Improving PM_{10} Emission Factors from Industrial Boilers in New Zealand - Stage 2

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Executive Summary

This report follows on from work undertaken in 2008 for the Foundation for Research, Science and Technology (FRST) "Protecting New Zealand's Clean Air" research programme. The previous report, 'Improving emissions factors for Industrial Boilers – Stage 1' report (Wilton et. al. 2008), aimed to improve the emission factors for industrial boilers used in emission inventories and in assessing environmental effects.

The objective of this Stage 2 report is to address the following recommendations from that work:

a. Obtain stack test results for additional industrial dischargers to improve the number of samplers for the different boiler types.

b. Undertake surveys of industry to improve classifications of boilers and emission control equipment.

c. Integration of these data with additional data used in Wilton et al. (2007) and Hennessy and Gong (2005).

As a result of the additional stack test data, the integration of some data from previous assessments and improvements to the classifications of boilers and emission control equipment "emission factors" for chaingrate boilers with multi cyclones and underfeed stokers are presented. These values should only be considered for use in the absence of site specific data.

- Chaingrate with multi cyclone - 1.9 g/kg TSP (200 mg/m^3) or 1.3 g/kg PM_{10} (assuming PM_{10} is 70% of TSP).
- Underfeed stoker (no controls) – 2.9 g/kg TSP (307 mg/m^3) or 2 g/kg PM_{10} (assuming PM_{10} is 70% of TSP).

In addition the report identifies probable emission factors for wood fired boilers and vekos boilers. These are reported as probable factors because results have been reported for them previously but the numbers of boilers included in the study are still too low to have sufficient confidence in how well the results represent average emissions from these boiler types.

- Wood fired boiler (no controls) – 2.0 g/kg TSP (309 mg/m^3) or 1.8 g/kg PM_{10} (assuming PM_{10} is 90% of TSP).
- Vekos boilers (no controls) – 5.4 g/kg TSP (569 mg/m^3) or 3.3 g/kg PM_{10} (assuming PM_{10} is 61% of TSP).

Emission factors have not been derived for other boiler types owing to small sample sizes.

The Stage 2 recommended emission factors and probable emission factors represent minor refinements to the Stage 1 recommendations. The Stage 2 emission factors are derived from a greater number of test results and therefore can be considered more representative and robust than those presented in Stage 1. However, the emissions data for different boiler types and levels of control within this report are the result of averaged values obtained from TSP emission tests for coal-fired boilers operating at a wide range of low to high output capacities. The average results are appropriate input data for the estimating the total daily TSP emissions into an airshed from industrial coal-fired boilers and for Tier 2 assessments as defined by MfE's 'Good Practice Guide for Assessing Discharges to Air from Industry. It should be noted that the emission factors have not been developed to be adopted as resource consent TSP discharge limits for a specific coal-fired boilers. Setting resource consent TSP discharge limits is much more appropriately done on a case-by-case situation and will also define the operating conditions of that specific boiler at the time of the test (e.g. at or above 75% of their maximum rated capacity (MCR)).

Recommendations arising as a result of the Stage 2 assessment include improving this database by:

- Regular updating every few years to include more recent test data for new and existing boilers.

- Searches for specific data such as LFO or pellet boiler test data.

Currently there are no plans to pursue the outstanding Stage 1 or Stage 2 recommendations in the HUA air quality research programme. However, this situation may be reviewed if there is sufficient stakeholder interest and the additional work aligned with the current direction of the programme.

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1 Introduction

The main air contaminant of concern in most urban areas of New Zealand is particulate matter less than 10 microns in diameter (PM_{10}). National environmental standards (NES) for PM_{10} were introduced in 2004 (effective from 2005) and specify a limit of 50 µg m^{-3} over 24 hours that is not to be exceeded more than once per year. This standard is regularly exceeded in many of New Zealand's urban areas during the winter months. In most urban areas of New Zealand, solid fuel burning for domestic home heating is the main source of PM_{10} emissions (MfE, 2003). However, in some areas, air discharges from industry can contribute to elevated PM_{10}.

Emission inventories are a key tool in determining the contribution of different sources to PM_{10} emissions in urban areas. The Foundation for Research, Science and Technology (FRST) "Healthy Urban Atmospheres" (HUA) research programme includes an objective relating to improving emission inventories. This report aims to advance previous work carried out under the previous FRST programme "Protecting New Zealand's Clean Air"(PCA) that identified some New Zealand specific industrial boiler emission factors for use in emission inventories and for assessing environmental effects.

The original report and the associated industrial emission database were produced to assist with fulfilling PCA output:

> 2.4.6 A database of emission measurements taken from industrial combustion sources in New Zealand. The data base will be accompanied by a report which will attempt to validate the use of generic emission factors for industrial combustion sources in New Zealand.

Emission factors for industrial boilers provide an indication of the amount of emissions per kilogram of fuel burnt, for an average boiler of that type, fuel and control equipment. Emission factors are typically derived based on stack testing data. In New Zealand, stack testing information for total suspended particles (TSP) is available for numerous coal boilers. Less information is available for wood boilers and only a few tests have been carried out on light fuel oil (LFO) boilers. Some of the information that is available for New Zealand was collated as part of the *'Improving emissions factors for Industrial Boilers – Stage 1'* report (Wilton et. al. 2008). Recommendations from that report include:

a. Obtaining stack test results for additional industrial dischargers to improve the number of samples for the different boiler types.

b. Undertake surveys of industry to improve classifications of boilers and emission control equipment.

c. Integration of these data with additional data used in Wilton et al. (2007) and Hennessy and Gong (2005).

d. The development of a publicly accessible database to hold stack testing information to improve the development of emission factors in New Zealand. Although some issues have been identified with this, an investigation into the feasibility of this option is recommended.

The objective of this report is to assist with fulfilling a number of the recommendations of the Stage 1 report by; obtaining further stack test results to increase the number of samples, undertaking surveys of industry to improve classifications of boilers and emission control equipment and integrating the additional emission data used in Wilton et al, (2007) and Hennessy and Gong (2005).

2 Method

The stack testers contributing to the 2008 industrial emissions data were K2 Environmental and Coal Research Limited (CRL) - with permission from their clients. To expand the database for this study, a wider range of stack testers were approached. Whilst a number of "new" testers expressed an interest in contributing; new data was only received from the two previous stack testers. In addition, data from Hennessy and Gong (2005) and Wilton et. al., (2007) were sourced for inclusion in the database.

The type of information collected varied depending on the source of the data. In all cases the minimum requirements for inclusion were:

- Mass of particulate per cubic metre of air (mg/m^3) when corrected to standard temperature and pressure (STP) and12% CO_2.
- Fuel type.
- Boiler type.
- Industry name.

Where available, other information was also obtained. This included, gas flow (m^3/min and m^3/min STP), the gas flow temperature.

Golder Associates (NZ) Limited (Golder) then undertook a review of the data. The review process involved a two pronged approach where boiler information was checked against information held by Golder and boiler information that required further clarification were identified. The review identified 23 boilers, and attempts to contact each industry to confirm boiler information were undertaken. It was not possible to contact three industries as they are assumed to no longer be in operation or were unwilling to provide further information.

Data were entered into a custom designed spreadsheet and average emissions in mg/m^3 STP, 12% CO_2, and grams of emissions per kilogram of fuel burnt (g/kg) were calculated for different boiler types. Because coal type and wood moisture data was not available, g/kg emission rates were calculated based on a gross calorific value of 22 MJ/kg for coal and 16% moisture and 16MJ/kg for wood. The equations used for this conversion are as follows:

- Emission rate (g/kg) = Concentration (mg/m^3 STP at 12% CO_2) x Air flow rate (m^3/kg STP at 12% CO_2) / 1000.

Where the air flow rate is the volume of air required for stoichiometric combustion of one kilogram of each fuel type, as follows:

- Coal Air Flow Rate = 9.48 m^3/kg.
  - 1 kilogram of sub bituminous coal (22 MJ/kg GCV at 12% CO_2) requires 9.48 Sm^3 air.
- Wood Air Flow Rate = 6.37 m^3/kg.
  - 1 kilogram of wood (16 MJ/kg GCV, 20% moisture at 12% CO_2) requires 6.37 Sm^3 air.
- Light Fuel Oil = 13.37 m^3/kg.
  - 1 kilogram of LFO (at 12% CO_2) requires 13.37 Sm^3 air.

3 'Stage 1' report

The *'Improving Emission Factors in Industrial Boilers in New Zealand - Stage 1'* report (Wilton et. al. 2008) examined a number of issues regarding emissions factors. The report found that in New Zealand, stack testing for particulate is usually only required for the filterable component of particulate matter and emission limits are also defined by filterable material. The extent to which total particulate emissions may be under represented by this approach will depend on the relative proportions of filterable versus condensable particulate matter. Condensable particulate may be an important issue especially in particulate limited airsheds where boiler emissions controls, such as bag filters are required. The report recommended further investigation of the impact of this component of PM_{10} in the New Zealand and this is considered in section 4 below.

An assessment of available emissions test data was undertaken in the Stage 1 report. Information on research undertaken by Wilton et. al. (2007) and Hennessy and Gong (2005) and others was presented. A summary of this information is provided in Appendix A? of this report.

In the '*Improving Emission Factors in Industrial Boilers in New Zealand – Stage 1*' report, emission test data was obtained for 79 boilers. Table 3.1 shows the type of boiler, the number of boilers that were included in the survey as well as median and mean TSP data. The data was presented as TSP as only seven of the 79 boilers included in the study had emissions test data for PM_{10}.

Table 3.1: TSP emission test data (from Wilton et al, 2008).

	Number	Mean TSP g/kg	Mean TSP mg/m^3 12% CO_2	Median TSP g/kg	Median TSP mg/m^3 12% CO_2	Max TSP g/kg	Min TSP g/kg
Chaingrate	3	2.2	235	2.5	259	2.7	1.5
Chaingrate - cyclone	2	3.1	324	3.1	324	4.3	1.9
Chaingrate - multiclones	13	1.9	201	1.6	167	4.7	0.8
Chaingrate - bag filter	4	1.3	140	0.9	98	3.3	0.1
Vekos - uncontrolled	6	4.9	519	2.4	255	14.8	1.6
Vekos – bag filter	1	1.0	110	1.0	110	1.0	1.0
Underfeed stoker – uncontrolled	16	2.8	295	2.5	265	5.9	1.0
Underfeed stoker – cyclones	8	1.1	116	1.1	265	2.0	0.5
Spreader stoker	4	6.0	637	6.8	718	9.1	1.5
Spreader - multiclone	1	4.0	422	4.0	422	4.0	4.0
Spreader – bag filter	3	0.7	74	0.5	57	1.3	0.2
Low Ram	2	1.8	194	1.8	194	2.4	1.3
Wood	6	1.9	296	1.7	269	2.9	1.3
Wood – bag filter	2	0.2	36	0.2	36	0.4	0.1
LFO	4	3.9	313	3.0	266	7.9	1.7
Bag filter - all types	10	0.9	100	0.7	78	3.3	0.1

Wilton et. al., (2008) identified a number of limitations that were encountered in the collation of emission test data. These included:

- It was difficult to classify boiler type and control equipment.
- Information on emission control equipment was not included in test reports.
- There was insufficient data for some boilers to allow for an assessment of an average emission factor.
- Stack testing appeared to focus on TSP when ambient air quality management focuses on the PM_{10} size fraction.

The results from the Wilton et. al. (2008) research found that the following emission factors may be used in emission inventories when site specific test data are absent:

- Underfeed stoker (no controls) – 2.8 g/kg TSP or 2 g/kg PM_{10} (assuming PM_{10} is 70% of TSP from Wilton et. al., 2007).

- Chaingrate with multi cyclone – 1.9 g/kg TSP or 1.3 g/kg PM_{10} (assuming PM_{10} is 70% of TSP from Wilton et. al., 2007).

- Wood fired boiler (no controls) – 1.9 g/kg TSP or 1.7 g/kg PM_{10} (assuming PM_{10} is 90% of TSP from Wilton et. al., 2007).

- Vekos boilers (no controls) – 6.2 g/kg TSP or 3.8 g/kg PM_{10}. These are the emission factors from Wilton et. al., (2007), which are considered more robust than the data derived in this study.

4 Results – Stage 2

Data collection resulted in an additional 40 boilers included in the database as well as the inclusion of 2008 and 2009 test data for a number of existing industries. Improvements in the boiler classifications/ emission control technology were found for around 20 boilers. Collated data are shown in Table 4.1.

Table.4.1: TSP emission test data.

	No.	Mean TSP g/kg	Mean TSP mg/m^3 12% CO_2	Median TSP g/kg	Median TSP mg/m^3 12% CO_2	Max TSP g/kg	Min TSP g/kg
Chaingrate	8	2.7	287	2.1	224	9.0	0.8
Chaingrate - cyclone	3	3.2	337	3.4	361	4.3	1.8
Chaingrate - multiclones	27	1.9	202	1.9	197	3.4	0.8
Chaingrate - baghouse	8	1.5	156	1.3	132	5.5	0.1
Vekos	8	5.4	569	4.6	487	14.8	1.5
Vekos - multiclone	4	5.1	569	3.4	487	11.4	2.2
Vekos - baghouse	2	0.6	59	0.6	59	1.0	0.1
Underfeed stoker	16	2.9	307	2.5	265	6.3	1.0
Underfeed stoker – cyclones	9	1.1	120	1.1	121	2.0	0.5
Spreader stoker	1	2.8	292	2.8	292	2.8	2.8
Spreader - multiclone	7	3.9	454	3.6	376	8.0	0.0
Spreader - baghouse	4	0.5	51	0.5	54	0.8	0.0
Spreader - ESP	1	0.6	51	0.6	54	0.6	0.6
Spreader - Sirocco Inertial	2	2.4	51	2.4	54	2.4	2.3
Low Ram	1	4.4	463	4.4	463	4.4	4.4
Low Ram - mulitclone	1	0.5	463	0.5	463	0.5	0.5
Underfeed - Pellet	1	0.5	71	0.5	71	0.5	0.5
Wood	6	2.0	309	1.7	269	3.4	1.3
Wood - baghouse	1	0.4	62	0.4	62	0.4	0.4
LFO	5	4.2	317	3.7	275	7.9	1.7
Baghouse filter - all types	16	1.0	106	0.7	75	5.5	0.0

The suitability of the average emissions from Table 4.1 for use as emission factors for industrial discharges in New Zealand depends on the number of boilers tested. A larger sample size results in a better estimate of the "average" emissions from a particular boiler type and minimises the impact of issues such as atypical results and potential misclassification of boilers.

For the purpose of this report, an estimate of an "emission factor" has been made for boiler categories for which 15 or more different boilers have been included in the testing. These boiler categories include chaingrates with multi cyclones, underfeed stokers and all boiler types with bagfilters. In addition some comment on probable emission factors has been provided for categories such as wood boilers and vekos boilers because these categories have been discussed previously (e.g., Wilton, 2007 and stage 1 report) and because this report includes additional information relating to these categories.

An emission factor for chaingrate boilers with multi cyclones was able to be assessed, as results for around 27 boilers were available. These gave an average TSP emission of 1.9 g/kg (200 mg/m^3). The Stage 2 report and database includes the 12 boilers in the CRL (Hennessy & Gong 2005) study which gave an average emission of 2.1 g/kg TSP. Using the PM_{10} to TSP ratio from Wilton, et. al., (2007) provides an estimated PM_{10} emission of 1.3 g/kg.

The emissions for chaingrate boilers with multi cyclones of 1.9 g/kg TSP (200 mg/m^3) or 1.3 g/kg PM_{10} are lower than USEPA AP42 emission factors of 4.5 g/kg and 2.5 g/kg. Similarly the underfeed stoker results are lower than the USEPA AP42 factors of 7.5 g/kg TSP and 3.1 g/kg PM_{10}. The lower New Zealand emissions observed for coal use in this study are consistent with the findings of Hennessey and Gong (2005).

Results suggest underfeed stokers with no emission control equipment in New Zealand typically perform at around 2.9 g/kg TSP (307 mg/m^3). This is based on the testing of 16 boilers and is a comprehensive collation of data for this boiler type for New Zealand. The average of 2.9 g/kg TSP is slightly higher than the value used by Wilton et. al., (2007) of 2.8 g/kg TSP.

Using the PM_{10} to TSP ratio from Wilton et. al. (2007) of 70% for underfeed stokers with no emission control equipment gives a PM_{10} emission factor of 2.0 g/kg. However, it should be noted that the ratio contains a high degree of uncertainty. Testing of PM_{10} emissions from underfeed stokers in New Zealand would improve the certainty around the PM_{10} emission factor.

Test results for 16 boilers with bag filters were included in the study. These gave an average emission of 1.0 g/kg (106 mg/m^3) and a median value of 0.7 g/kg (75 mg/m^3). The difference between the mean and the median occurs because of a small number of higher emitting boilers in this category. It is possible that these industries use only partial bag filters, as suppliers indicate that this control technology can typically achieve emission concentrations of around 50 mg/m^3.

The Stage 2 report and database contains eight vekos boilers without controls other than an internal cyclone. The average emission was 5.4 g/kg TSP (569 mg/m^3). This compares with six boilers and an average of emission of 4.9 g/kg TSP (520 mg/m^3) for the Stage 1 report and database. Both are lower than the 6.2 g/kg (650 mg/m^3) used by Wilton et. al., (2007) that was based on 13 boilers. Actual test results for the additional boilers included in Wilton et. al., (2007) were unable to be sourced. It is probable that the average emission from a vekos boiler will be in the range of 4.9 to 6.2 g/kg and in the absence of better information it is recommended that the results from this study (5.4 g/kg TSP) be used, but with caution.

The average emission for wood fired boilers for this study was 2.0 g/kg TSP (309 mg/m^3) and is similar to the emission factor used by Wilton et. al., (2007) of 1.8 g/kg (TSP) (280 mg/m^3). This was based on testing of six wood fired boilers burning either wood or sawdust. Using a TSP to PM_{10} ratio of 90% (based on USEPA AP 42) gives a PM_{10} emission of 1.8 g/kg PM_{10}, which is similar to the USEPA AP42 TSP emission factor of around 2 g/kg for industrial wood combustion. This factor should be used with caution owing to the small number of wood boilers included in the study.

Emissions from five LFO boilers were included in the study. All boilers had TSP emissions greater than the 1.3 g/kg TSP from USEPA AP42, with results showing an average of 4.2 g/kg (317 mg/m^3). While there is insufficient data available to recommend an emission factor at this time, results do suggest some caution when considering emissions from LFO boilers. Further investigations including an analysis of fuel quality is recommended.

In summary, test results from the Stage 2 study are consistent with the emission factors recommended in the Stage 1 report with some minor refinements. Emission factors were recommended for chaingrate boilers with multi cyclones and underfeed stokers. Probable factors were indicated for vekos boilers and wood fired boilers.

Results of the latter should be treated with caution because of the small sample sizes.

- The underfeed stoker (no controls) emission rate increased from 2.8 to 3.0 g/kg TSP with the addition of a further boiler.
- The emission rate for a chaingrate with multiclones remained at 1.9 g/kg TSP with the addition of a further 14 boilers in this category within the database.
- The average emissions for wood fired boilers remained at 2.0 g/kg TSP.
- The average emission rate for a vekos boiler with no controls other than an internal cyclone was 5.4 g/kg TSP. This is lower than the emission rate of 6.2 g/kg TSP recommended in the Stage 1 report.

5 Discussion

The objective of this report was to fulfil a number of the recommendations of the Stage 1 report by; obtaining further stack test results to increase the number of samples, undertaking surveys of industry to improve classifications of boilers and emission control equipment and integrating the additional emission data used in Wilton et al, (2007) and Hennessy and Gong (2005). This objective has been achieved with additional emission test data providing increased confidence in emission factors for some boiler type/control mechanisms combinations. The report also provides probable (limited confidence) emissions factors for other type boiler type/control mechanisms combinations.

The information provided in this report is intended to assist in the development of the industrial components of emission inventories through the development of New Zealand specific emission factors for various boiler types. A second potential application for these data, also raised in the Stage 1 report, is the preparation of assessments of environmental effects for industrial discharge consent applications. The Ministry for the Environment recently released the '*Good Practice Guide for Assessing Discharges to Air from Industry*' that includes recommendations for a three tiered approach to assessing discharges. Tier two requires a general modelling of the discharge which in the past would have relied on United States Environmental Protection Authority AP42 (USEPA AP42) emission factors or other information on emissions held by the consultant preparing the application. The above New Zealand specific emissions could be considered as input data for Tier two assessments as an alternative to, and perhaps more relevant than the USEPA AP42 factors, particularly for coal fired boilers because of differences in the coal properties between New Zealand and the USA.

The emissions data for different boiler types and levels of control within this report are the result of averaged values obtained from TSP emission tests for coal-fired boilers operating at a wide range of low to high output capacities. As noted above, the average results are appropriate input data for the estimating the total daily TSP emissions into an airshed from industrial coal-fired boilers and for Tier 2 assessments. However, the emission factors have not been developed to be adopted as resource consent TSP discharge limits for a specific coal-fired boilers. Setting resource consent TSP discharge limits is much more appropriately done on a case-by-case situation and will also define the operating conditions of that specific boiler at the time of the test (e.g. at or above 75% of their maximum rated capacity (MCR)).

Issues that have arisen during the collation of the emission testing information include;

- Some boilers that were included in the database have been decommissioned.
- Limited information is available for some boilers.

Consequently the quality of the information held in the database is uncertain in some cases. The impacts of any misclassifications or atypical results will be minimised for categories with test data from a greater number of boilers.

6 Recommendations

There are a number of recommendations raised in the Stage 1 report that were included with the intention that they would stimulate debate and discussion amongst stakeholders. These recommendations are included here because the issues they raise are still relevant at the completion of this stage 2 report. Decisions on the uptake or otherwise of these recommendations rests with the appropriate agencies and other stakeholders. Recommendations in the Stage 1 report not addressed in this report are outlined below.

1. It is recommended that councils evaluate the option of setting additional or alternative emissions limits for industrial boilers based on PM_{10}, as this is consistent with the NES. It is noted that some industrial stacks are not suitable for PM_{10} measurements and therefore implementation may need to be case specific. A number of test methods are available for the measurement of PM_{10} including OTM - 27 and USEPA 201.

2. Further collation of stack testing data for PM_{10} for New Zealand boilers is recommended to increase certainty around the proportion of TSP that is PM_{10} for different boiler types be undertaken.

3. An investigation into the cause of high particulate emissions from LFO boilers in New Zealand.

4. The development of a publicly accessible database to hold stack testing information to improve the development of emission factors in New Zealand. Although some issues have been identified with this, an investigation into the feasibility of this option is recommended.

5. Further investigation is required on the effects of condensable particulate on the total amount of PM discharged.

Recommendations arising as a result of the Stage 2 assessment include improving this database by:

- Regular updating every few years to include more recent test data for new and existing boilers.
- Searches for specific data such as LFO or pellet boiler test data.

Currently there are no plans to pursue any of these recommendations within the HUA air quality research programme. However, this may be reviewed if there is sufficient

stakeholder interest and the additional work aligned with the current direction of the air quality research programme.

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Appendix A: Assessment of existing test data (from Wilton et al 2008)

Tables 1 and 2 show indicative emissions from Hennessy and Gong (2005) and Wilton et al., (2007). Sources contributing to the different TSP emissions for the latter are shown in Table 3. Estimates of PM_{10} shown in Table 2 are based on the following assumptions: 1) that combustion of one kilogram of sub bituminous coal requires 9.48 Sm^3 of air at 12% CO_2; and 2) the following ratios of PM_{10} to TSP:

- Most boiler coal fired types – 70%
- High emission (e.g., vekos) boiler – 61%
- Wood-fired boiler – 90%
- Bag filtration – 100%
- Light fuel oil – 100%

Table 1: Summary of CRL emission data

Classification	TSP kg/tonne coal	No. of boiler systems	Standard deviation/ average
Chaingrate + multicyclone	2.1	12	40%
Chaingrate + bag filter	0.7	1	6%
Chaingrate pre-2002	1.3	8	47%
Spreader + multicyclone	3.8	7	44%
Spreader + bag filter	1.8	5	49%
Spreader +ESP	0.14	1	33%
Spreader pre-2002	2.1	9	35%
Low ram stoker + multicyclone	3	2	41%
Vekos + internal cyclone	6.7	3	21%
Vekos pre-2002	7.6	3	35%
Underfeed + multicyclone	1.9	4	25%

Table 2: Emission factors for PM_{10} and TSP used by Wilton et al. (2007)

Classification	PM_{10} (g/kg)	TSP (g/kg)	TSP (mg/m^3)
Chaingrate - multi cyclone	1.5	2.1	220
Light Fuel Oil	1.3	1.3	98
Vekos – standard with simple cyclone (coal)	3.8	6.2	650
Vekos – one multi cyclone (coal)	2.0	2.8	300
Coal boiler – two multi cyclones	1.7	2.4	250
Solid fuel boiler with bag filter	0.5	0.5	50
Low ram stoker with multi cyclone	2.0	2.8	300
All wood boilers	1.6	1.8	280
Underfeed stoker uncontrolled (coal)	2.0	2.8	300

Table 3: Typical total particulate emissions (mg/m^3 corrected to standard conditions) for various boiler types, without modification and with good maintenance and operating practice.

	Coal					Wood	Oil		Gas (LPG)
Boiler Construction	**Underfeed stoker (no controls or single cyclone)**	**Underfeed stoker with multi-cyclone**	**Drop Tube Stoker (Vekos with internal cyclone)**	**Chaingrate Stoker with multi-cyclone**	**Low Ram, Spreader and Vekos with multi-cyclone**		**LFO**	**Light (Diesel)**	**All types**
Sectional	300 (1)	200 (4)				280 (5)			
Shell & tube, multi-pass			650 (2)	220 (4)		280 (6)			
Shell & tube, reverse pass							100mg/m^3, all types	21mg/m^3, all types	8mg/m^3, all types
Vertical shell & tube	280 (3)	200 (4)							
Water tube				220 (4)	300 (7)				
Waste heat									
Tubular gas									
Condensing									

(1) Data comes from ESR 1998 testing of 16 school boilers in Christchurch, average <300mg/m^3, with only 3 tests above this value

(2) Data comes from Powell – Fenwick project work, Hennessy & Gong (2005) + other known NZ emission test results (average of 13)

(3) Data comes from Powell-Fenwick project work.

(4) Data from CRL (2005), plus knowledge of other NZ testing.

(5) From USEPA data at 1.8g/kg, assuming typical 16MJ/kg wood burned. Consistent also with testing

(6) Based on limited NZ test data and USEPA data.

(7) Based on information provided by suppliers and limited emission test data, assuming good operation at steady rate at the time of testing.