POLLUTANT EMISSIONS FROM NEW ELECTRIC OVENS

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ABSTRACT

A procedure has been developed for assessing pollutants emitted from electric ovens and their insulations when new ovens are first operated at 250°C. The procedure allowed the quantitative measurement of the emissions under controlled conditions, such that the hazards from the emissions could be assessed and the emission performance of different insulations could be ranked. Distinct differences were observed for three insulated ovens, with two emitting significant quantities of formaldehyde that exceeded occupational exposure guidelines. No isocyanates were emitted from any of the ovens. Several VOCs exceeded environmental exposure goals and odour thresholds for the first 4 to 48 hours of operation of the ovens. Respirable particulate matter and carbon monoxide were also emitted, with a contribution from residual oil on heated metal surfaces. Also, several siloxane volatiles were emitted from wiring within the oven casing. Oven 'burn off' times need to be substantially longer than 4 hours to prevent hazardous emissions during initial appliance use.

INDEX TERMS

VOC, formaldehyde, new electric oven, insulation, chamber test procedure

INTRODUCTION

Researchers have investigated the impact of cooking on indoor air quality (IAQ) by emissions of gaseous combustion products and gases/fine particles from food items (CARB 2003). However, emissions from the cooking appliances themselves are largely unknown, even though manufacturers commonly instruct consumers to initially operate new ovens in well-ventilated spaces for approximately 4 hours to 'burn off' these emissions. Domestic ovens are manufactured from heat-resistant materials (stainless steel, metal enamels) and components (wiring, switches) and are well-insulated to ensure their function and to reduce energy consumption. Generally, these insulations consist of fibreglass or rockwool fibre bound with a resin such as phenol-formaldehyde. When first operated, some surface materials and oven insulations will be exposed to the operating temperatures of the oven (up to 250°C) or locally to higher temperatures (e.g. adjacent to electric elements) and thermal degradation emissions are likely. This study utilised CSIRO's room environmental chamber to develop a procedure for investigating pollutant emissions from new ovens, and used this procedure to provide better understanding of the emissions and the potential to reduce them by material selection. Specifically we investigated:

- the nature and duration of pollutant emissions from an electric oven insulated with rockwool/phenol-formaldehyde resin in the first 2 days of operation (to determine the adequacy of current 'burn off' advice),
- the potential contribution to these emissions from components other than insulation,
- the nature and duration of the emissions from the same oven with a rockwool/acrylic resin binder, and
- pollutant levels achieved in chamber experiments in comparison to occupational and environmental exposure criteria.

METHODS

Oven Description And Operation

A single oven was used for the whole study, the oven being returned to the manufacturer for re-insulation between experiments. This was a new, 'multi-function separate grill oven' from a large global manufacturer and had not been previously operated. The oven had a stainless steel body and a separate grill below the oven compartment. This grill was not operated in the testing and the grill door remained closed for all experiments. The oven (closed) was operated only from the start of each emission experiment, by setting the temperature to 250°C with the fan operating. The power drawn by the oven was measured with a Yokogawa Digital Power Meter (Model 2534) for one hour periods after the temperature had stabilised and this was generally ~1.2kWh. Pollutant emissions from

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this oven were assessed with three specific insulations from the manufacturer, which were as follows (in the order of assessment):

- Oven/Insulation A – rockwool insulation with a phenol formaldehyde binder resin which was originally formulated with ~10% free formaldehyde, subsequently reacted with ammonia to bind the formaldehyde;
- Oven/Insulation B – identical (same batch of product) to insulation A, to assess whether oven components other than insulation (e.g. residual oil on the metal surfaces, wiring/switches) may have contributed to emissions when testing insulation A; and
- Oven/Insulation C – a rockwool insulation with an acrylic binder.

Chamber Experiments

Pollutant emission experiments were carried out in CSIRO's room dynamic environmental chamber described in Brown (2004). This is a 4.0 m × 3.0 m × 2.7 m high room constructed of inert materials, with negligible sink effects for VOCs (Mason *et al*. 1999). Chamber air was temperature and humidity controlled to 25 ± 1°C and 50 ± 2% RH, and was set to a nominal ventilation rate of 1.0 air change per hour (ACH). The actual ventilation rate in the room chamber was determined during experiment by tracer gas decay (ASTM 2000) to be 1.1 ACH (due to oven heating effect). Air within the chamber was well mixed by recirculating air from floor level to ceiling level at a rate of 18 chamber volumes per hour. The air recirculation system was equipped with a chiller coil through which water at 16°C was circulated when the oven was operated. This chiller temperature was selected to prevent water condensation, so that loss of water-soluble pollutants was prevented. Under these conditions, the chiller coil removed approximately 5 MJ/h of heat to compensate for heat generation by the ovens.

Pollutant Sampling

Sampling and analysis methods are fully described elsewhere (Brown 2004).

Formaldehyde: fritted glass bubblers containing a sodium hydrogen sulfite solution were used to capture the formaldehyde from room chamber exhaust air, generally as 30 L samples.

VOCs: duplicate samples from the chamber exhaust air were collected onto Envirochem multisorbent tubes (containing Tenax TA/Ambersorb/Activated Charcoal), generally as 1-2 L samples, which were analysed by thermal desorption/GC-MS. The TVOC concentration was also estimated from the total GC peak area from 5 to 35 minutes (approximately C5-alkanes onwards and including ethanol but not methanol), expressed as toluene-equivalent concentration.

Organic Isocyanate: Air was sampled onto a filters impregnated with methoxy phenyl piperazine at 1-2 L/min for 30 min. The sample filters were analysed by a HPLC abbrev? method (HSE MDHS-25/2 'Organic Isocyanates in Air', The Barton Hygiene Laboratory, University of Adelaide, private comm.) providing a limit of detection of 2 μg/m3.

Carbon Monoxide, Respirable Particles and Hydrogen Cyanide; Carbon monoxide was monitored using a Q-Trak™ Model 8550/8551 IAQ Monitor (TSI Inc., USA). Respirable suspended particles (RSP) were measured using a Dustrak Model 8520 Aerosol Monitor (TSI Inc., USA) fitted with a nylon cyclone that provided a 4.0 μm cut-point for particle sampling. Hydrogen cyanide was monitored in a limited number of experiments using a Kittagawa gas pump/colorimetric tube No. 112SB Hydrogen cyanide (2-100 ppm).

RESULTS

All pollutant concentration measurements are presented in Tables 1 to 3.

A complex range of VOCs was emitted from the ovens, as well as formaldehyde, carbon monoxide, respirable particles and hydrogen cyanide (measured only for Oven/Insulation C). Table 4 summarises published exposure guidelines (occupational and environmental) for the pollutants measured in these experiments. It is seen that the new oven/insulation A caused chamber air concentrations that:

- were above occupational exposure standards for formaldehyde and respirable particles for 2-4 hours or more, and environmental goals for 1 day or more,
- were above odour thresholds for several aldehydes for over 4 hours and for 2,4-dichlorophenol for more than

2 days
- were associated with thermal degradation products (particles, carbon monoxide),
- contained high levels of several siloxanes, probably from wiring at elevated temperature.

***Table 1**. Emissions from oven with oven/ insulation A.*

POLLUTANT	ID[a]	Concentration (µg/m^3)					
		0.5h	1h	2h	4h	1d	2d
Formaldehyde	-	1600	2400	1800	850	110	37
Total Isocyanate	-	<2	<2	<2	<2	<2	<2
Carbon monoxide	-	8ppm	8ppm	4ppm	0	1ppm	0
Respirable particles	-	7,900	17,000	13,000	5,900	700	300
Acetone	T	270	520	370	140	18	14
Butanal or MEK	T	90	160	110	23	4	3
Benzene	C	20	30	24	13	1	1
1-Butanol	T	18	72	56	28	<1	<1
Acetic acid	C	240	120	280	68	7	2
3-Methylbutanal	T	52	92	65	28	3	2
Toluene	C	16	12	17	6	<1	<1
Hexanal	T	54	100	77	29	2	2
Hexamethylcyclotrisiloxane	T	51	89	95	64	37	4.2
Heptanal	T	57	120	77	34	4	2
Octamethylcycloterasiloxane	T	26	56	68	34	16	16
Phenol	C	80	110	86	59	27	12
Octanal	T	48	96	68	34	4	4
2-Hydroxybenzaldehyde	U	20	31	24	7	2	1
Nonanal	T	38	82	57	30	4	2
Decamethylcyclopentasiloxane	T	360	560	400	140	8.9	5.4
3-Hydroxy-2-methylbenzaldehyde	T	29	47	36	11	<1	<1
2,4-Dichlorophenol	T	46	93	62	32	3	2
Decanal	T	9	56	9	15	1	1
2,6-Dimethyl-4-hydroxybenzaldehyde	U	32	55	28	9	1	<1
Decamethylpentasiloxane	T	1800	3700	2400	880	28	15
Dodecamethylpentasiloxane	T	940	2100	1900	900	34	18
Tetradecamethylhexasiloxane	T	300	750	860	570	41	16
Hexadecamethylheptasiloxane	T	110	230	260	220	55	24
Other VOCs	-	<20	<30	<30	<20	<1	<2
TVOC	-	1900	5300	4200	1800	160	97

[a] compound identification: C = confirmed, T = tentative (good match of mass spectra), U= unknown (insufficient match of mass spectra)

In general, even with 2 days continuous operation this oven was still emitting particles and irritants, though most VOC emissions had diminished significantly.
Retesting this oven as oven/insulation B, it was found that:
- emissions of particles, carbon monoxide and to a smaller extent formaldehyde were reduced, showing that these emissions in the original oven were associated with thermal degradation of components in addition to the thermal insulation (e.g. oils on metal surfaces); and
- similar pollutant emissions occurred for most other pollutants, confirming that a 4 hour ‘burn off’ was generally inadequate.

Retesting the oven as oven/insulation C, it was found that:
- formaldehyde emission were almost eliminated since an acrylic binder was used in the insulation; and
- carbon monoxide and respirable particle emissions increased c.f. insulation B, showing that thermal degradation of the acrylic binder was occurring (a factor confirmed by the hydrogen cyanide measurements).

Table 2. *Testing of oven with oven/ insulation B*

POLLUTANT	ID	Concentration (μg/m^3)			
		0.5h	1h	2h	4h
Formaldehyde	-	1,200	1,900	1,300	700
Carbon monoxide	-	5ppm	6ppm	4ppm	0
Respirable particles	-	900	3,000	4,200	2,700
Acetone/propanal	T	270	440	290	140
Butanal/MEK	T	45	140	76	23
Benzene	C	25	49	10	12
1-Butanol	T	5.6	9.2	6.3	1.7
Acetic acid	C	15	120	42	52
3-Methylbutanal/pentanal	T	61	92	53	28
Toluene	C	9.1	14	5.9	2.1
Hexanal	T	42	85	53	28
Hexamethylcyclotrisiloxane	T	40	80	92	50
Heptanal	T	48	91	55	28
Octamethylcycloterasiloxane	T	430	670	400	100
Phenol	C	95	110	48	44
Octanal	T	35	69	47	22
2-Hydroxybenzaldehyde	U	25	47	20	15
Nonanal	T	47	100	44	24
Decamethylcyclopentasiloxane	T	2,400	3,900	2,400	780
3-Hydroxy-2-methylbenzaldehyde	T	9.0	18	11	2.7
2,4-Dichlorophenol	T	15	29	18	6.4
Decanal	T	21	42	28	13
2,6-Dimethyl-4-hydroxybenzaldehyde	U	13	28	15	3.2
Decamethylpentasiloxane	T	1800	3500	2400	930
Dodecamethylpentasiloxane	T	660	1500	1200	560
Tetradecamethylhexasiloxane	T	180	500	480	310
Hexadecamethylheptasiloxane	T	55	150	140	130
TVOC	-	3,000	5,700	3,800	1,600

Table 3. *Testing of oven with oven/insulation C*

POLLUTANT	ID	Concentration (μg/m^3)			
		0.5h	1h	2h	4h
Formaldehyde	-	<10	120	<10	380
Carbon monoxide	-	12ppm	15ppm	11ppm	3ppm
Respirable particles	-	2,000	4,700	5,100	2,600
Hydrogen cyanide	-	4ppm	10ppm	4ppm	<0.5ppm
Propanal	T	290	500	380	220
Butanal	U	61	76	<40	<20
MEK	U	79	120	79	35
Isopropyl methyl ketone	U	270	550	210	79
Benzene	C	110	n.a.	110	59
Pentanal/alcohol	U	41	200	100	59
1-Methylpyrrole	T	85	<70	75	60
Toluene	C	37	45	10	<10
Pyridine sulfur trioxide	T	460	380	590	280
2-Methyl pyridine	T	55	68	35	<16
3-Methyl pyridine	U	38	56	37	<16
Phenol	C	200	250	150	69
3-Methyl phenol	U	54	<50	<30	<20
Decamethylpentasiloxane	T	120	240	230	150
Dodecamethylpentasiloxane	T	<60	160	160	120
Tetradecamethylhexasiloxane	T	<60	<80	100	87
Hexadecamethylheptasiloxane	T	<60	<90	<60	52
TVOC	-	2,400	3,800	2,300	1,100

DISCUSSION

In general it is found that a new electric oven can emit significant quantities of pollutants (of diverse types) for substantially greater than 4 hours. Assuming that the oven operated in our 34m^3 chamber is realistic for some buildings (e.g. small apartment kitchens), the pollutant levels occurring during oven start-up were higher than occupational and environmental exposure criteria for many air pollutants, and would be sufficient to cause mucosal irritation and other health effects to occupants, probably for days to weeks depending on the extent of oven operation. Formaldehyde emission was virtually eliminated by selecting an acrylic binder for the oven insulation, but thermal degradation of this binder still led to emissions of health concern to building occupants (notably particles, carbon monoxide and irritant aldehydes). It was interesting to note that benzene emissions from the acrylic bound insulation (chamber concentrations 60-110 µg/m^3) were much higher than observed with the phenol-formaldehyde binder (10-50 µg/m^3). The development of an electric oven that will not lead to high levels of hazardous pollutants is considered the optimum approach to this problem, rather than the current manufacturers' advice of 'burn-off' for 4 hours. In any case, a burn-off of a day or more is considered advisable based on this limited investigation.

***Table 4:** Occupational and environmental exposure criteria for air pollutants.*

Pollutants	Exposure Criteria (µg/m^3)		
	Occup TWA[a]	Envir[b]	Odour[c]
Formaldehyde	1200	100	1,000
Total Isocyanate	20	-	16,000
Carbon monoxide	30ppm	9ppm	-
Hydrogen cyanide	10ppm	-	0.6ppm
Respirable particles	2,000	50	-
Acetone	$1.2{\times}10^6$	36,000	14,000
Propanal	-	-	14
Butanal	-	-	28
MEK	$4.5{\times}10^5$	390	870
Isopropyl methyl ketone	$7.1{\times}10^5$	-	16,000
Benzene	1,600	15	33,000
1-Butanol	$1.5{\times}10^5$	360	90
Acetic acid	25,000	2,500	43
Pentanal	-	-	22
Hexanal	-	-	58
Heptanal	-	-	23
Toluene	$3.8{\times}10^5$	1,400	640
Pyridine sulfur trioxide	(16,000)	800	-
2-Methyl pyridine	-	-	14
Phenol	4,000	90	430
3-Methyl phenol	-	-	1
Octanal	-	-	7
Nonanal	-	-	14
2,4-Dichlorophenol	-	-	0.1
Decanal	-	-	6
TVOC		300-2,000	-

[a] Worksafe Australia occupational exposure standards
[b] air quality (indoor, outdoor) goals (Brown 2000)
[c] VOCBase Version 2.1, B. Jensen & P. Wolkoff (1996) National Institute of Occupational Health, Denmark

CONCLUSION AND IMPLICATIONS

A procedure has been developed for assessing pollutants emitted from electric ovens when first operated. The procedure allows quantitative measurement of the emissions under controlled conditions, such that the hazards from the emissions can be assessed and the emission performances of different insulations ranked. Distinct differences were observed for the three ovens assessed, with A and B emitting significant quantities of formaldehyde, exceeding occupational exposure guidelines. Also, these two ovens exhibited differences in emissions of carbon monoxide and respirable particles showing that residual oils on metal surfaces also contributed to emissions. While oven C emitted virtually no formaldehyde, it appeared more susceptible to thermal degradation and was a larger source of benzene. Further research and product development is recommended to produce electric ovens that do not emit hazardous pollutants.

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