Air Quality Problems Inside a House Following a Fire

YOSHIO TSUCHIYA

Institute for Research in Construction
National Research Council of Canada
Building M-59, Montreal Road
Ottawa, Ontario
Canada K1A 0R6

ABSTRACT: Fire-damaged houses are often refurbished for further use. In some cases occupants complain about odours from the fire in the refurbished houses. Experimental box fires and a field study of refurbished houses were undertaken to investigate the problem. Concentrations of combustion products from fires in the experimental box were measured for up to 30 days afterwards and the decay of concentrations of the combustion products was calculated. The decay was faster in humid conditions than in dry conditions. There was a correlation between the boiling point of compounds and the decay constant. Some compounds remained in higher-than-normal concentrations for several hundred or several thousand days. Field studies of refurbished houses showed results consistent with the experimental study.

KEY WORDS: refurbished house, combustion products, decay, odours, field study, humidity, GC/MS.

INTRODUCTION

THERE WERE 70,624 unwanted fires in Canada in 1988, of which 31,752 were residential fires. The monetary loss from residential fires was $442 million [1], an average of $13,900 per house. When damage is minor to medium, houses are refurbished for continued use. The Institute for Research in Construction, National Research Council of Canada received several inquiries from residents of refurbished houses regarding odours and ill-health suspected to be due to the presence of combustion

products. One house was treated with odour-control chemicals by a contractor before refurbishing. In this case improper application of the chemicals, causing decomposition or interaction with combustion products, was suspected in the subsequent ill-health of the residents.

Little information is available on odour problems in houses after a fire, methods of odour control, compositions of chemicals used for the odour control and their reaction to combustion products. This paper summarizes information collected from the literature, a laboratory study, and a field study of refurbished houses after a fire.

EXPERIMENTAL

Fire Experiments

Three experiments were conducted in a 1.73 m³ cubical box constructed of mineral fibre/cement boards (12 mm thick, density 0.85 g/ml) without surface treatment. In the first experiment, a crib of nominal 50 mm square white pine studs (total weight 10 kg) was ignited with a torch. Air for the combustion was supplied by natural convection through an opening (0.38 × 1.02 m) made in the wall. When about half the wood was consumed, the fire was smothered by closing the opening. After the box cooled, humid air (50% relative humidity at 22°C) generated from a commercially available humidity controller was supplied through a hose attached to one wall and exhausted through an opening on the opposite wall at a rate of 0.233 L/sec (0.5 air change/hour). In the second experiment, using a similar crib, the same procedure was followed except that dry air was supplied. In the third experiment, mixed fuel (wood, PVC, polymethyl methacrylate, polystyrene in approximately 2.5 kg each) was burned and 50% RH air was supplied.

Analysis of Air

A known volume of the exhaust air from the box was periodically sampled for up to 30 days through sorption tubes by suction from a small mechanical pump. These were commercially available, 3-layer (glass beads-Tenax-Ambersorb) sorption tubes. Volatile organic compounds (VOC) in the air were collected and concentrated in the tube. Volumes of the sampled air varied from 100 mL to 10 L depending on the expected concentrations of the VOC. The absorbed organic compounds were thermally released using an Envirochem Unacon Model 810 desorption unit under a helium flow. Two 4% splits of the flow went

into a flame ionization detector (FID) for monitoring purpose at different times. The latter of the two was used for quantification of the total volatile organic compounds (TVOC). The remaining 92% flow was introduced into the gas chromatograph separation column of a Hewlett Packard Model 5995 gas chromatograph/mass spectrometer (GC/MS). The column was a methyl-silicone bonded phase glass capillary, 25 m × 0.2 mm i.d. The desorbed compounds were cryofocused on the beginning of the GC column at −50°C. The oven temperature was programmed from −50°C to 250°C at an increasing rate of 10°C/min for GC separation. Inorganic compounds were not measured.

Major components in the GC effluent were identified by the MS using a spectra library and search program supplied by the manufacturer of the instrument. All the identifications were confirmed by comparing the sample spectra and the reference spectra. To measure concentrations of organic compound in sample gases, the response factor of the FID, f in count/μg, was determined using known volumes of cylindered cyclohexane/helium mixture (Matheson certified standard 607 ppm cyclohexane) as:

$$f = c_s/V_s/C_s \tag{1}$$

where

c_s = FID count for a known volume of standard cyclohexane/helium
V_s = volume of the standard cyclohexane/helium in m³
C_s = concentration of the standard cyclohexane/helium in μg/m³

The TVOC, T in μg/m³, was then calculated as:

$$T = c/f/V \tag{2}$$

where

c = FID count for an air sample
V = volume of the air sample taken into the tube in m³

Concentration of an organic component is then

$$C = T \times A_i/A \tag{3}$$

where

A = total area under peaks in the chromatogram in ion count of MS
A_i = area under a peak of interest in ion count of MS
C = concentration of the interested component in μg/m³

Field Study

Five refurbished buildings—three houses, a senior citizens' home a an office building—were visited and room air was sampled using same type of sorption tubes. These buildings had been cleaned and furbished after a fire and were occupied. The collected samples w analyzed in the laboratory using the procedure described above.

RESULTS AND DISCUSSION

Experimental Box Fires

Concentrations of organic components in the air in the box decay with time. Measured concentrations and days after the fire were s jected to a regression analysis. The following equation had the b linear correlation:

$$\log C = \log C_0 - a \times \log d$$

where C is the concentration in v/v of an organic component measu on days, d, after the fire and C_0 is the initial (24 hours after fire) conc tration. The constant, a, is the decay constant.

Identified compounds, their regression constants and correlation f tors, r, are shown in Tables 1(a–c) in the order of their boiling poin

In the 50% RH air experiments, the logarithm of concentration cor lated well with the logarithm of days after the fire according to Eq tion (4). In the dry air experiment on wood, however, the results w more erratic and the decay was slower than in the 50% RH experim by a factor of 2.5 in terms of the averaged decay constant.

The decays of various compounds in Equation (4) are plotted in F ure 1 for the wood burn and in Figure 2 for the mixed fuel burn, b in the 50% RH experiments. The experimental data, measured up to days [log (day) = 1.5], were extrapolated to log (day) = 3.

Various organic compounds are always present in the air insid

Table 1(a). *Decay of combustion products in experimental fires. Wood burn, decay in 50% RH air.*

Compound	bp °C	Mol. wt.	Regression Constants		Correlation Factor
			a	Log C_0	r
Furan	31.	68.1	1.191	−4.578	−0.945
Methyl furan	63.2	82.1	1.349	−4.112	−0.957
Methylethylketone	79.6	72.1	2.803	−3.345	−0.998
Methylisopropylketone	95.	86.1	2.456	−3.878	−0.966
Toluene	110.6	92.1	1.053	−4.440	−0.957
Hexanal	131.	100.2	1.211	−3.801	−0.943
Pinene	155.	136.2	0.939	−3.601	−0.967
Camphene	159.	136.2	0.670	−4.092	−0.936
Furfural	161.7	96.1	1.743	−3.557	−0.977
Limonene	178.	136.2	0.940	−3.787	−0.959
Methylfurfural	186.	110.1	0.906	−5.179	−0.947

Table 1(b). *Decay of combustion products in experimental fires. Mixed fuel burn, decay in 50% RH air.*

Compound	bp °C	Mol. wt.	Regression Constants		Correlation Factor
			a	Log C_0	r
Propenenitrile	77.3	53.1	1.245	−4.040	−0.804
Benzene	80.1	78.1	2.289	−4.270	−0.951
Propanenitrile	97.2	55.1	1.191	−4.717	−0.903
Methylmethacrylate	101.	100.1	1.632	−2.410	−0.976
Toluene	110.6	92.1	2.178	−4.567	−0.960
Methylpropenenitrile	122.4	67.1	0.804	−4.202	−0.844
Styrene	145.2	104.2	2.101	−3.420	−0.962
Pinene	155.	136.2	1.069	−4.248	−0.977
Camphene	159.	136.2	0.914	−4.949	−0.944
Methylstyrene	165.4	118.2	3.038	−4.266	−0.923
Benzofuran	174.	118.1	1.227	−5.462	−0.933
Limonene	178.	136.2	0.945	−4.911	−0.961
Benzaldehyde	179.1	106.1	0.692	−4.752	−0.917
Indene	181.8	116.1	1.064	−5.092	−0.941
Benzonitrile	191.1	103.1	0.620	−5.111	−0.885
Naphthalene	218.0	128.2	1.168	−4.177	−0.943
Biphenyl	256.1	154.2	0.499	−6.257	−0.855

Table 1(c). *Decay of combustion products in experimental fires. Wood burn, decay in dry air.*

Compound	bp °C	Mol. wt.	Regression Constants		Correlation Factor
			a	Log C_0	r
Hexanal	131.	100.2	0.261	−4.880	−0.391
Pinene	155.	136.2	0.489	−4.410	−0.624
Camphene	159.	136.2	0.350	−4.512	−0.580
Furfural	161.7	96.1	0.193	−5.625	−0.544
Limonene	178.	136.2	0.341	−4.668	−0.601

house. In a study of indoor air quality of residential houses (not fire houses), occurrence and average concentrations of various organic compounds were reported [2]. Compounds common to the present study are listed in Table 2. The calculated number of days required for the concentration of these common compounds in the air of the box fires to decay to their average level in residential houses is also shown. High boiling point compounds such as styrene and naphthalene will take several hundred or several thousand days to decay to the average concentration.

Values of the decay constant are plotted against boiling points in Figure 3. For three groups of compounds, 1) styrene and methyl styrene, 2) furan and methylfuran, and 3) propanenitrile, propenenitrile, and methylpropenenitrile, the values deviate from those of the other compounds. A partial explanation of this observation is that: (a) styrenes polymerize and quickly decay by this additional mechanism, (b) furans undergo reversible oligomer formation, which reduces their vapour pressures, and they decay slowly. Except for the three groups of compounds, there was a correlation between boiling points of combustion products and decay constants ($r = 0.789$). Compounds with low boiling points decayed quickly, as expected. Other mechanisms such as absorption and diffusion into a solid phase may also affect the decay rate.

Field Study

An example of GC/MS results of organic compounds in the air inside a fire house is shown in Figure 4 (house #2 in Table 4). Quantitative analytical results of the five field studies are shown in Table 3. Details about the five buildings investigated in the field study are given in Table 4.
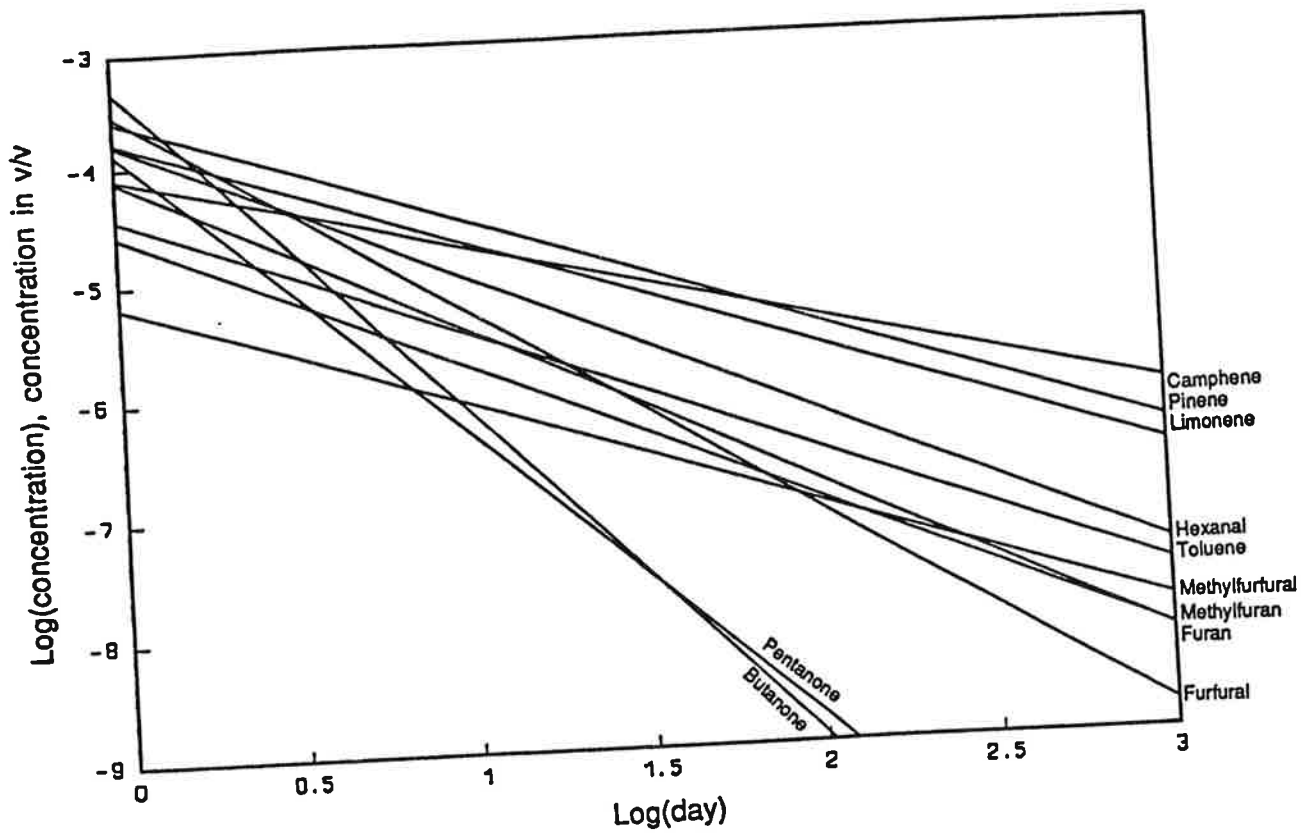
Figure 1. Decay of combustion products of wood burn, decay in 50% RH air.
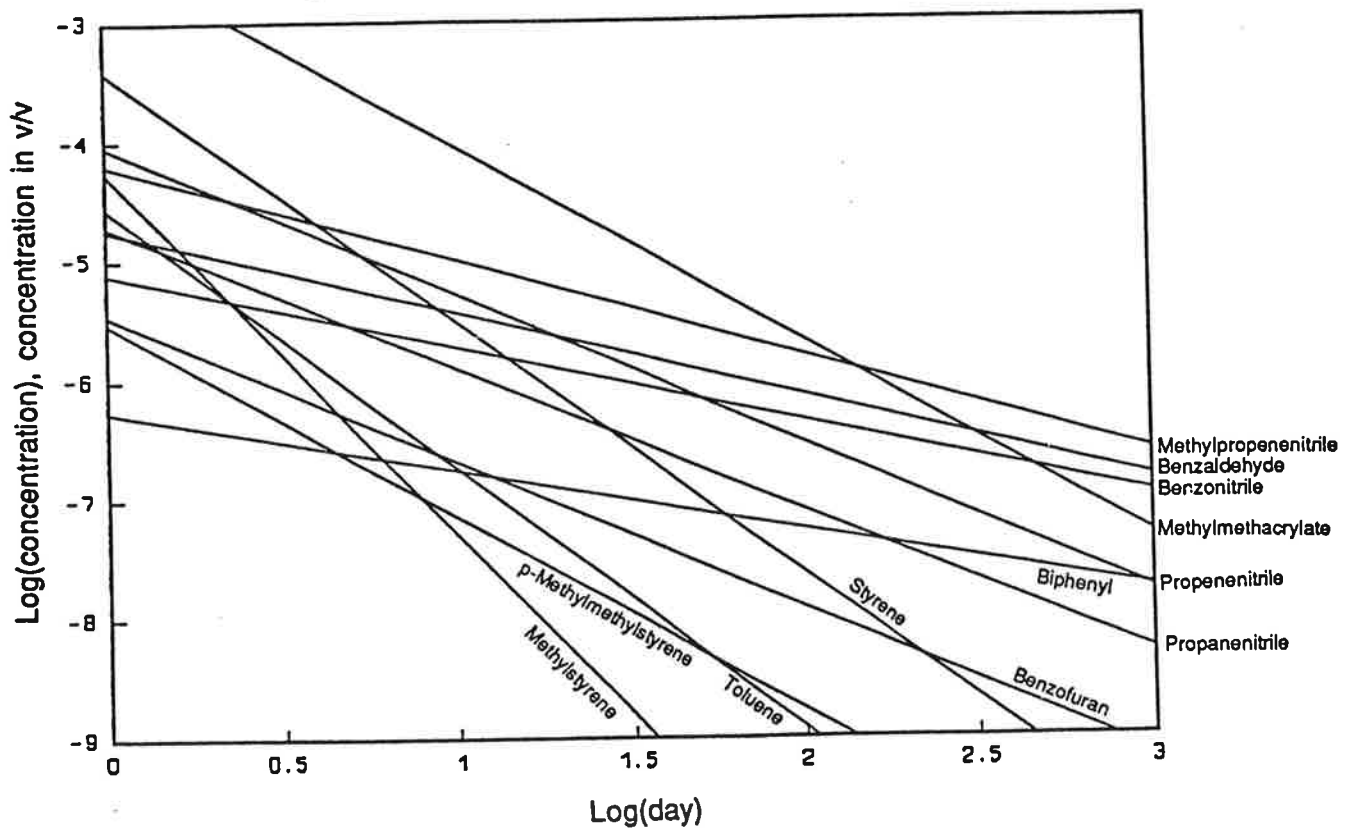

Figure 2. Decay of combustion products of mixed fuel burn, decay in 50% RH air.

Table 2. Average concentration in v/v × 10⁻⁹ of some organic compounds occurring in residential houses (not fire houses) and days required for the concentration of the experimental fires to decay to the average concentration.

Compound	Avg. Conc.	Log (Conc.)	Days
Methylethylketone	5.53	−8.257	57.
Benzene	3.04	−8.517	72.
Toluene	9.71	−8.013	38.
Styrene	0.52	−9.287	620.
Naphtalene	7.16	−8.145	2495.

Table 3. Organic compounds, concentration in v/v × 10⁻⁹ quantified in the air of refurbished fire buildings. Building numbers correspond with numbers in Table 4.

No.	Furfural	Benzene	Toluene	Xylenes	Hexanal	Pinene	Camphene	Limonen
1	0.02	13.1	19.5	18.8	4.5	4.5	1.1	4.8
2	0.23	1.6	11.6	16.8	3.0	2.3	1.9	2.9
3	0.00	1.6	2.6	9.7	0.2	0.0	0.0	0.0
4	0.00	12.8	8.1	0.0	0.0	5.6	22.0	0.0
5	0.00	4.9	16.7	13.5	29.2	29.5	37.3	36.7

Table 4. Details on buildings refurbished after a fire.

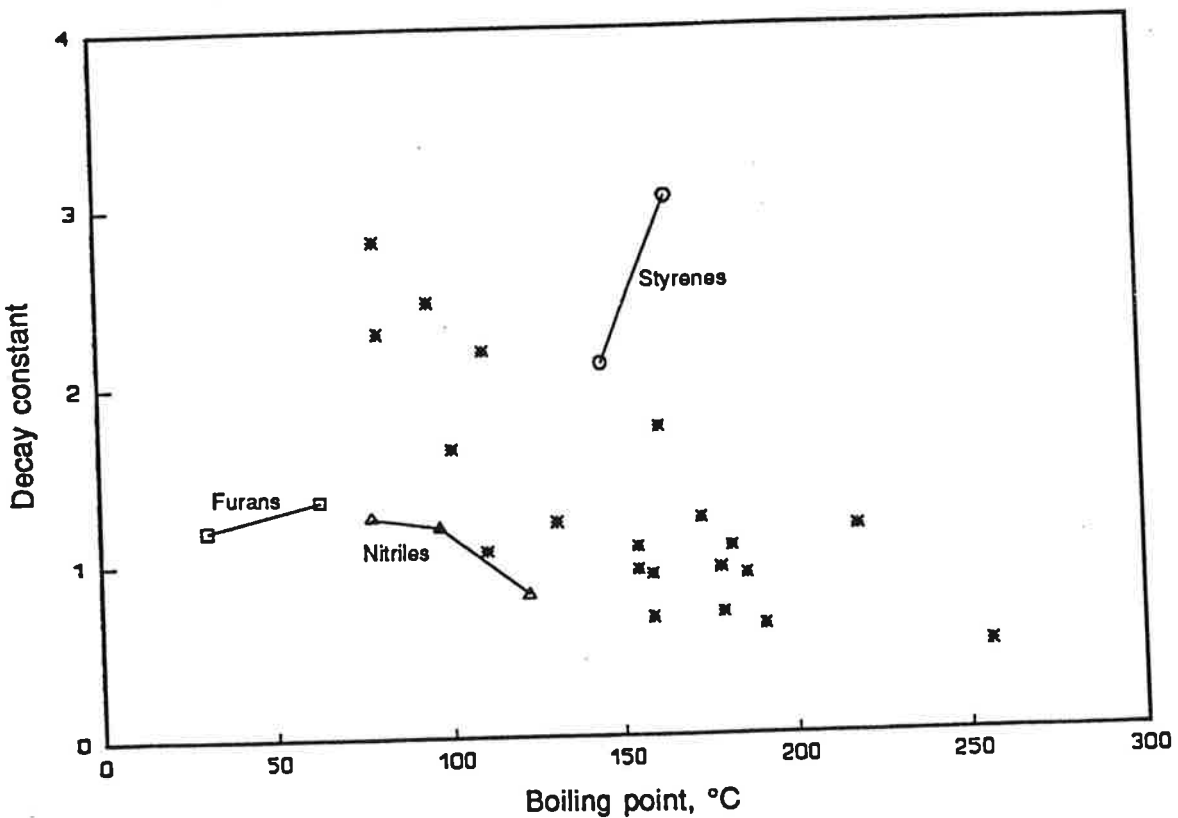| No.	Type of Building	Fire Date	Type of Fire	Analysis After Fire	TVOC* mg/m³
1	House	881014	Kitchen fire	40 days	2.0
2	House	880803	Kitchen fire	4 months	1.4
3	Office bldg.	860303	Major fire	16 months	0.4
4	Seniors' home	900101	Major fire	3 months	1.2
5	House	900427	Medium fire	5 months	4.8

* Total volatile organic compounds.

Figure 3. Boiling points versus decay constants for all the compounds in Table 1(a) wood burn and Table 1(b)
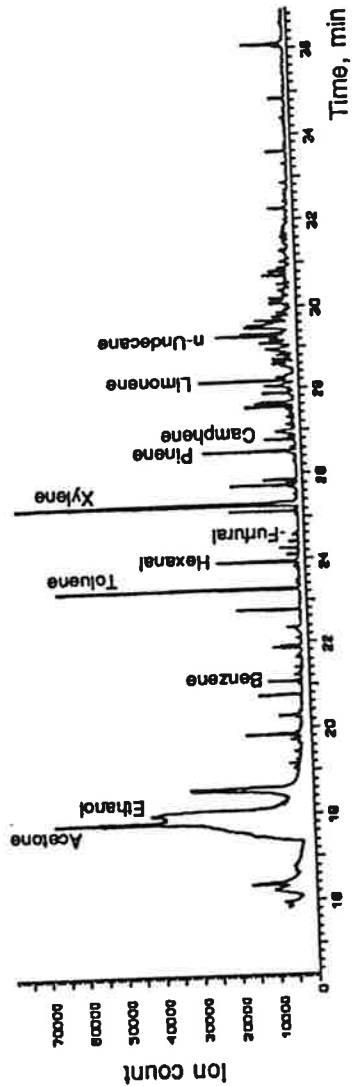
Compounds with low boiling points such as furans and ketones wer(
not detected. Quantities of hexanal and larger quantities of high boil
ing point terpenes were detected. These are common combustion prod
ucts of wood. In building #4, the concentration of camphene was un
usually high. It is suspected that the compound was from an externa
source such as deodorizer. Aromatic hydrocarbons such as benzene
toluene, and xylenes are commonly detected in indoor air and are com
mon combustion products of various plastics and hydrocarbons. Thes(
results are in line with the results of the box fire experiments.

Unpleasant Odour

Residents of refurbished houses after a fire may complain of unpleas
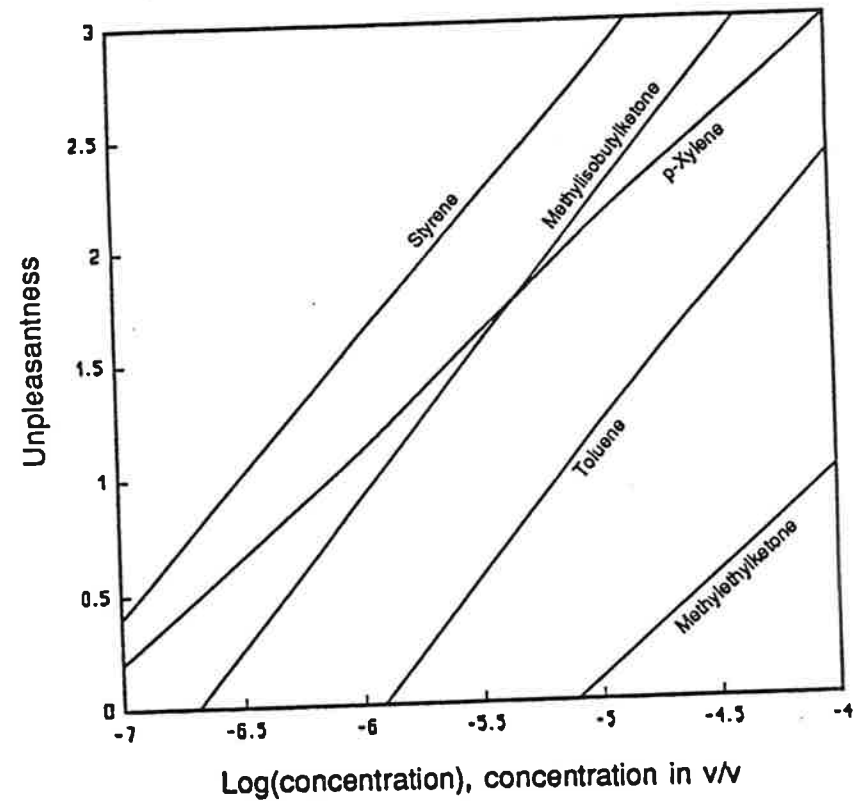ant odours. Nagata and others studied the relationship between con

Figure 4. Example of GC/MS analytical results of air in a fire, house #2 in Table 4, four months after a fire, TVOC = 1.4 mg/m³, December 1988.

Log(concentration), concentration in v/v

*Figure 5. Empirical relationship between concentration of odorous compounds an(
unpleasantness (from Reference 2).*

centrations of about 50 odorous compounds and their degree of unpleasantness to humans [3]. Unpleasantness in this case is an empirical scale for human perception with scale 3 being "very unpleasant" and 0, no perception. Figure 5 shows the empirical relationships between concentration and unpleasantness for five compounds commonly found after a fire. It is noteworthy that in order to reduce unpleasantness by a unit degree, concentrations have to be reduced by a factor of ten. This is why cleaning alone will not reduce odour effectively. Compared with decay data in Figure 2, it is estimated that styrene in the box experiment reach at unpleasantness degree 1 on day 31 and at degree 0 on day 77. Styrenes were relatively quick decaying compounds. More data on concentration-unpleasantness relationship for slow decaying combustion products produced in fires are required for further discussion of individual compounds.

Commercial deodorizers are commonly used after a house is refurbished. There is a wide variety of products containing many types of chemicals [4]. For example, typical ingredients are alcohols, glycol, glycol esters, hydrocarbons, organic amines, chlorohydrocarbons, surfactants, and fragrant compounds. Compositions of commercial products are not normally disclosed.

The mechanism of deodorizing in most cases is to mask the unpleasant odour by fragrance, not to reduce concentrations of odorous compounds [4]. Deodorizers will not reduce the toxic effects of inhaled compounds. The present author was consulted by a house owner who was suspicious about improper usage of deodorizers by the refurbishing contractor; chemical interactions of combustion products and deodorizing agents were suspected to have produced toxic products.

CONCLUSIONS

The concentrations of combustion products and number of days after fire showed good linear correlation on a log-log scale.

Slopes of the decay line on the log-log scale (decay constants) had a correlation with boiling points of combustion products, except for several types of compounds that may polymerize. The lower the boiling point the faster the decay.

In experimental wood fires, the decay of concentrations of combustion products in a 50% RH atmosphere was 2.5 times faster than in a dry atmosphere.

Some combustion products could remain in a house in noticeable con-

ACKNOWLEDGEMENTS

REFERENCES

1. 1990. "Fire Losses in Canada," *Labour Canada, Annual Report 1988*. Ottawa: Department of Supply and Services.
2. Chan, C. C., L. Vainer, J. W. Martin and D. T. Williams. 1990. "Determination of Organic Contaminants in Residential Indoor Air Using an Adsorption-Thermal Desorption Technique," *J. Air Waste Management Assoc.*, 40:62.
3. Nagata, Y., T. Ishiguro, T. Hasegawa, N. Takeuchi, O. Furukawa, S. Nakayama and Y. Shigeta. 1981. "Studies on the Relationship between Concentration of Odorants and Hedonic Tone," *Bull. Jap. Environ. Sanitary Center* (8):76 (in Japanese).
4. Slivka, D. C., R. Leverenz and T. R. Steadman. 1979. "Room Deodorizers and Air Fresheners: Market, Manufacturers, and Chemical Compositions," CPSC-C-78-0091, Task 11, Subtask 11.01. Columbus, OH: Battelle.

BIOGRAPHY

Yoshio Tsuchiya

Dr. Yoshio Tsuchiya is a senior research officer at the National Fire Laboratory, Institute for Research in Construction, National Research Council of Canada. His Bachelor of Engineering (1953) and Doctor of Engineering (1962) degrees from the University of Tokyo were based on studies on explosives. He is the author of over 70 papers in the fields of pyrolysis and combustion of polymers, fire gas toxicity, and indoor air quality.