Nitrogen dioxide (NO$_2$) emissions from low NOx flueless gas space heaters – a field study$^1$

Ibrahim Tas  
SAI Global, Sydney, Australia  
Email: ibrahim.tas@saiglobal.com

SUMMARY  
Flueless gas space heaters, burning natural or liquefied petroleum gas, vent their combustion products into the space they heat and are therefore subject to a limit on the NO$_2$ they can emit before being certified as being acceptable under the Australian Standards used for the Australian certification scheme. Nitrogen dioxide is a by-product of combustion, and it is one of the common air pollutants regulated for health reasons. All modern flueless gas space heaters have to comply with the emission requirements prescribed by the standards and regulations. The main focus of this study is ‘emission class 1’ flueless gas space heaters, which emit levels of NO$_2$ less than or equal 2.5 ng/J. The study utilised two different measuring techniques to measure NO$_2$ levels, direct-reading instrumental method (using a chemiluminescence analyser) and passive gas badge sampling, to measure NO$_2$ levels in the homes studied. Most health-based studies tend to use passive badges because they are inexpensive and convenient to use for longer-term exposures, only lacking information on peak exposure. This study is one of the firsts to apply both techniques to determine the level of NO$_2$ in a home arising from the use of flueless gas space heaters.

KEYWORDS  
Unflued, passive badge sampler, surface combustion burners, pollutant, indoor air quality

1 INTRODUCTION  
Nitrogen dioxide is a by-product of combustion, and it is one of the common air pollutants regulated for health reasons. Flueless heaters, burning natural gas or liquefied petroleum gas (LPG), emit their combustion products into the space they heat and are therefore subject to a limit on their levels of nitrogen dioxide (NO$_2$) emission before being certified. It should be noted that the mass-balance method is used to predict the room concentration of a NO$_2$ due to presence of a flueless heater in the room. The model assumes a well-mixed chamber and outdoor NO$_2$ concentration to be additive (Tas, 1998).

Among other countries, flueless heaters are widely used in the USA, Japan and Australia. In Australia, a maximum allowable emission rate of 15 ng/J NO$_2$ from flueless gas space heaters was introduced in 1989. This limit was subsequently reduced to 10 ng/J, then 5 ng/J NO$_2$ (which still remains the limit for ‘emission

$^1$The bulk of this study was conducted while the author was employed by Jemena in its gas appliances research and testing laboratory in Sydney.
class 2’ flueless heaters) and then 2.5 ng/J NO₂ in 2008 for emission class 1 flueless heaters, Standards Australia (AS 4553, 2008). Prior to 1989, simple blue-flame bar burner technology, where gas (partially premixed with air) burns as a series of “Bunsen-type” flames along a tube was common. Blue-flame burners usually produce relatively high emissions of nitrogen oxides (NOx), varying from 30 to 50 ng/J, 20 to 40% of which can appear as NO₂. Radiant or tile burners, because of their cooler flame temperatures, produce much less NOx, under 10 ng/J, and the emission rates of nitrogen dioxide are typically 3 to 7 ng/J. Heaters with these burners are usually known as emission class 2 low-NOx heaters. Heaters with multi-layer metal/fibre mesh or ceramic based surface combustion burners, which are the subject matter of this study, are able to emit 2.5 ng/J or less NO₂, which are now known as emission class 1 flueless gas heaters. It is worth noting that, so far, the class 1 flueless heaters, tested in Australia, have proved to be low in total NOx as well as being very low in NO₂ emissions.

2 STUDY BACKGROUND
A field study conducted on behalf of the Department of the Environment and Heritage endeavoured to determine the impact of flueless gas-heating appliances on the indoor air quality within Australian homes (AWN Consultants & Team Ferrari Environmental, 2004). The results showed that in two-thirds of homes tested, levels of nitrogen dioxide were above the World Health Organisation (WHO 2006) guideline limit of 110 ppb (parts per billion). Whilst these findings might be indicative of some flueless gas-heating appliances, a limitation of the study was the lack of differentiation of the data collected from homes using the emission class 1 flueless heaters.

In another study (Pilotto et al. 2004), where essentially old flueless gas heaters were the subjects, NO₂ had been determined by the passive badge sampling technique. The 6-hour average concentrations of nitrogen dioxide in classrooms with flueless gas heaters ranged from 12 – 116 ppb (average 47 ppb). Bromly and Zhang (2004) noted that it was not clear how readings as low as 12 ppb could have been obtained with an out-dated flueless gas heater.

The objectives of this study were:
- To determine the contribution of emission class 1 flueless gas heaters to indoor NO₂ (nitrogen dioxide) levels
- To compare nitrogen dioxide concentration results using the passive badge sampling with those obtained by the direct-reading instrumental method
- To evaluate the emission performance of emission class 1 heaters with that of an old blue-flame heater
- To investigate the ventilation levels in the homes tested.

3 FIELD TESTING
Two different brands of emission class 1 flueless space heaters were used in this investigation. On one occasion, an obsolete blue-flame flueless heater was also included in the program to provide a comparison. All heaters were tested in an accredited laboratory for their NO₂ emission rates before being taken out to the field. The emission class 1 heaters were found to emit 2.5 ng/J NO₂ or less, while the “blue-
flame” heater was found to emit 9 ng/J NO₂. The field-testing was conducted in four homes within the Sydney metropolitan area. The choice of houses was consistent with the range of houses found in Sydney.

The nitrogen dioxide measurements were made by two different methods: direct-reading instrumental method (chemiluminescence analyser used) and passive badge sampling. An infrared analyser was used to measure CO₂ concentration. The analysers were operated continuously for the duration of the test and the results were recorded. The badge samplers were provided and after use analysed by the Atmospheric Research Division of the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Ecotech Pty Limited, the manufacturer and supplier of chemiluminescence and infrared analysers, provided the analysers and conducted the entry and exit calibrations of the analysers at each site. Two stands were used to collect samples within the room. The collection points, simulating the position of seated occupants, were at a distance between 1.7 m to 3.3 m from the heater, at a height of about 1.5 m from the floor. Each collection point also had a thermocouple to measure room temperature and a passive gas sampler to determine the 6-hour average NO₂ concentration. A thermocouple was positioned near the heater’s air intake and another thermocouple was used to monitor the outside temperature during the testing period. The occupants were asked to operate the heaters exactly in the same manner as they would their own heaters, except that the heating period had to be six hours long, the period needed for passive badge sampling. When higher than normal seasonal outdoor temperatures existed, the heater thermostats were set higher than the occupants’ choice to ensure uninterrupted operation of the appliance throughout the testing period.

The infrared analyser monitoring CO₂ concentration was kept running, after the heater had been turned off, to record the steady dilution of CO₂ by ventilation. The dilution in the concentration of CO₂ in a room is a good indicator of the room’s ventilation rate.

4 RESULTS and DISCUSSIONS

Room NO₂ Concentrations

Four houses were selected for the study. The morning heating session results, conducted on three consecutive days in one of these dwellings, are presented in Figures 1, 2 and 3. These figures contain the plots of hourly averages of NO₂ (measured by the analyser), CO₂, and inside and outside temperatures while the heaters were operating. The line of WHO guideline for NO₂ is also superimposed.

The room concentrations of NO₂ by these low NOx heaters were below the WHO guideline, Figure 1 and 2, whilst the obsolete blue-flame heater produced levels well above the WHO guideline, Figure 3. These results clearly demonstrate the improvement in the flueless gas space heaters technology, and the level of success in reducing the nitrogen dioxide emissions of these heaters. A close examination of the graphs will show that the results of the blue-flame heater are several times higher than the low NOx heaters tested under similar conditions. In almost all testing situations, the low NOx flueless heaters were able to sustain comfortable indoor temperatures with NO₂ levels being in the vicinity of the WHO guideline.
Figure 1. Emission Class 1 Flueless Heater (Brand A)

Figure 2. Emission class 1 Flueless Heater (Brand B)

Figure 3. Blue-flame Heater (Brand C - obsolete)
**NO₂ Measurement - Direct-reading Instrumental Method vs Passive Badge Sampler**

Most health-based studies tend to base health effects against longer-term (6-hour) exposures (AWN Consultants & Team Ferrari Environmental, 2004), hence it is prudent to have some data to compare passive badge sampling with the direct-reading instrumental method as passive badge method is widely used by researchers in this field. The six-hourly averages of NO₂ results from both chemiluminescence NOx analyser and passive badge samplers are plotted in Figure 4 below.

![Figure 4 Six-hour average NO₂ concentrations obtained from passive badge samplers and chemiluminescence analyser](image)

**Notes**
1. Passive badge samplers analysed by the CSIRO Atmospheric Research.
2. WHO guideline limit 110 ppb.
3. Test Nos 13 and 14 belong to the obsolete “blue-flame” heater.

The six-hour average NO₂ concentrations obtained by the passive badge sampling method are higher than the results obtained via chemiluminescence analyser measurement. This raises the possibility of overestimation of six-hour average NO₂ concentrations by passive badge sampling.

**Ventilation Rates**

Residential ventilation rate has become the subject of considerable interest as ventilation is the most significant means of removing indoor air pollutants. Despite the significance of indoor air quality from both energy and health perspectives, little is known about Australian residential ventilation rates.

The measurement of ventilation rate, when related to the use of gas appliances, is a complex issue and in this study it was simplified by continuing to record the decay in the level of carbon dioxide (CO₂) in the room for several hours after the heater had been turned off. This is assumed to produce reasonably representative results, since carbon dioxide is a non-reactive gas, the only mechanism to remove CO₂ discharged...
into a room by a flueless gas appliance would be the ventilation of the room. It is, of course, acknowledged that the loss of thermal head after the heater has been turned off would affect the ventilation rates, as would changes in external weather conditions. The rooms tested were communicating with one or more other rooms in the house. That is, they have had one or more unhindered openings to the other room(s) in the house. This condition has also significant effect on the ventilation of the room. From the CO₂ decay curves plotted, after the heater being turned off, average ventilation rates calculated were 1.1, 0.8 and 1 ach (air change per hour), respectively for the dwellings numbered 2, 3 and 4. Therefore it is fair to infer the existence of, on average, a ventilation rate about 1 ach during the field this field investigation.

5 CONCLUSIONS
The conclusions of this study can be summarised as follows:

- Emission class 1 flueless gas space heaters with NO₂ emission rates 2.5 ng/J or less were able to meet the WHO indoor air NO₂ guideline of 110 ppb NO₂. Only on few occasions did the NO₂ concentration in the space being heated slightly exceeded the guideline.
- The six-hour average results from passive gas badge samplers exceeded those obtained by a chemiluminescence analyser in the majority of cases. Although this requires further investigation, these findings give rise to concerns on the accuracy of badge sampling, which has been the only measurement technique of some past studies.
- The ventilation rate in the Sydney homes studied came out to be about 1.0 ach.

ACKNOWLEDGEMENT
The author would like to thank the Gas Appliance Health & Safety Council of Australia (GAHSCA) for the conception of and partially funding the study, CSIRO for providing badge samplers and analysing them after use, Ecotech for their assistance with the NOx and CO₂ analysers during the field testing.

6 REFERENCES
AWN Consultants & Team Ferrari Environmental 2004: Flueless Gas Appliances and Air Quality in Australian Homes Study, Department of the Environment and Heritage, Canberra, ACT.
Bromly J. and Zhang D. 2004: Comments on Published Paper Dealing with Flueless Gas Space Heaters in Schools by Louis Pilotto and Co-authors, Centre for Fuels and Energy Curtin University of Technology, Perth, WA.