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Air Quality & IT Specialists

Improving PM_{10} Emission Factors from Industrial Boilers in New Zealand - Stage 1

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Executive Summary

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, 2002). However, in some areas, air discharges from industry can contribute to elevated $PM_{10.}$

Emission inventories are a key tool to determine the contribution of different sources of PM_{10} emissions in urban areas. The Foundation for Research, Science and Technology (FRST) "Protecting New Zealand's Clean Air" research programme includes an objective relating to improving emission inventories. This report aims to improve emission factors for industrial boilers used in emission inventories and in assessing environmental effects. The report also aims to fulfil the requirements of the FRST contracted 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.

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 completed on light fuel oil (LFO) boilers. Until now the information that is available on stack testing from industrial boilers has not been collated and assessed to ensure that there is consistency in the emission factors that are used.

This report improves existing PM_{10} emission factors used for industrial coal, wood, and LFO in New Zealand. The following emission factors are proposed for use with emission inventories, in the absence of site specific data:

- Underfeed stoker (no controls) – 2.8 g/kg TSP (300 mg/m^3) or 2 g/kg PM_{10} (assuming PM_{10} is 70% of TSP).
- 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).
- Wood fired boiler (no controls) - 1.9 g/kg TSP (300 mg/m^3) or 1.7 g/kg PM_{10} (assuming PM_{10} is 90% of TSP).
- Vekos boilers (no controls) – 6.2 g/kg TSP (650 mg/m^3) or 3.8 g/kg PM_{10} (from Wilton, et. al., 2007)

A second potential application for these data 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*' which 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 the USEPA AP42 factors.

The report identifies some issues with particulate emissions from LFO boilers in New Zealand. In particular the four boilers tested all showed high TSP emissions (average 3.9 g/kg, 313 mg/m^3 STP, 12%CO_2. This is greater than a USEPA AP42 emission factor for LFO of 1.3 g/kg, 98 mg/m^3. This result may have implications for air quality management of LFO boilers and requirements relating to the testing of LFO boilers. Further investigation into the cause of the higher LFO emissions is recommended.

The report also recommends that the issue of stack testing for PM_{10} be considered by the air quality community in New Zealand and that Councils also evaluate whether setting emission limits for PM_{10} on industrial boilers, as opposed to (or in addition to) TSP limits is appropriate. It should be noted that not all stacks are suitable for measurement of PM_{10}. Stack testing for PM_{10} would then be consistent with air quality management of PM_{10} in the NES.

A number of recommendations have been made on how to improve industrial emission factors for different boiler types in New Zealand. The key recommendations include; further collation of stack testing data throughout New Zealand and investigation into the feasibility of a publicly accessible data base for stack testing information.

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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) "Protecting New Zealand's Clean Air" research programme includes an objective relating to improving emission inventories. This report aims to improve industrial boiler emission factors used in emission inventories and for assessing environmental effects. The report also aims to fulfil the requirements of the FRST contracted 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.

Other related work included in this programme includes "real life" testing of wood burner emissions to improve emission factors for domestic heating (Wilton et al., 2006) and investigations into motor vehicle emission estimates (Bluett, 2007; Kuschel & Bluett, 2007)

Emission factors have long been the fundamental tool in developing national and regional emission inventories for air quality management and in the development of emissions control strategies.

More recently, emission factors have been applied to determine emission limits for resource consent applications for industrial boilers. Emission limits are generally made either on the basis of site specific stack monitoring or, in cases where stack testing is not considered warranted, through the application of emission factors.

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. The information that is available has not been collated and assessed to ensure that there is consistency in the emission factors that are used.

This report seeks to strengthen the existing emission factors that are used for PM_{10} for industrial coal, wood, and LFO in New Zealand. The focus of the report is on PM_{10} as the main air quality management issue for New Zealand. No evaluation of gaseous emissions has been undertaken.

Two approaches to improve emission factors for industrial boilers are used in this report. The first has been to review existing emission factors used in New Zealand. These include the United States Environmental Protection Agency emission factors (USEPA

AP42) and those used by existing organisations in New Zealand. Secondly, test data for New Zealand boilers have been collated and reviewed to evaluate average emission rates for different boilers.

The study has resulted in the development of emission factors for underfeed stoker (no controls), chaingrate boilers with multi cyclones, LFO boilers, and wood fired boilers (no controls). Recommendations are made on how to improve industrial emission factors for different boiler types.

2 Methodology

A number of different sources were used to obtain emission test data from different industry across New Zealand. These included:

- Stack testers K2 Environmental and Coal Research Limited (CRL) with permission from their clients.
- Stack testing results provided by industry to the authors.
- Regional Council information supplied by industry for compliance purposes.

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) and the gas flow temperature.

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 Review of existing emission factors

3.1 Filterable and condensable particulate

Particulate emissions can be described as either filterable or condensable. The United States Environmental Protection Agency (USEPA) describe filterable emissions as particles that are trapped by the glass fibre filter in the front half of a Reference Method 5 or Method 17 sampling train. Particles less than 0.3 microns and vapours are known to pass through the filter and are therefore not included in the measurement.

Condensable particulate matter is material that is emitted in the vapour state which later condense to form particles. Condensable particulate matter from industrial combustion is typically inorganic in nature (USEPA AP42, 2008). The condensable fraction of particulate is typically small in comparison to filterable particulate. An exception is when some emission reduction technologies (e.g., bag filters) cause the condensable fraction to become a significant proportion of total particulate, because the overall emissions are attenuated by use of the technology.

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 PM. Condensable particulate may be an important issue especially in particulate limited airsheds where boiler emissions controls, such as bag filters are required. Further investigation of the impact of this component of PM_{10} in the New Zealand context would be of value.

3.2 USEPA AP42 Emission Factors

Emission factors for a range of sources have been developed by the USEPA and are regularly used in New Zealand. The emission factors are averages of all available data from a particular process that are of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category.

The USEPA data are graded for reliability from A to E. ‘A’ is defined as top class data from an adequate number of randomly chosen sites, with sampling carried out via a sound methodology. The opposite extreme is ‘E’, where there are many uncertainties surrounding the methodology and validity of the data, or there is evidence of variability within the source category. Generally A, B, and C category data can be considered as being of average or above average quality. D and E are only used in the absence of anything better (USEPA AP42, 2008).

Table 3.1 shows filterable PM_{10} and TSP emission factors from USEPA AP42, for a range of boiler types. Condensable particulate emission factors are given as 0.4 kg/ tonne in USEPA AP42 for all boiler types included in this study. The ratio of PM_{10} to TSP for each boiler type is also shown.

Table 3.1: USEPA AP42 Filterable TSP and PM_{10} emissions, along with ratio of PM_{10} to TSP

	lbs/ton TSP	kg/tonne TSP	mg/m^3 TSP	lbs/ton PM_{10}	kg/tonne PM_{10}	mg/m^3 PM_{10}	Ratio of PM_{10} to TSP	Grade: The first grade refers to the quality of the TSP data, the second to the PM_{10} data
Hand fed boilers	15	7.5	791	6.2	3.1	338	41%	Grade "E/E" data
Chaingrate + multicyclone	9	4.5	475	5	2.5	272	56%	Original unit lbs/ton. Grade "C/E" data
Spreader + multicyclone	17	8.5	897	12.4	6.2	675	73%	Assumes re-injection. Original unit lbs/ton. Grade "B/E" data.
Spreader + multicyclone (without flyash re-injection)	12	6	653	7.8	3.9	411	65%	From table 1.1-9, page 1.1-29 EPA-AP42
Spreader + multicyclone (with flyash re-injection)	17	8.5	897	12	6.0	633	71%	From table 1.1-9, page 1.1-29 EPA-AP43
Spreader + bag filter	0.12	0.06	6	0.072	0.04	4	60%	From table 1.1-9, page 1.1-29 EPA-AP42
Spreader +ESP	0.48	0.24	25	0.44	0.22	23	92%	From table 1.1-9, page 1.1-29 EPA-AP43
Spreader pre-2002	66	33.00	3418	13.2	6.6	719	20%	Original unit lbs/ton. Grade "B/E" data
Overfeed stoker	16	8	844	6	3.0	316	38%	From Table 1.1-10, page 1.130, EPA-AP42
Overfeed stoker with multiple cyclones	9	4.5	475	5	2.5	264	56%	From Table 1.1-10, page 1.130, EPA-AP43
Underfeed	15	7.5	791	6.2	3.1	338	41%	Original unit lbs/ton. Grade "D/E" data
Underfeed + multicyclone	11	5.5	580	6.2	3.1	338	56%	Original unit lbs/ton. Grade "D/E" data
Wood	4	2						
	lb/1000 gallon			lb/1000 gallon				
Light Fuel Oil	10	1.3	98	10	1.3	98	100%	From table 1.1-5 page 1.3-16

3.3 Existing New Zealand Assessments

In New Zealand, measurements are primarily available for TSP but limited data are also available for PM_{10}. Several reports have been produced that use emission factors based on results of New Zealand specific test data.

In 2007 a review of emission factors was included in the Environment Canterbury publication ‘Cost effectiveness of policy options for boilers – Christchurch’ (Wilton et al., 2007). The report included an evaluation of emission factors for coal and wood boilers that was based on emission factor reports by Hennessy and Gong (2005), as well as test results held or known by the authors.

It was noted that for coal burning devices with comparable USEPA AP42 and New Zealand data, the New Zealand data records emissions of typically one third to one half of the USEPA AP42 data. Coal quality is a likely cause of these differences, because New Zealand coals have relatively low ash content (typically 2-5%).

Wilton et al. (2007) and Hennessy and Gong (2005), classify boilers according to the following burner feed mechanisms:

- Underfeed stoker – automatically transfers coal from the storage bunker to the bottom of the combustion chamber. The underfeed stoker is almost predominantly used in conjunction with sectional boilers. Underfeed stokers are mostly small scale boilers (typically less than 2MW) and are commonly used to heat schools in New Zealand.

- Drop Tube stoker (Vekos) – fuel is transported via an auger and then dropped onto the combustion chamber from above. This is used by shell and tube boilers and is commonly referred to as a “Vekos” boiler (after their first maker, although there are a number of manufacturers)

- Spreader stoker – coal is fed from above, similar to the drop tube stoker but the positioning is different (see Wilton et al., 2007 for illustrations).

- Chaingrate – coal is fed to the combustion chamber via a conveyor of chain links which run the length of the combustion chamber.

Tables 3.2 and 3.3 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 3.4. Estimates of PM_{10} shown in Table 3.3 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 3.2: 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 3.3: 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 3.4: 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)**	**Chain Grate 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..

4 New Zealand Emission Test Data

Table 4.1 summarises the results of the TSP emission testing data collated for this report. Only seven of the 79 boilers included in this study had emissions test data for PM_{10}. Because of the small sample, derivation of emission factors for PM_{10} or ratios of PM_{10} to TSP based on these data was therefore considered inappropriate. Where PM_{10} estimates have been made in subsequent text, these have been based on USEPA- AP42 ratios or the factors used by Wilton et. al. (2007).

Table 4.1: TSP emission test data

	Number	Mean TSP g/kg	Mean TSP mg/m3 12% CO_2	Median TSP g/kg	Median TSP mg/m3 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

4.1 Limitations

Classification of the boilers and the control equipment was a key issue in the evaluation. Most of the data came from emission test reports which rarely included information on emissions control equipment. Boiler classifications and emissions control equipment were provided by the testers or from other studies carried out by the authors. It is possible that the information could be improved further through discussions with industry on the boiler classifications and emissions control or through testers collecting more detailed boiler information during subsequent tests.

For many boiler types, insufficient data were collected to allow for an assessment of an average emission factor. In some cases data are available but were unable to be included in this study.

A key limitation in the approach to stack testing would appear to be the focus on TSP when ambient air quality management focuses on the PM_{10} size fraction. Management of industrial emissions based on TSP requires assumptions about the ratio of PM_{10} to TSP. The cost difference in managing PM_{10} versus TSP is approximately $200 per sample.

5 Emission Factors

Results suggest underfeed stokers in New Zealand typically perform at around 2.8 g/kg TSP (300mg/m^3). This is based on the testing of 18 boilers and is a comprehensive collation of data for this boiler type for New Zealand. A further eight underfeed stokers with cyclones were included in the study. These gave an average TSP emission of 1.1 g/kg (120 mg/m^3).

Using the PM_{10} to TSP ratio from Wilton et. al. (2007) of 70% for underfeed stokers with no controls 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.

An emission factor for chaingrate boilers with multi cyclones was also able to be assessed as results for around 13 boilers were available. These gave an average TSP emission of 1.9 g/kg (200 mg/m^3). This compares with 2.1 g/kg TSP based on 12 boilers in the CRL (Hennessy & Gong 2005) study. It is likely that many of the boilers used in these assessments are the same, although this study included results of more recent testing. 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 chain grate 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).

Emission data were collected for six Vekos boilers burning coal. The average of emissions from Vekos boilers was 4.9 g/kg TSP (520 mg/m^3), which is lower than the 6.2 g/kg (650 mg/m^3) used by Wilton et al. (2007). As the latter was based on the testing of 13 boilers, 6.2 g/kg is likely to represent a more robust emission factor.

The average emission for wood fired boilers for this study was 1.9 g/kg TSP (300 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 seven 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 1.7 g/kg PM_{10}, which is similar to the USEPA AP42 TSP emission factor of around 2 g/kg for industrial wood combustion.

Test results for 9 boilers with bag filters were included in the study. These gave an average emission of 0.9 g/kg (100 mg/m^3) and a median value of 0.5 g/kg (56 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.

Emissions from four LFO boilers were included in the study. All four boilers had TSP emissions greater than the 1.3 g/kg TSP from USEPA AP42, with results showing an average of 3.9 g/kg (310 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.

6 Recommendations

The following recommendations are included in this report with the intention that they will stimulate debate and discussion amongst stakeholders. Decisions on the uptake or otherwise of these recommendations rests with the appropriate agencies.

1. 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.

2. 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.

3. 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.

4. Discussions with stack testing agencies and industry is recommended, to expand the information that is included during testing to include recording of boiler classification and emissions control technology and other necessary information.

5. Further investigation is required on the effects of condensable particulate on the total amount of PM discharged. In particular, the following should be addressed:

   a. Is the condensable component of PM_{10} an issue?

   b. Are there any issues associated with its measurement?

   c. Does this component require consideration in air quality management?

6. Consideration may be given to the use of the emission factors discussed in this report for Tier Two emissions assessments as specified in the Ministry for Environment '*Good Practice Guide for Assessing Discharges to Air from Industry'.*

7. Further work and collection of information is recommended, with the aim of strengthening the findings of this report. Potential enhancements to this work could be carried out as a second stage to this project. These could include:

    a. Obtaining 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).

    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.

References

Bluett J.G., 2007. *Toward an improved understanding of Vehicle Emissions.* Proceedings of the 14th International Union of Air Pollution Prevention and Environmental Protection Associations Congress. - Brisbane 9-13 Sept 2007. ISBN 978-0-9757571-6-1

Hennessy W. and Gong D., 2005. *Review of Particulate Emissions from Industrial Coal Combustion in New Zealand*, CRL Energy Ltd Report

Kuschel G. and Bluett J.G., 2007. *Remote Sensing of Vehicle Emissions - Helping to Bust Two of the Great Air Quality Myths?* Proceedings of the 14th International Union of Air Pollution Prevention and Environmental Protection Associations Congress. - Brisbane 9-13 Sept 2007. ISBN 978-0-9757571-6-1

Ministry for the Environment (MfE), 2003. *Emission inventories for PM_{10} in New Zealand*. Air Quality Technical Report No 38 prepared by Environet Limited for the Ministry for the Environment

Ministry for the Environment (MfE), 2008. *Good Practice Guide for Assessing Discharges to Air from Industry*, Ministry for the Environment Publication Number ME 880

Opus International Consultants Limited, 1998. *Particulate Testing of Coal Boilers, Physical Testing of 16 School Boilerhouses Winter 1998 - Ministry of Education. Further information provided to Environment Canterbury in support of air discharge permit applications for school coal boilers in Christchurch,* October 1998

United States Environmental Protection Authority
http://www.epa.gov/ttn/chief/ap42/

Wilton E., Smith J., Dey K. and Webley W., 2006. Real life testing of woodburner emissions. *Clean Air and Environmental Quality 40(4):* 43-47

Wilton E., Anderson B., and Iseli J., 2007. '*Cost effectiveness of policy options for boilers – Christchurch'*, Environment Canterbury Report

Appendix A: CRL Limited Review of Particulate Emissions from Industrial Coal Combustion in New Zealand

In 2005, CRL Energy Ltd (CRL) undertook a study to review particulate emission factors of coal plants in New Zealand and compare these to the USEPA emission factors that are used throughout New Zealand to model the likely PM_{10} concentrations from coal fired plants.

Part of the need to compare New Zealand emissions with USEPA emission factors is that much of the US data relates to the use of coals of different rank, on considerably larger scale plant than that commonly found in New Zealand.

New Zealand industrial coals have a consistent ash content of between 2-5%, which is low by world standards. Emission levels are primarily influenced by the type of firing system used to burn the fuel. The CRL report identified that three of the most commonly encountered systems in New Zealand are spreader (or sprinkler) stokers, chaingrates and Vekos boilers.

The CRL study involved collecting 175 measurements from 35 boiler systems on 24 sites throughout New Zealand between 2002 and 2004. A further 96 pre-2002 measurements were also collated from 20 boiler systems, including most of the 2002-2004 boilers. The average measurements for each equipment type, their coefficients of variation (standard deviation as a percentage of the average) and the minimum and maximum values were determined. All (apart from Vekos boilers with internal cyclones) used multiple cyclones for particulate control while six boiler systems used bag filters and another used an electrostatic precipitator (ESP).

Some boiler systems had up to 10 measurements taken over 2002-2004 while others had only a single measurement. To test the variability of the boiler systems, the average measurements were all treated as equivalent rather than weighting them for the numbers of readings.

The results from the study are shown in Table A1.

Table A1: Average Total Suspended Particulates (TSP) for Different Stoker Equipment

Average for the boiler systems	TSP kg/tonne coal	Standard deviation/ average	No. of measure-ments	No. of boiler systems	Minimum *kg/tonne	Maximum* kg/tonne	TSP g/kWh input
Chain grate + multicyclone	2.1	40%	71	12	1.0	3.5	0.30
Chain grate + bag filter	0.7	6%	2	1			0.10
Chain grate pre-2002	*1.3*	*47%*	*19*	*8*	*0.6*	*2.5*	*0.21*
Spreader + multicyclone	3.8	44%	30	7	1.6	5.9	0.77
Spreader + bag filter	1.8	49%	35	5	0.3	2.3	0.29
Spreader + ESP	0.14	33%	3	1			0.03
Spreader pre-2002	*2.1*	*35%*	*74*	*9*	*0.7*	*3.4*	*0.35*
Low ram stoker + multicyclone	3.0	41%	12	2	2.1	3.9	0.43
Vekos + internal cyclone	6.7	21%	7	3	5.2	8.0	1.13
Vekos pre-2002	*7.6*	*35%*	*3*	*3*	*4.6*	*9.4*	*1.21*
Underfeed + multicyclone	1.9	25%	15	4	1.2	2.2	0.29
Total measurements 2002-04			175	35			
Total measurements pre-2002			*96*	*20*			

*Minimum and maximum values for the average readings for boiler systems are presented to illustrate the spread of the average results.

Source: Hennessy and Gong (2005)

The results of the CRL study followed the expected pattern that particulate emissions from chaingrate (2.1 kg/tonne) and underfeed stoker equipment (1.9 kg/tonne) with multicyclones were significantly lower than those from spreader (or sprinkler) stokers with multicyclones (3.8 kg/tonne) or from Vekos (overfeed) boilers (6.7 kg/tonne). Two boiler systems with low ram stokers with multicyclones had an intermediate average value (3.0 kg/tonne). The two chain grate stoker systems with bag filters had average emissions only one third of those without and the five systems with bag filters were on average about half of those without. The single spreader stoker system with ESP had less than one twentieth of the average spreader emissions.

CRL concluded that the sample numbers were too small and the variability too high for any meaningful comparison to be made with average pre-2002 measurements

(Chaingrate and spreader averages were both approximately half of the 2002-2004 averages while the Vekos averages were similar.)

The USEPA's AP-42 publication reviewed its emission factors for bituminous and sub-bituminous coal combustion in 1998, leaving the factors unchanged and adding estimates of filterable PM_{10} emissions. For spreader stokers with multiple cyclones and no fly ash reinjection, they use a particulate factor of 6 kg/tonne, around 60% higher than the average figure found in the CRL study. For overfeed stokers, they use 8 and 4.5 kg/tonne for uncontrolled and multiple cyclones respectively. CRL found that this is the firing configuration that best corresponds to the Vekos boiler with its internal cyclone, which is arguably an intermediate category that is in good accordance with the 6.7 average found in this study.

CRL found that it was difficult to categorise the chain grate and low ram firing systems in terms of the USEPA categories. CRL considered them to be more like the USEPA category of underfeed stokers, which has an emission factor of 5.5 kg/tonne with multiple cyclones. The average underfeed stoker was only 35% of that value in this study, the average chain grate system was only 38% of it and the average low ram stoker only 55%.

The overall conclusion from the CRL study was that the use of USEPA emission factors for New Zealand chaingrate, underfeed and low ram stoker installations would result in substantial over-estimation (by a factor of 2 to 3 times) of average particulate emissions. The USEPA emission factor for spreader systems would result in only a 60% over-estimation while the factor for Vekos boilers would be approximately in agreement with the results of this study.

Appendix B: Opus International Consultants Limited - Emission testing of School Boilers

In winter 1998 Opus International Consultants Limited undertook particulate testing of 16 school boilers in Christchurch on behalf the Ministry for the Environment (Opus, 1998). These boilers were all underfeed stokers and did not have emission control technology. The testing of the boilers was in response to resource consent application where Canterbury Regional Council requested further information regarding the applicability of USEPA factors to determine emissions from school boilers.

The results from the study are shown in Table B1.

Table B1: Total Particulate Emissions related to Boiler Operating Loads at Schools in Christchurch

School	Maximum Boiler Rating (kW)	Particulate Emission Measurements (mg/m^3) 0 degrees 12% CO_2)				Comments
		Actual			Average	
Aranui	370	58	49	58	55	
Belfast	240	236	181	152	190	
Cashmere High	630	332	239	258	276	
Central New Brighton	300	111	104	96	104	
Heaton Intermediate	750	70	62	77	70	
Hillmorton High	**900**	**367**	**330**	**352**	**350**	**All samples were effected by caretaker operations**
Linwood High	1400	323	357	374	351	
Mariehau High	1460	198	184	195	192	
North New Brighton	186	74	64	62	67	
Riccarton High	670	366	353	358	359	
Richmond	155	128	774	882	128	Sample 1 used, sample 2&3 were badly effected by caretaker operations
Roydvale	125	216	263	284	254	
Shirley Boys High	727	68	244	184	265	Large variations in concentrations partly due to caretaker operations.
St Martins	83	102	100	107	103	
Waltham	111	218	184	196	200	
Westburn	300	199	127	136	154	

Source: Opus 1998