
Limonene	37	12	3.1
Undecane	29	12	2.4
Naphthalene	43	21	2.0
Dodecane	29	12	2.4
Indole	11	3	3.7
Biphenyl	26	6	4.3
Methanol	6	3	2.0
Trichloroethylene	14	9	1.6
Methylethylketone	3	3	1.0

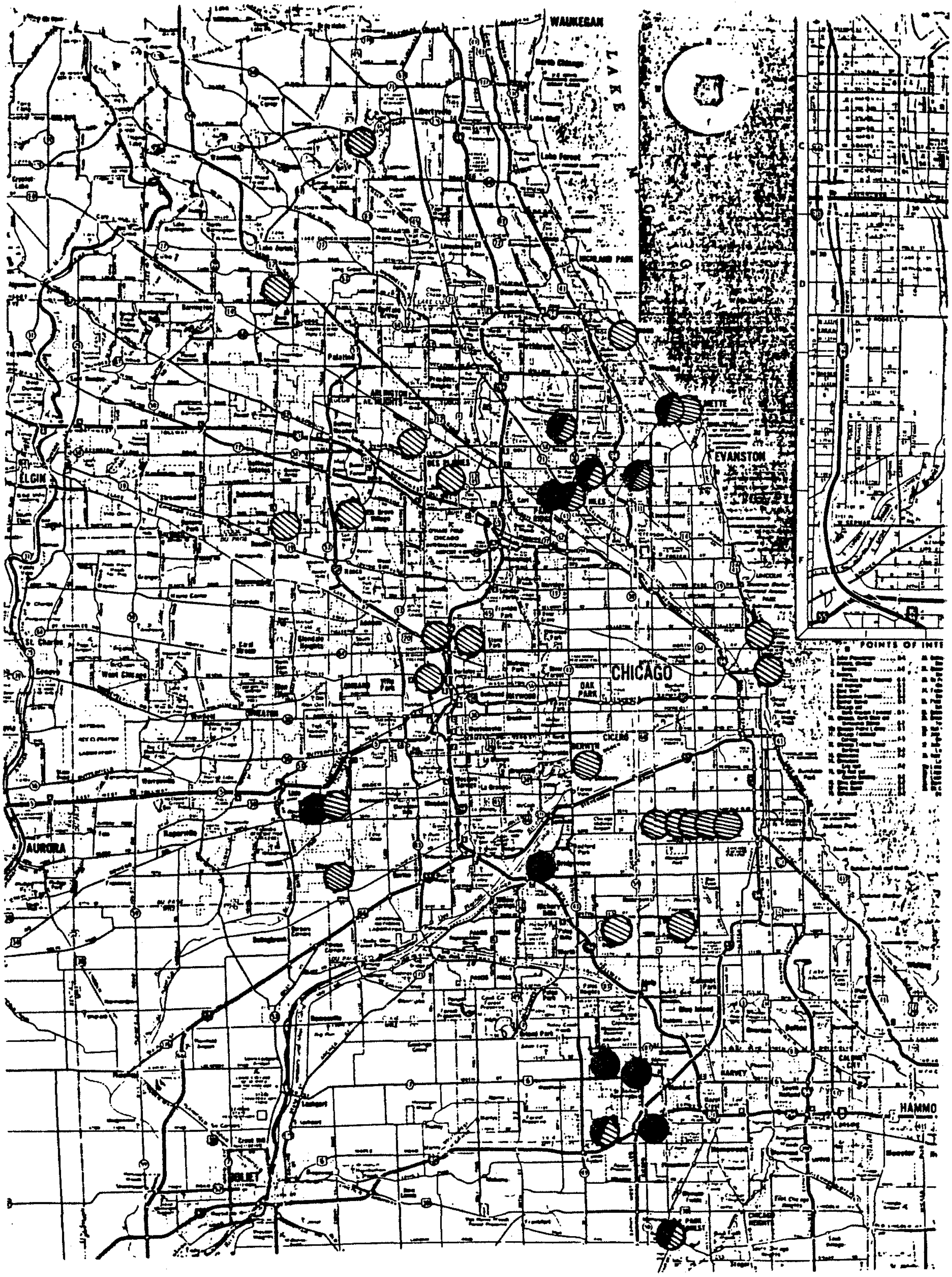

Fig. 6 Sites selected in Chicago metropolitan area

ALKENES

ketene
1-butene
1-pentene
Cyclomethyl butadiene
Cyclopentene
Isoprene
Methylethyl ketene
2-methyl-3-butadiene
Cyclopentadiene
C_6H_{12}
1-hexene
3-methyl-1-pentene
1-heptene
2,4-dimethyl-1,3-pentadiene
C_7H_{14} (2)
C_8H_{16} (2)
Styrene
C_9H_{18}
$C_{10}H_{20}$ (4)
$C_{11}H_{22}$ (7)
1-undecene

ALKYNES

Phenyl acetylene

NITROGEN COMPOUNDS

C_2H_3N, Acetonitrile
C_3H_3N, Acrylonitrile
C_4H_6N, Pyrrole
C_5H_5N, Pyridine
$C_6H_{11}N$, 4-methyl pentyl nitrile
$C_6H_{11}N_3$, 1-butyl-1,2,4-triazole
$C_9H_{12}N$, Cyanobenzene
C_8H_7N, Benzyl Cyanide
C_7H_5NS, Benzothiozole
C_8H_7N, Indole

KETONES

Ketene
Acetone
2-Butanone (Methylethyl ketone)
Methylisobutyl Ketone
Acetophenone

AROMATICS

Benzene
Toluene
Ethyl benzene
o,m,p-xylene
Styrene
Ethyltoluene (3)
C_9H_{12}, alkybenzene (6)
n-propyl benzene
Trimethyl benzene (4)
2-methyl styrene
$C_{10}H_{14}$, alkyl benzene (5)
Phenol
n-propl toluene
Isobutyl benzene
Ethylxylene
Cresol
$C_{11}H_{16}$, alkyl benzene (2)
Dimethyl styrene
Naphthalene
Methyl naphthalene (2)
$C_{13}H_{20}$, alkylbenzene (2)
$C_{14}H_{22}$, alkylbenzene
Biphenyl
Methyl diphenyl
Methyl fluorene

SULFUR COMPOUNDS

CS_2, Carbon Disulfide
C_7H_5NS, Benzothiazole

CHLOROFLUORO CARBONS

CH_3Cl, Chloromethane
CH_2Cl_2, Dichloromethane
$C_2Cl_3F_3$ Freon 113
$CHCl_3$, Trichloromethane
$C_2H_3Cl_3$, 1,1,1-Trichloroethane
C_2HCl_3, Trichloroethylene
C_2Cl_4, Tetrachloroethylene
C_6H_5Cl, Chlorobenzene
$C_6H_4Cl_2$, Dichlorobenzene

ALCOHOLS

Methanol
Ethanol
2-propanol
Amylalcohol
1-butanol
Pentanol
2-methyl-1-pentanol
Hexanol
2-Ethyl-1-butanol
$C_6H_{14}O_3$, 2-bis(2-ethoxy)-ethanol
Ethyl-hexanol
Octanol
Phenol
Ethyl hexanol
Cresol
Terpeneol

ALDEHYDES

Acetaldehyde
Propanol
Crotonaldehyde
Ethyl hexanal
Phenyl acetaldehyde
Benzaldehyde
Nononal
Decanal

ESTERS

$C_4H_8O_2$, Ethylacetate
$C_5H_{10}O_2$, n-propyl acetate
$C_8H_{14}O_2$, b-butyl methacrylate
$C_9H_{10}O_2$, benzlyacetate

ACIDS

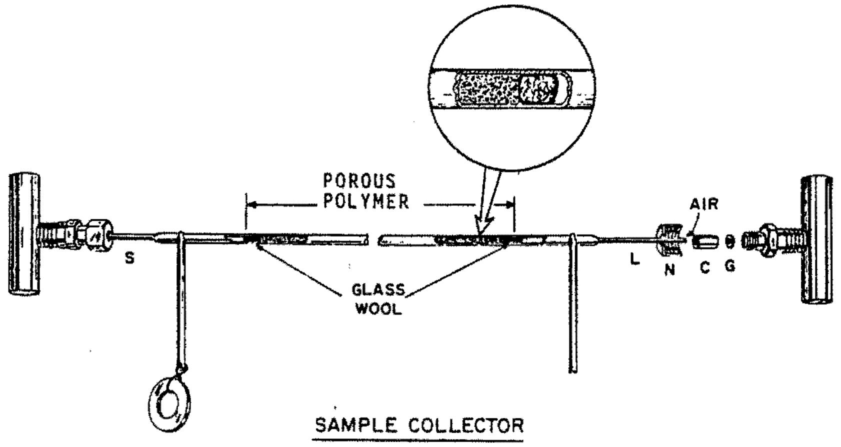

Fig. 1 Collector for organic contaminants in air

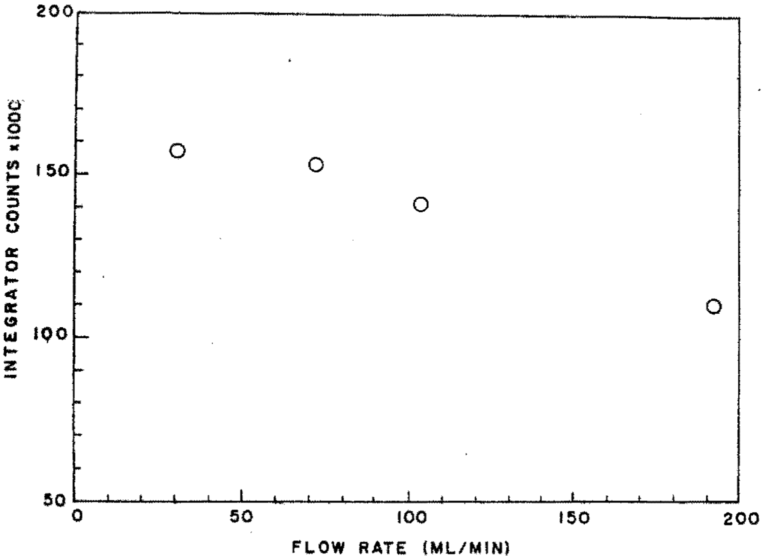

Fig. 2 Collection efficiency

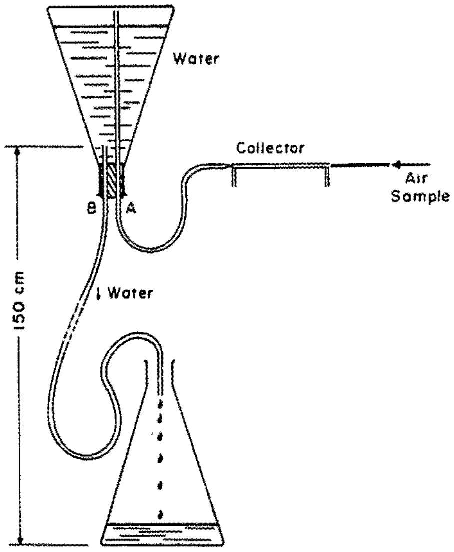

Fig. 3 Suction sampling device for all sampling

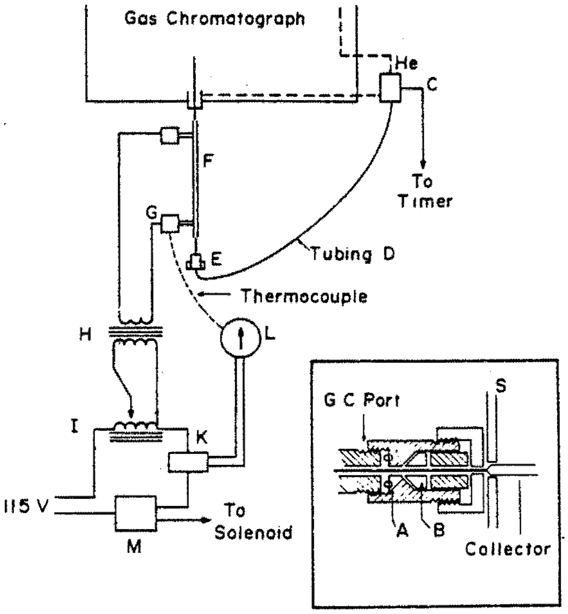

Fig. 4 Principal electrical and pneumatic features of devices for injection of samples from collector into gas-chromatograph

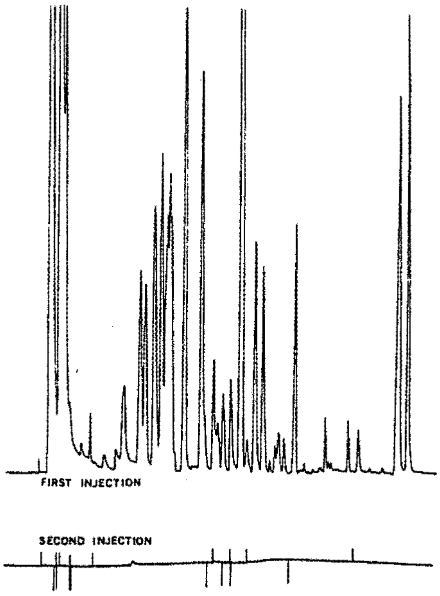

Fig. 5 Desorption efficiency of organic vapor collection system

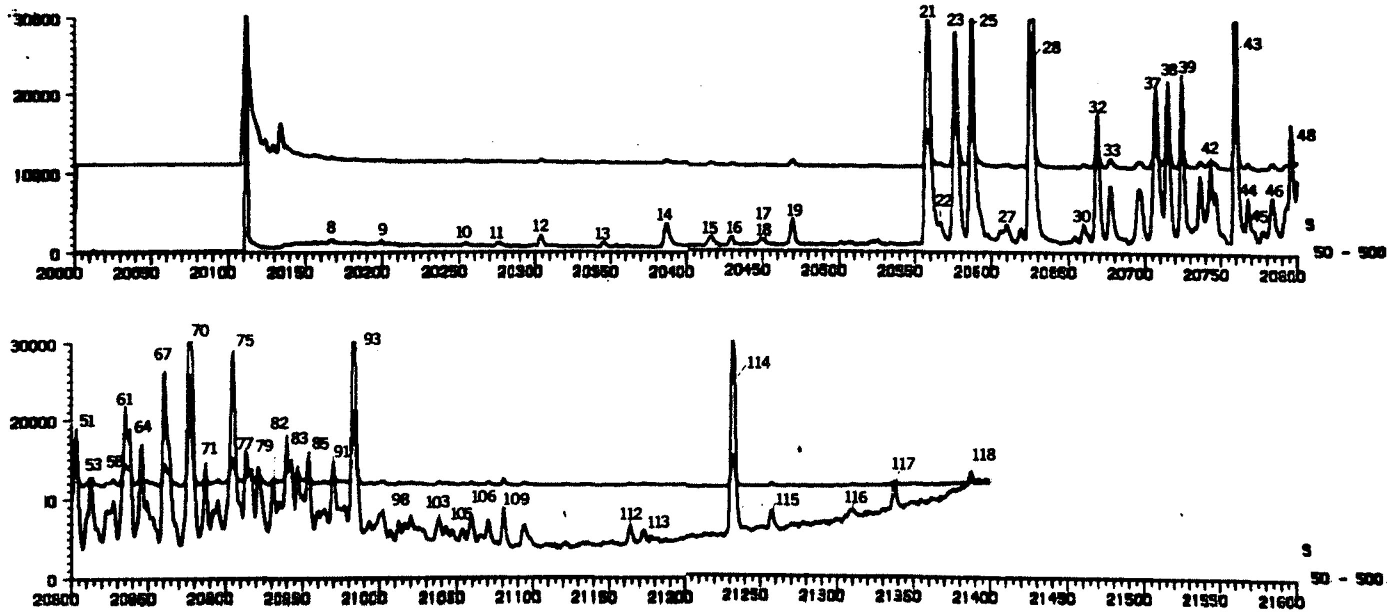

Fig. 7 Typical indoor chromatogram

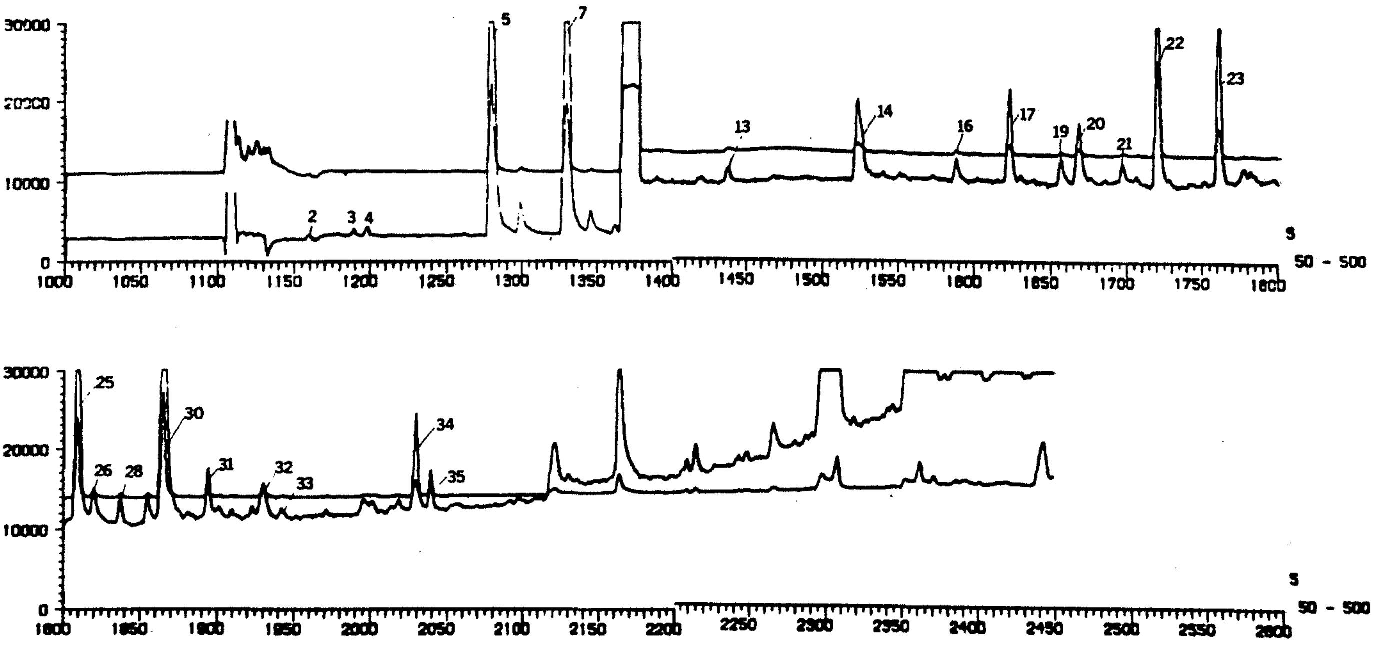

Fig. 8 Typical outdoor chromatogram