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Manatū Mō Te Taiao

Warm Homes Technical Report

Real-life Emissions Testing of Pellet Burners in Tokoroa

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Warm Homes Technical Report: Real-life Emissions Testing of Wood Burners in Tokoroa

Ministry for the Environment
Manatū Mō Te Taiao

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1 Introduction

The Warm Homes project was set up by the Ministry for the Environment to look at ways to encourage New Zealand households to move to cleaner heating sources and increase household energy efficiency, and overall to encourage warmer and healthier homes.

The aim of this study was to gain a better understanding of emission factors[1] for wood-pellet burners. Wood-pellet burners were chosen because there is very little data on their real-life emissions. These burners are an emerging technology in New Zealand and their numbers are expected to grow, which will make it increasingly important to have an understanding of their emissions and how these may affect an air shed.

Of the four wood-pellet burners tested, one was found to be faulty. The average emission from the faulty burner was 11.35 g/kg, which was much higher than the other three burners and brought the average emissions from the four burners to 3.9 g/kg. Excluding the emissions from the faulty burner the average emission was 1.4 g/kg.

The Ministry recommends that the emission factors for pellet burners calculated in this report be applied in air shed modelling because they represent the best available information on real-life emissions in New Zealand. In doing so, users will need to assume a percentage of faulty burners to realistically approximate real-life emissions. However, as with all emission factors based on limited data, we advise caution. It is important to take into account the small sample size, test methodology, faulty burners and narrow range of burner designs covered.

[1] 'Emission factor' refers to a unit of particulate matter (PM_{10}) discharged for every unit of fuel consumed. The emission factors in this report are expressed in grams of particulate per kilogram of fuel burnt where the weight of fuel is expressed on a dry weight basis.

2 Methodology

2.1 Selection of heaters

All households involved in the study were participants in a Warm Homes pilot project funded by the Ministry for the Environment. Households were selected on the basis that they had a suitable heater and were willing to participate in the emissions testing programme. As part of the programme, chosen households had a pre-1994 wood burner replaced with a pellet burner supplied by Nature's Flame. Of the four burners tested, three were Sherwood Industries EF2 free-standing fires and one was a Sherwood Industries EF3 Meridian free-standing fire.

2.2 Fuel

All householders fuelled their burners with pellets from Nature's Flame. Pellets from both plants (Rotorua and Christchurch) were burned during the testing. The onsite technician noted that pellets from the Rotorua plant appeared to be longer, resulting in lower feed rates and reduced outputs.

2.3 Emissions sampling

A portable emissions sampler was installed in each household for the duration of the tests. Results from the sampler can be used to calculate an emissions rate in g/kg (dry wood basis) independently of any information recorded by the householder. The method employed by Applied Research Services is based on the Oregon Method 41 (OM41), also known as the Condar Method. Filters on the sampler were changed daily, and the sampler was run for seven days in each household. Further details on the sampler are given in Appendix 2.

3 Results

Results from the study are summarised in Table 1. The emissions rate in g/kg is obtained directly from measurements recorded by the portable emissions sampler. This shows the grams of particulate emissions per kilogram of fuel burned, where the fuel weight is expressed on a dry weight basis. This is the same as used in AS/NZS 4013 for laboratory measurements of particulate emissions.

Table 1: Summary of results for pellet burners

Heater	Manufacturer	Model	Average emissions rate (g/kg)	Pre-1994 heater replaced*
1	Sherwood Industries	EFIII Meridian	1.54	1
2	Sherwood Industries	EFII	11.35	3
3	Sherwood Industries	EFII	1.09	6
4	Sherwood Industries	EFII	1.95	7

* This is the number of the heater from Environment Waikato 2006,[2] which describes the results of emissions tests on households participating in the Warm Homes Pilot Project before removal of their pre-1994 wood burner.

[2] Environment Waikato 2006, *Real-life Emissions Testing of Pre-1994 Woodburners in New Zealand*, Environment Waikato Technical Report 06/05. See Appendix B.

4 Discussion

4.1 Heater number 2

The result for heater number 2 appeared to be anomalous. On further inspection it was found that the heater had suffered from damage and incorrect operating procedures, which would have led to pellets smouldering in the firebox outside the burn pot and in the ash drawer. It is likely that this would have led to the high emission results observed for this heater. Pellets can not pass directly to the ash drawer from the firebox under normal conditions. It is possible that the pellets were placed in the ash drawer by the householder.

4.2 Emissions factor

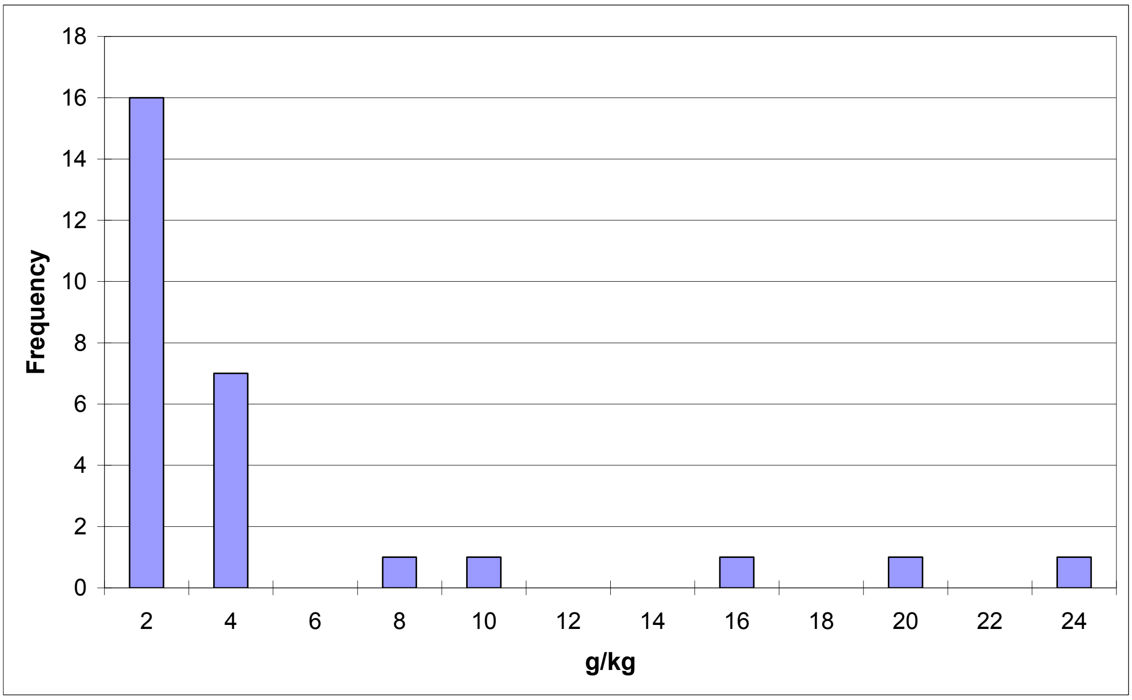
Appendix 1 provides the raw data from the 28 test runs, and this data is presented in the form of a histogram in Figure 1. This shows that the data is positively skewed, with a long tale to the right-hand side. In this case, pellet burner number 2 represents all five data points that form the tail in the histogram.

Emission factors are mainly used to calculate emissions inventories. Emissions inventories tend to calculate total emissions as emissions per kilogram of fuel, multiplied by total kilograms of fuel burned per time period, multiplied by the number of such burners in an air shed. This calculation is then summed with the emissions from all other types of solid fuel burners, and other sources.

Although the median may be useful as a descriptive indicator of central tendency, it is not the appropriate figure to report if one wishes to use the results to develop an emission factor. Therefore, only the mean is reported; specifically, the mean of the mean of each individual pellet burner is calculated. This estimation method avoids biasing the overall mean estimate towards the mean of the burner with the most observations.

To account for the affects of burner number 2, two cases are presented and results are presented including and excluding burner number 2. This gives an average of 3.9 g/kg and 1.4 g/kg, respectively. The 95% confidence interval around the mean is 3.9 g/kg ± 7.9 g/kg and 1.4 g/kg ± 0.7 g/kg respectively (see Appendix 2).

Figure 1: Distribution of emissions



4.3 Fuel

Until recently most of the pellet fuel used in New Zealand was produced at a single plant near Christchurch. As a result, the fuel produced was relatively uniform. As with wood stoves, pellet burners tend to be optimised with a given fuel. As noted above, pellets produced recently by a plant in Rotorua appeared to be longer than those produced in Christchurch, with the result that they were fed more slowly by the auger. This had the effect of causing a noticeable decrease in the output of the appliance and is likely to have affected the emissions as well.

Other factors that may affect the performance of a pellet fuel include density, composition and moisture content.

5 Conclusions

As part of the Warm Homes trial in Tokoroa, emissions from four pellet burners were tested *in situ* under real-life conditions. This has provided valuable information that has not been available before in New Zealand. Previously emissions data for wood-pellet burners has been based on laboratory results and overseas data.

The real-life testing revealed the presence of a pellet burner that was not working correctly. This meant that the data contained several outliers, which are probably not representative of the wider population of pellet burners. To account for this situation, means were calculated with and without the faulty burner. These were 3.9g/kg and 1.4g/kg respectively. Air quality practitioners are recommended to make their own assumptions about the number of faulty pellet burners in the underlying population when preparing emissions inventories.

The Ministry recommends that the emissions factors for pellet burners calculated in this report be applied in air shed modelling because this represents the best available information on real-life emissions in New Zealand to date. However, as with all emission factors based on limited data, we advise exercising caution. It is important to take into account the small sample size, test methodology, faulty burners and narrow range of burner designs covered.

Appendix 1: Results of Individual Test Runs

Table A1: Results of individual runs

Heater	Emissions rate (g/kg)	Average
1	0.88	
	0.91	
	1.21	
	3.02	
	1.58	
	2.21	
	0.95	1.54
2	3.78	
	2.33	
	6.63	
	19.78	
	14.57	
	9.77	
	22.57	11.35
3	0.98	
	1.19	
	1.39	
	1.09	
	0.76	
	1.23	
	0.98	1.09
4	0.88	
	0.96	
	1.13	
	2.01	
	1.58	
	3.00	
	2.02	1.65

Appendix 2: Estimating the Emissions from Wood-pellet Burners

Four wood-pellet burners were tested on 28 occasions and their emissions measured. One burner was determined to be working improperly and its emissions were unusually high. To estimate the total emissions from all pellet burners in a population, the mean emissions from a pellet burner (estimated from the sample) should be multiplied by the estimate of the number of appliances in the population and by an estimate of the average household usage. The mean should be used in this exercise because the aim is to estimate the total emissions. The total emissions cannot be determined from the median emissions of a new burner.

Even though the distribution of emissions from new burners (in real-life situations) is skewed, we can use Student's t-distribution to obtain a confidence interval for the mean. The Central Limit Theorem and robustness studies indicate that the mean of four observations is close to a normal distribution, even when the underlying distribution is skewed.[3] We use the t-distribution to estimate the confidence interval because the standard deviation is unknown.

This confidence interval is accurate if the sample of the pellet burners is representative of the population of pellet burners; that is, if the brands and models used in the sample testing are similar to the brands and models used in the population.

Table A2: Mean emissions (g/kg) of individual pellet burners

Burner	1	2	3	4	Mean (with burner #2)	Mean (without burner #2)
Mean emissions	1.54	11.35	1.09	1.65	3.91	1.43

The 95% confidence interval for the mean was calculated, as follows. With burner number 2:

$$\overline{X} \pm t_3\, s/\sqrt{4} = 3.91 \pm 3.182 \times 4.97/2 = 3.91 \pm 7.90$$

Without burner number 2:

$$\overline{X} \pm t_2\, s/\sqrt{3} = 1.43 \pm 4.303 \times 0.30/\sqrt{3} = 1.43 \pm 0.74$$

Since improperly functioning burners are likely to occur in practice, but at a lower rate than 25%, the true mean emissions of wood-pellet burners is likely to be somewhere between the two estimates.

[3] Moore D. 2004. *The Basic Practice of Statistics*. New York: WH Freeman & Company.

Appendix 3: Portable Emissions Sampler

Based on Applied Research Services Technical Bulletin 72 (2005)

The portable emissions sampler captures particulate emissions using a method based on Oregon Method 41 (OM41). This method is also known as the Condar Method.

Principle of operation

The sampling head includes a dilution system to dilute and cool the flue gas. This simulates the dilution and cooling that occurs when flue gases mix with ambient air, and results in condensation of oily compounds such as polyaromatic hydrocarbons, which can then be captured on the filter.

Flue gases are drawn into a manifold through the sample probe. Dilution air is also drawn into the manifold through small holes in its face. The diluted gases are then drawn through two filters, which collect the particulate emissions.

Details of the sampler

General

The sampler includes a sampling head (detailed below), which captures the sample of particulates. In addition, flue temperature is measured, flue gases are analysed continuously for oxygen and carbon dioxide content, and the carbon dioxide content of the diluted gas stream is analysed. The sampler also contains gauges to monitor and set gas flows through the sample head and flue gas analysers, canisters of drying agent to remove water vapour from the gas streams, a gas meter to quantify the sample flow, and a vacuum sensor to monitor filter loadings.

The sampler contains two analysis trains, which are programmed to start and stop at a flue temperature of 100°C. The calculation of the emissions rate is made using results from both analysis trains. The first sampling train draws diluted flue gases on to a filter and gives the weight of particulates per litre of flue gas (Wp/V). The other sampling train performs a gas analysis, which gives the volume of flue gas per kg (dry weight) of fuel burned (V/Wf). This is done directly from the analysis and does not rely on a knowledge of how much fuel was burned.

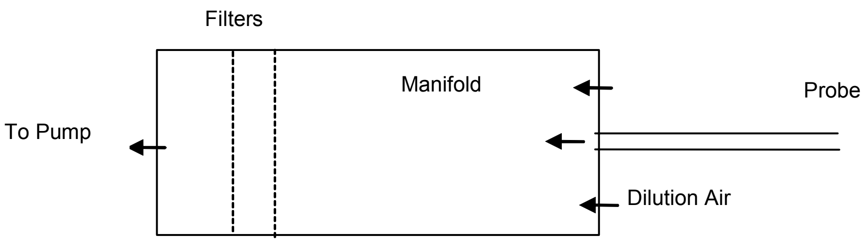
The chemistry of the process means a fixed amount of fuel requires a well-defined volume of air to burn it completely and generate a known volume of flue gas. If exactly this amount of air is supplied, then the volume of flue gas produced per kg of fuel burned is also known. Under these conditions the flue gases contain no oxygen (it would have all been used up). In reality additional air is supplied. This additional air will dilute the flue gases and result in a measurable amount of oxygen in the flue gases, which allows the degree of dilution to be calculated and hence the actual volume of flue gas per weight of fuel burned.

Dividing the first result by the second ([Wp/V]/[V/Wf]) gives the emissions rate (Wp/Wf). Filters on the samplers were changed daily, and where possible the sampler was run for seven days in each household. The sampler is interfaced to a laptop computer, which activates the sampling pump when the heater is operated and the flue temperature rises. The computer is also used to log data.

Sampling head

The sampling head consists of a stainless steel dilution manifold (length 100 mm, internal diameter 49 mm) fitted with two end caps. One end cap is fitted with a short probe with a glass insert. The probe is inserted into the flue so that the inlet is near the flue centre. Dilution air is admitted to the manifold via 12 x 1 mm diameter holes in the face of the end cap. The sample is collected on two 47 mm glass fibre filters (Gelman Type A/E Cat No 61631) mounted on two filter holders fitted to the other end cap of the manifold.

Figure A1: Schematic of sampling head



Apart from the probe and manifold assembly, the sampling assembly is the same as used in AS/NZS 4012/3. As with NZS4013, two glass fibre filters are used to collect the particulate materials. The flue gas composition is also measured, and is used to calculate the total volume of gas that has passed up the flue per kg of fuel burnt. The total emissions can then be calculated from the rate at which material is collected on the filter and the dilution ratio.

Comparison with results obtained with AS/NZS 4012/3

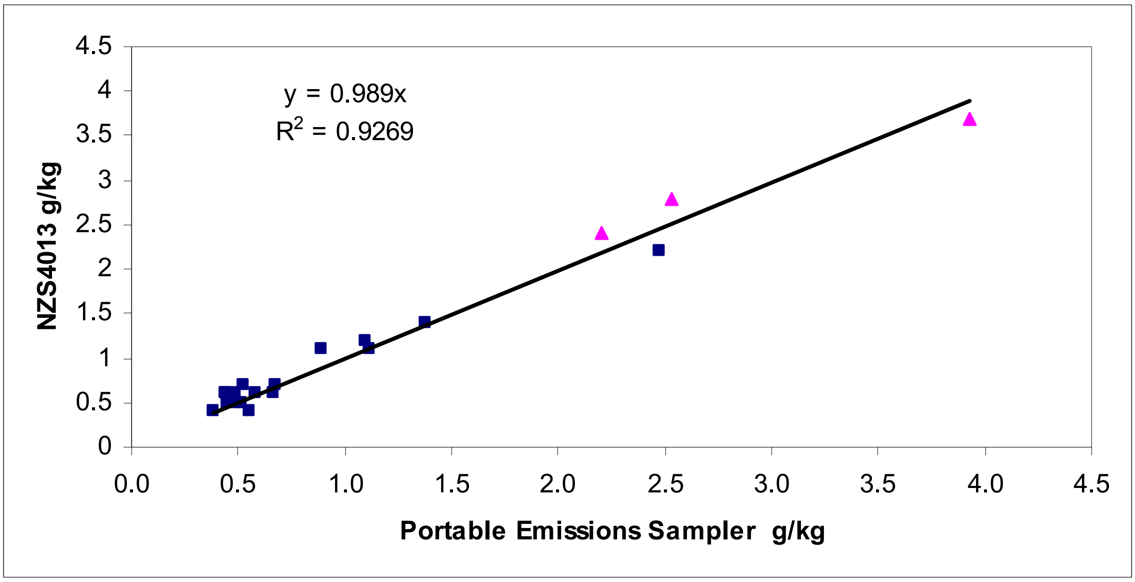
Laboratory tests of wood burners for compliance to particulate emissions standards in New Zealand are currently carried out according to methods set out in the joint Australian–New Zealand standard AS/NZS 4012/3. The test involves capturing the entire gas stream exiting the flue, which is then passed to a dilution tunnel where it is mixed with room air, which provides dilution and cooling. The particulate sample is drawn from the end of the dilution tunnel. Because the velocity of gas in the dilution tunnel is more easily measured than that in the flue, the amount of particulate generated is relatively easily calculated.

During the comparative tests the portable emissions sampler was set up in the test room and run at the same time as the laboratory test rig.

Results

Figure A2 shows the results of 19 runs carried out on a range of heaters. Of these, 17 (squares on the graph) were obtained during tests where fuelling was carried out in accordance with the requirements of AS/NZS 4012/3, and three (triangles) were carried out during five-hour runs under a 'real-life' fuelling regime, in accordance with Sustainable Management Fund Contract Application Number 2205. Results are particulate emissions in g/kg.

Figure A2: Comparison of results obtained with portable emissions sampler and AS/NZS 4012/3



The results show that there is a good correlation between the results obtained with the two methods.