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AGL LOY YANG EMISSIONS MONITORING PROGRAM – PARTICULATE MATTER (FOR 90TH PERCENTILE PM2.5 AND PM10 ANNUAL FREQUENCY DISTRIBUTION) - RESULTS

Prepared for	AGL Loy Yang Pty Ltd
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Executive Summary

HRL Technology Group (HRL) was retained by AGL Loy Yang Pty Limited (AGL Loy Yang) to report on the outcomes of an Emissions Monitoring Program for fine and coarse particulate matter (i.e. $PM_{2.5}$ / PM_{10}) (PM Program) for Loy Yang A Power Station (LYA) as required by condition LI_DA4.3 of EPA Licence No. 11149 (Licence):

> *You must establish and implement a program for a 12-month period to monitor the discharge to air, at discharge point(s) 1 to 4, of fine particles PM2.5 and coarse particles PM10 to establish the 90th percentile annual frequency distribution. The results of this program must be made available to EPA on request and must be published to the publicly accessible website required by condition LI_DA4.2 by 31 March 2022.*

HRL followed the guidelines in EPA Publication 440.1 *Guide to Air Quality Sampling and Analysis* in developing the PM Program for monitoring $PM_{2.5}$ and PM_{10} emissions at LYA. A report describing the proposed PM Program was submitted to the EPA for review and comment on 19 July 2021, prior to implementation. On 3 August 2021, the EPA advised that the scope of work detailed in the report was appropriate for the purpose of complying with condition LI_DA4.3.

HRL understands that condition LI_DA4.3 was imposed by the EPA following the recent review of the EPA Licence to facilitate, if feasible, the development of a methodology to estimate $PM_{2.5}$ and PM_{10} mass emissions (on a 30-minute average basis). HRL understands that the aim of this was to, if feasible, enable the continuous calculation of a rolling annual 90th percentile annual frequency distribution for $PM_{2.5}$ and PM_{10} emissions from LYA.

The emission of $PM_{2.5}$ and PM_{10} from the LYA power station is influenced by many variables, including:

- Coal quality, which varies from hour to hour, with varying ash content, ash constituents, combustion temperature and residence time (impacting carbon burnout in fly ash particles);
- Mills, swirler and classifier performance, each of which impacts the pulverised coal particle size being introduced to the burners;
- Boiler performance – mills in service, combustion air flows, temperature profile, excess air levels, carbon in ash;
- Unit load variation, impacting combustion air and hence flue gas flows;
- Potential biasing of PM distribution results at higher dust loads; and
- Electrostatic Dust Precipitator (EDP) performance, zones / flow pairs in service.

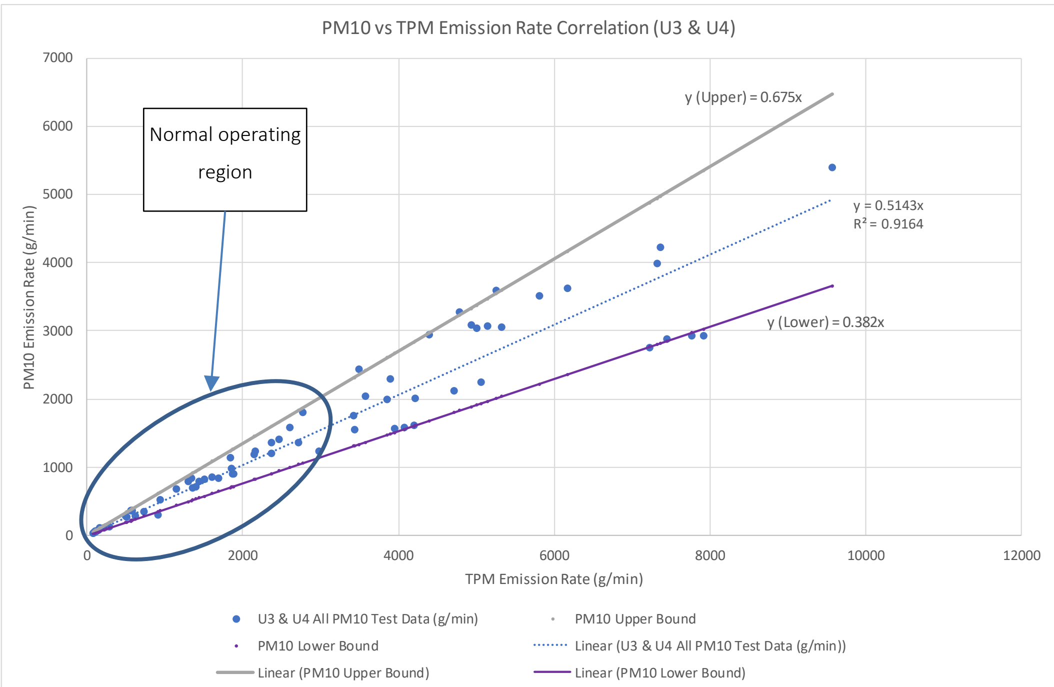
The PM Program was designed to utilise the large number of stack tests relating to particulate matter emissions, which are undertaken annually at LYA. This testing is to facilitate annual National Pollutant Inventory (NPI) reporting (of $PM_{2.5}$, PM_{10} and Total Particulate Matter (TPM)) and correlation testing (for biennial correlation calibration testing) of the Opacity Monitors on Units 3 and 4, which provide continuous monitoring of particulate emissions. For the purposes of this PM Program, the correlation testing, which typically only measures TPM against opacity monitor response, was extended to include measurement of $PM_{2.5}$, PM_{10} and TPM. To date, sampling and analysis for $PM_{2.5}$ and PM_{10} for National Pollutant Inventory (NPI) reporting purposes has utilised AS4323.2 *Stationary source emissions Determination of total particulate matter - Isokinetic manual sampling - Gravimetric method* in conjunction with laser analysis of the sample i.e. particle size analysis (PSA). This methodology was also applied to the PM Program.

A total of 77 stack tests were undertaken across Unit 3 (Flues 1 & 2) and Unit 4 (Flues 1 & 2) over two separate stack sampling and testing campaigns (i.e. August and September 2021 for Unit 4 and post-outage, in November and December for Unit 3). Correlation testing is required to occur over the full range of particulate matter emissions from normal (low) concentrations through to concentrations approaching the licence limit. This is crucial given that the accuracy of a correlation to determine the rolling annual 90th percentile annual frequency distribution is reliant on the availability of data points on the frequency distribution closest to the licence limit.

During stack testing for $PM_{2.5}$ and PM_{10} emissions, it is desirable for the Unit undergoing testing to be operating stably and near to nameplate generation capacity. DCS data collected during the stack testing campaigns indicates that the Unit undergoing testing was operating at or near to nameplate capacity for most of the test period. Coal grab samples were taken simultaneously during the stack testing campaigns for Units 3 and 4 to provide analytical information to assess the potential impacts of coal quality on the collection efficiency of the EDPs, which were being operated under normal conditions for the NPI and compliance tests, and under correlation test conditions for the Opacity Monitor correlation tests.

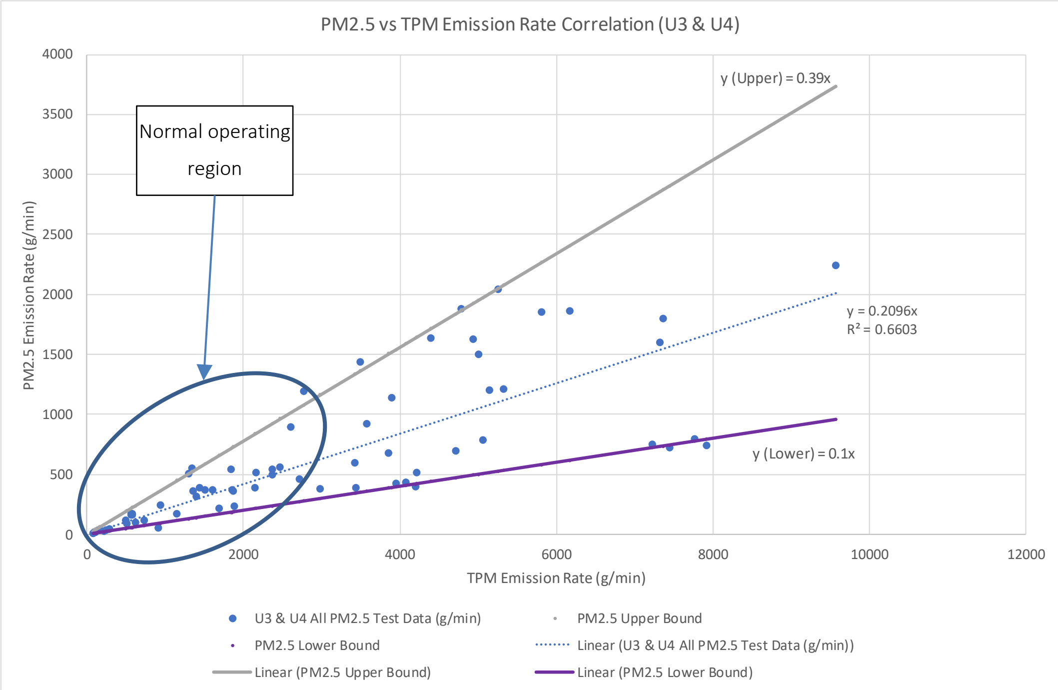
A correlation between measured PM_{10} and TPM emission rates is presented in Figure 1 along with Upper and Lower Bound correlations, which capture 90% of all available measurements obtained during the PM Program.

Figure 1: PM_{10} to TPM emission rate correlation for LYA with Upper and Lower Bounds



A correlation between measured PM_{10} and TPM emission rates is presented in Figure 2 along with Upper and Lower Bound correlations, which capture 90% of all available measurements obtained during the PM Program.

Figure 2: $PM_{2.5}$ to TPM emission rate correlation for LYA with Upper and Lower Bounds



Key findings and outcomes of the PM Program are as follows:

- Under normal operation of the EDPs (i.e. excluding start-up and shutdown), the TPM emission rate is well below the licence limit for particle emissions, with most emissions grouped towards the zero end of the correlation, as shown in Figure 1 (PM_{10}) and Figure 2 ($PM_{2.5}$).
- PM_{10} and $PM_{2.5}$ emission rates are influenced by numerous physical and operational factors, of which few are continuously monitored by LYA power station at present nor are there technologies available that can continuously monitor all known factors. Each of these operational parameters can impact emission particle size.
- It was also found that correlations between TPM and PM_{10} and $PM_{2.5}$ emission rates exhibited significant divergence from the best-fit trendline at higher TPM emission rates, though more so for $PM_{2.5}$ than PM_{10}. The higher uncertainty associated with $PM_{2.5}$ analytical results is not unexpected given the very small concentrations of $PM_{2.5}$ present in the samples collected during testing. It is noted that the correlation error spread was considerably larger for Unit 4, which experienced greater variability in coal quality and composition during the testing campaign. As such, it is concluded that correlation error at LYA is dependent on the variability of several key parameters including coal quality and composition. Given the potential for a larger range of plant operation and coal quality variability over an entire year of operation, the correlation error is likely to be substantially higher on an annual basis.
- Analysis of coal samples collected concurrently with the emissions sampling has identified that stack test results which exhibited the greatest level of correlation divergence coincided with elevated TPM emissions and either of the following combination of coal quality characteristics:
    - Low moisture and very low ash content i.e. expected to be predominantly inherent ash only, rather than extraneous ash associated with sandy interseam material or overburden, as well as high iron content (as Fe_2O_3), high alkali metals content (as MgO, Na_2O and CaO), high in sulphates (SO_3) and low silica (SiO_2), or
    - High ash content i.e. expected to be predominantly extraneous ash associated with sandy (high silica) and clay interseam material or overburden, rather than inherent ash,

as well as high or elevated aluminium content (as Al_2O_3), which is typical of high clay ash content.

Correlations between PM_{10} and TPM and $PM_{2.5}$ and TPM cannot accurately account for the numerous variables relating to coal quality, EDP and Unit performance, as many of those variables are not or cannot be accurately monitored in real-time. Given the large number of variables impacting TPM, $PM_{2.5}$ and PM_{10} emissions at any point in time, the outcomes of the PM Program confirm that it is not feasible to obtain an accurate correlation for predicting PM_{10} and $PM_{2.5}$ emissions at LYA, using TPM measurements as a surrogate.

However, a possible approach to achieve the EPA's understood objective of continuously monitoring emissions of PM_{10} and $PM_{2.5}$ at LYA is as follows:

- For the purpose of establishing a rolling annual 90th percentile PM_{10} mass emission rate limit for LYA, apply a PM_{10} to TPM mass emission rate correlation coefficient corresponding to the Upper Bound (i.e. 0.675 x TPM), based on all available test data for LYA, to the Licence 90th percentile TPM mass emission rate limit for LYA (i.e. 0.675 x 16,200 g/min = 10,935 g/min).
- For the purpose of establishing the rolling annual 90th percentile $PM_{2.5}$ mass emission rate limit for LYA, apply a TPM to $PM_{2.5}$ mass emission correlation coefficient corresponding to the Upper Bound (i.e. 0.39 x TPM), based on all available test data for LYA, to the Licence 90th percentile TPM mass emission rate limit for LYA (i.e. 0.39 x 16,200 g/min = 6,318 g/min).
- For the purpose of determining the rolling 90th percentile for compliance purposes, apply the best-fit (average) PM_{10} to TPM and $PM_{2.5}$ to TPM correlation coefficients obtained from all available test data for LYA (i.e. 0.5143 x TPM for PM_{10} and 0.2096 x TPM for $PM_{2.5}$), to the measured rolling average 90th percentile TPM mass emission rate for LYA.

HRL understands that AGL Loy Yang will discuss these options with the EPA.

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1 Introduction

HRL Technology Group (HRL) was retained by AGL Loy Yang Pty Limited (AGL Loy Yang) to report on the outcomes of an Emissions Monitoring Program for fine and coarse particulate matter (i.e. $PM_{2.5}$ / PM_{10}) (PM Program) for Loy Yang A Power Station (LYA) as required by condition LI_DA4.3 of EPA Licence No. 11149 (Licence):

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Additional "Support to Comply" guidance provided by the EPA in relation to condition LI_DA4.3 states that:

> *EPA expects licence holder to engage with EPA when developing the monitoring program. EPA acknowledges technological [challenges] for direct monitoring PM10 and PM2.5 in real time. As such, EPA supports use of surrogate methods together with an appropriate number of stack tests. You are encouraged to engage with EPA when establishing the program.*
>
> *Refer to EPA publications 440 & 1322.9.*

HRL Technology Group (HRL) has prepared this report for AGL Loy Yang to document the outcomes of the PM Program completed at LYA.

1.1 Parameters Impacting Total Particulate Matter (TPM) and $PM_{2.5}$ and PM_{10} Emissions

Parameters that may affect Total Particulate Matter (TPM), $PM_{2.5}$ and PM_{10} emissions include:

- Coal quality and ash particulate properties:
  - Sulphur and ash content of coal;
  - Electrical resistivity / chemical composition of ash (including sand and components that affect the precipitability of ash (such as carbon, alumina and sodium content));
  - Coal seam and lithotype;
  - Coal moisture content and calorific value;
  - Ash particle density (sand will have a higher density than inherent ash in the coal matrix);
  - Particle size distribution of the pulverised fuel and of the particulate matter in flue gas after combustion (related to combustion / boiler plant performance, as summarised below).
- Combustion / boiler plant performance including:
  - Mills, Classifiers, Swirlers each of which impacts the pulverised coal particle size being introduced to the burners;
  - Combustion in boiler and excess air levels (which affects flue gas temperature and the level of unburnt carbon in the ash);
  - Particle size distribution of ash at EDP inlet.

- Electrostatic Dust Precipitator (EDP) performance:
  - Flow Pairs out of service due to scheduled maintenance or for repair following a fault;
  - Flue gas volumetric flow (affected by load, excess air levels and air ingress);
  - Precipitator Energy Management System (PEMS) operation.
- Plant operating conditions:
  - Including load and flue gas volumetric flow.

These parameters are considered in more detail below.

1.1.1 Coal Quality

The primary mining operations at Loy Yang coal mine comprise of the excavation of material by Bucket Wheel Excavators known as Dredgers operating at various levels within the Loy Yang coal mine. The combination of excavated coal from various levels can result in significant short term variability in coal quality and composition.

Ash content (the solid residue after combustion) of the coal is in the form of inherent ash (structurally part of the coal itself and cannot be separated by mechanical means) and extraneous ash (inorganic material introduced during formation of the seam (e.g. sedimentary particles), including interseam material) and overburden. The inherent ash is relatively low for Loy Yang coal at about 1%. However, the total ash content of the coal can vary from 1% to over 10%, including extraneous ash. Most of the extraneous ash is sand (silica), but also clay (which contains aluminium). The quantity of sand and clay in the coal can be highly variable.

The combustion of inherent ash will tend to produce finer particulate material when combusted, which will tend to be low density and highly porous.

The sand has a high particle density of about 2,650 kg/m^3 and relatively low porosity. The particle size distribution of the sand will depend on the size distribution in the coal seam and the impact of milling and classification within the boiler that will reduce the size until fine enough to be elutriated out of the milling circuit. Once in the boiler, the sand particle size distribution will not change significantly due to combustion. Larger sand particles will fall to the bottom of the boiler. There may be some agglomeration of particles due to reaction at temperature with sodium in the coal. Some of this material deposits on boiler surfaces and is periodically removed using water cannons and sootblowers as large pieces that will mostly report to the ash hopper at the bottom of the boiler, as well as finer material that will report to the EDP (increasing the dust burden on the EDP during this period).

On combustion, the clay material tends to produce a very low density, light fluffy ash and likely fine particulate matter.

Based on the above, the particle size distribution and the density of the ash reporting to the precipitator will be highly variable depending on the relative portions of inherent ash, sand and clay in the ash (i.e. ash composition).

1.1.2 Combustion / Boiler Plant Performance

The performance of the following unit operations is known to influence TPM, PM_{10} and $PM_{2.5}$ particulate emissions:

- Mills;
- Classifiers;
- Swirlers;
- Combustion in the boiler and level of unburnt carbon.

The mills used at LYA are a beater wheel type. The beater wheel acts as a fan to draw hot gas from the boiler into the mill to dry the coal and to pulverise the coal into finer particles known as pulverised fuel (PF). The vapour and dried coal leaving the mill passes into a classifier, which allows larger particles to be separated and returned to the mill. This ensures that the coal is fine enough for efficient combustion.

With a higher density, sand particles will tend to be recirculated back to the mill from the classifier. Also being harder than dried coal, the breakage on impact with the beater wheel blade will be lower. Given that the sand content is the dominant component of the ash content of the coal, how the sand behaves in the mills and how much finer particulate matter is produced will have a significant impact on $PM_{2.5}$ and PM_{10} concentrations in the flue gases leaving the boiler and passing through to the EDPs.

The dry PF is concentrated by the swirlers and separated from the gas and water vapour from the mills and supplied to the Main Burners. The vapour and fine PF that passes through the swirlers are supplied to the Inerts Burners.

The performance of the mills and classifiers has the greatest impact on the PF size supplied to the boiler. It can be expected that different mills will produce somewhat different particle size distributions as a result of slight design differences and due to beater wheel blade wear over time. Scheduled mill outages return the condition of the beater wheel blades to full working order (there is usually one mill out of service at any given time). During normal operation between 5 and 7 mills (of a total 8 mills per Unit) are in service at any given time.

Further, at lower load or if the moisture content of the coal is low, then a finer PF will be produced, due to increased classification and particle recirculation as a result of lower gas flows exiting the mill.

1.1.2.1 Boiler Performance

The particulate matter in the flue gas at the inlet to the EDP is predominately a function of ash content of the coal being supplied to the boiler, the total coal feed to the boiler and unburnt carbon.

The unburnt carbon content in fly ash entrained with the flue gas is a function of combustion temperature, temperature distribution throughout the boiler furnace zone, coal reactivity, excess oxygen level and residence time in the furnace zone. At higher load, flue gas flow rates increase, which reduces the residence time in the furnace zone, however the combustion temperature is higher.

Unburnt carbon increases the total mass of TPM at the precipitator inlet but will tend to result in a larger particle size distribution as part of the inherent ash will be contained within a larger char matrix. Unburnt carbon affects the resistivity of the fly ash and can reduce the effectiveness of the downstream EDP.

1.1.3 Factors Affecting Electrostatic Dust Precipitator (EDP) Performance

Electrostatic precipitator performance is affected by numerous factors including:

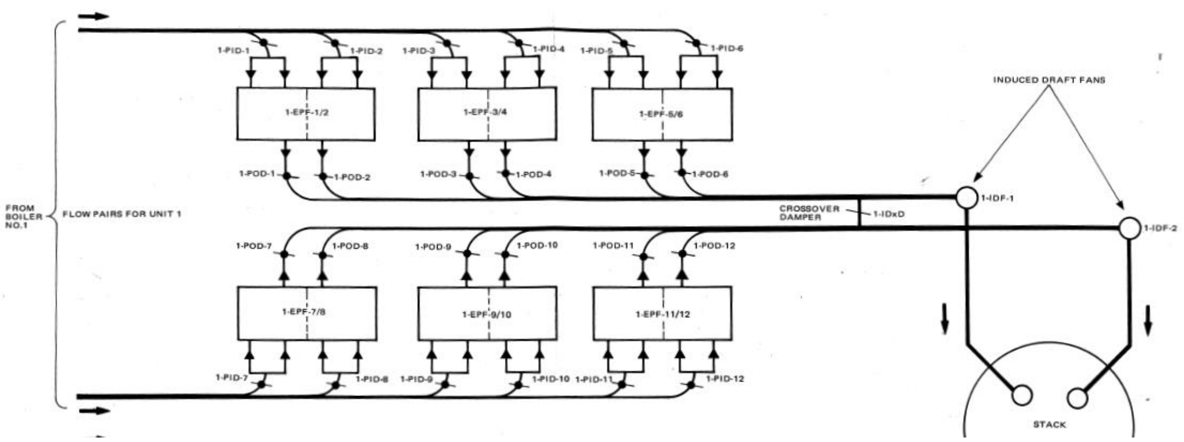
- Coal and ash particulate properties;

  - Sulphur and ash content of coal;
  - Electrical resistivity / chemical composition of ash (including alumina, sodium and carbon);
  - Ash particle density and particle size distribution;
  - Carbon in ash content.
- Flue gas temperature and moisture content;
- Degree of variability in flue gas conditions (e.g. temperature, flowrate and dust concentration) from one side of the EDP to the other;
- Char collector design and condition;
- Gas inlet flow distributor design and condition;
- Gas volumetric flowrate (impacted by combustion air and tramp air inflows);
- EDP collecting plate area;
- Rapping design, condition, performance and rapping frequency;
- Particle sneakage (noting that a portion of the gas and PM flow will be below, above or around the available collection plates);
- Number of EDP fields and chambers (including number out of service);
- Voltage control devices used;
- EDP control system;
- Corona power and power density achievable with EDP design;
- Ability to control to a set sparking rate;
- Size of Transformer-Rectifier (T-R) sets for each field.

1.1.3.1 Electrostatic Dust Precipitator (EDP) Performance at LYA

At LYA the flue gas from the boiler outlet is split into two, with each flow passing through an air heater. The flow from each air heater is supplied to three parallel "Flow Pairs" (as shown in Figure 3). The outlet flow from each of the Flow Pairs is combined into a common duct on each side upstream of an Induced Draft (ID) Fan – with a separate ID Fan servicing each of the three parallel Flow Pairs. The outlet of each ID fan supplies a separate flue in the stack (i.e. there are two flues per Unit and four flues in total per stack, with each stack shared by two Units).

Figure 3: EDP Arrangement at LYA



A Flow Pair is shown in Figure 4. Each Flow Pair has two inlet and two outlet evases (i.e. gradually enlarging ducts). There is a flow divider between the Flow Pairs. Each Flow Pair consists of three

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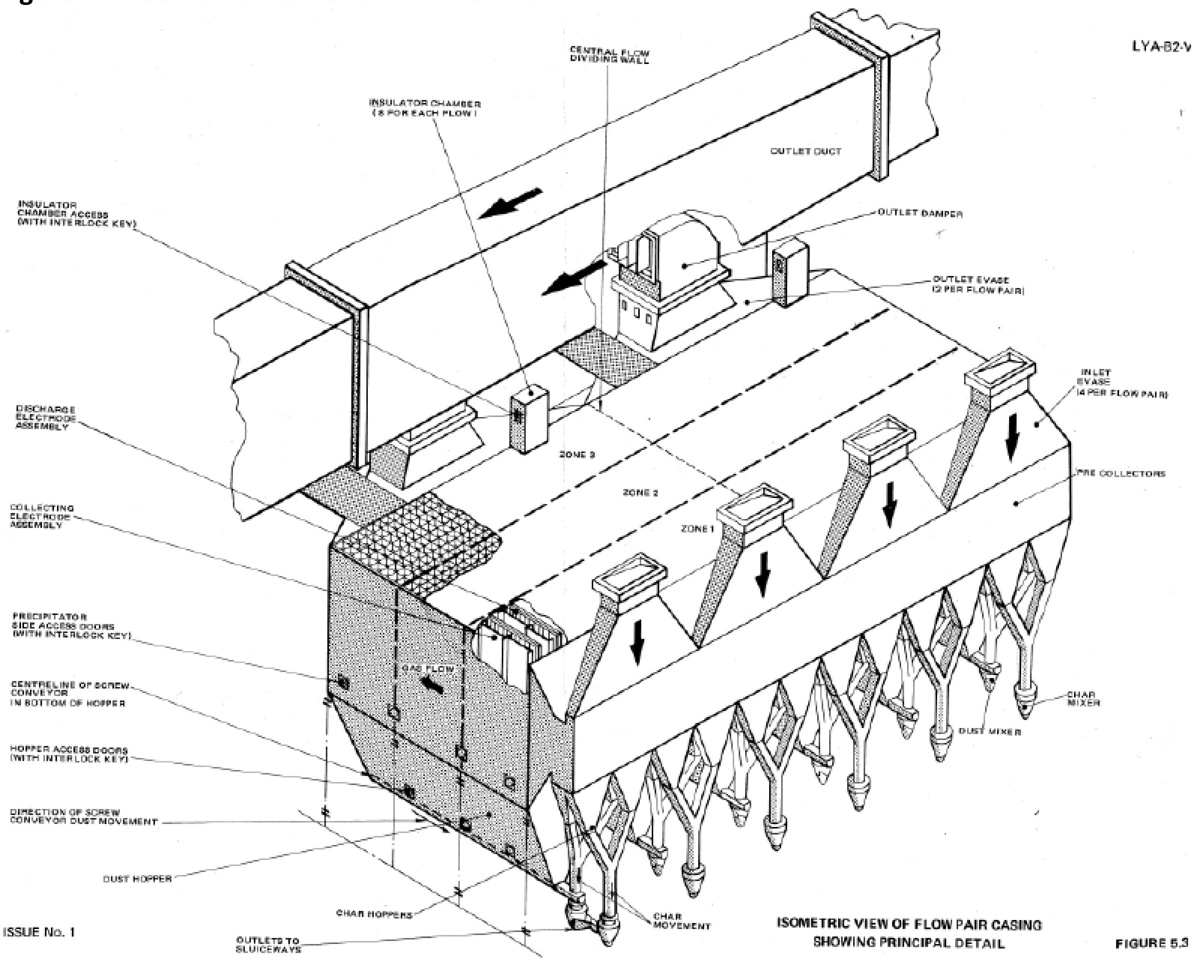
independently electrically controlled zones, each with a Transformer-Rectifier (T-R) Set and electrically charged plates.

Each flow pair can be isolated by dampers from the inlet and outlet flows as well as electrically, to be worked on when the Unit is in operation. The EDP is designed with additional redundancy to allow one Flow Pair being out of service whilst maintaining performance. It is usual for one Flow Pair to be out of service for maintenance on at least two boiler Units at any given time. However, the loss of another Flow Pair can require a reduction in Unit load to ensure that dust emissions remain below the licence limit.

Dust collected on the charged plates in each zone is dislodged into collection hoppers below the zones by mechanical ‘rapper’ bars with hammers. While rapping results in spikes in dust emissions due to re-entrainment in the gas flow, the effect is minimised by staggering rapping, with each zone rapped at different times. The rapping frequency is intended to allow dust to build up to an adequate thickness on the collection plates so that the accumulated ash can be dislodged in sheets, which helps to reduce re-entrainment of dust. However, the rapping may still result in emissions of larger particles that have been captured and dislodged from the plates.

Figure 4: Isometric View of an EDP Flow Pair



The EDP performance is highly dependent on EDP Flow Pair and zone availability. If one or more Flow Pairs are taken out of service the velocity through the remaining in-service Flow Pairs increases, which reduces the residence time and will result in an increase in emissions. As coal ash content increases, this will likely be due to extraneous ash (e.g. from interseam material or overburden). However, the nature of the extraneous ash will have implications for both the boiler mill performance and the EDP separation efficiency and therefore, PM emissions. For example, if the ash is high in silica (sand) which is more dense than inherent ash, there will be a higher proportion of larger particles at both the inlet and outlet of the EDPs, even though the larger and more dense particulates would be more easily removed in the EDPs.

2 PM Program Methodology

EPA Publication 1322.9 *Licence Management* requires sampling and analysis to be conducted in accordance with EPA Publication 440.1 *Guide to Air Quality Sampling and Analysis*. The PM Program developed to address Licence condition LI_DA4.3 was prepared based on guidance from EPA Publication 440.1 and utilises the large number of stack tests for particulate matter emissions conducted annually for both National Pollutant Inventory (NPI) monitoring and Opacity Monitor calibration correlation tuning, known as 'correlation' testing.

The PM Program proposed by AGL Loy Yang included utilising the results from stack testing of Unit 4 and Unit 3 (post outage) for both NPI monitoring and Opacity Monitor correlation testing. The PM Program utilised the sampling location on each stack or flue utilised for routine annual Licence compliance monitoring.

EPA Publication 440.1 specifies Australian Standard (AS) 4323.2-1995 *Stationary Source Emissions - Determination of Total Particulate Matter - Isokinetic Manual Sampling - Gravimetric Method* for total particulate matter (TPM) sampling but does not specify a method for PM_{10} or $PM_{2.5}$. LYA typically utilises AS 4323.2 for TPM sampling and has for many years utilised Particle Size Analysis (PSA), which is undertaken using a laser particle size analyser, to determine $PM_{2.5}$ and PM_{10} for NPI reporting purposes.

AGL Loy Yang engaged a National Association of Testing Authorities (NATA) accredited specialist stack emission sampling and testing service provider, Ektimo Pty Ltd (Ektimo) to:

- Implement the physical sampling and testing aspects of the PM Program using NATA accredited methods and laboratories; and
- Prepare reports for each sampling and testing campaign.

The sampling and analysis test methods used in the program along with measurement uncertainty and availability of NATA accreditation for each parameter are summarised in Table 1.

Table 1: Summary of Sampling and Analysis Methods for the PM Program

Parameter	Sampling Method	Analysis Method	Uncertainty*	NATA Accredited	
				Sampling	Analysis
Sample plane criteria	AS 4323.1	N/A	N/A	✓	N/A
Moisture	USEPA Method 4	USEPA Method 4	8%	✓	✓
Flow rate, temperature and velocity	ISO 10780	ISO 10780	8%, 2%, 7%	N/A	✓
Carbon Dioxide and Oxygen	USEPA Method 3A	USEPA Method 3A	13%	✓	✓
Total Particulate Matter	AS 4323.2	AS 4323.2 (Gravimetric Analysis)	7%	✓	✓
Particulate matter (PM_{10} and $PM_{2.5}$) by particle size analysis	AS 4323.2	HRL in-house (Note 1)	-	-	No (Note 1)

* Uncertainties cited in this table are estimated using typical values and are calculated at the 95% confidence level (coverage factor = 2).

Notes:

1. Particle Size Analysis performed by HRL Technology using a Malvern Instruments Mastersizer laser particle size analyser. NATA Accreditation does not cover the performance of this service. Utilised annually for NPI reporting purposes.

A report describing the proposed PM Program was submitted to the EPA for review and comment on 19 July 2021, prior to implementation. On 3 August 2021, the EPA advised that the scope of work detailed in the report was appropriate for the purpose of complying with condition LI_DA4.3.

The PM testing campaigns included routine annual NPI testing and routine annual Opacity Monitor correlation testing for Unit 4 (in July and August 2021) and for Unit 3 (in November and December 2021), as shown in Figure 5. The sampling campaign covered a wide range of TPM concentrations and took ~2 weeks for each Unit undergoing testing. Where practicable, the testing was undertaken at high to maximum Unit load conditions and stable operation. Coal sampling was also undertaken during the stack sampling campaigns to facilitate coal quality analysis, to inform the assessment of the stack testing results.

Figure 5: Schedule for Emissions Monitoring Program – Particulate Matter

	2021										2022		
Activity	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Development of PM Emissions Monitoring Program and issue to EPA for review and comment													
EPA Review and Approval of PM Emissions Monitoring Program Scope													
PM Testing Campaign, combined with Annual Compliance, NPI Monitoring & Opacity Monitor Correlation testing (Unit 4)						U4	U4						
PM Testing Campaign, combined with Annual Compliance, NPI Monitoring & Opacity Monitor Correlation testing (Unit 3, post Outage)						Unit 3 Outage			U3	U3			
Coal Quality Testing & Analysis of coal samples collected during PM Testing Campaign													
Particle Size Analysis to determine $PM_{2.5}$ & PM_{10}													
Analysis of Results and development of calculation methodology to estimate $PM_{2.5}$/PM_{10} mass emissions (on a 30-minute average basis)													
Publish on Website													

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3 PM Program Results Summary & Assessment

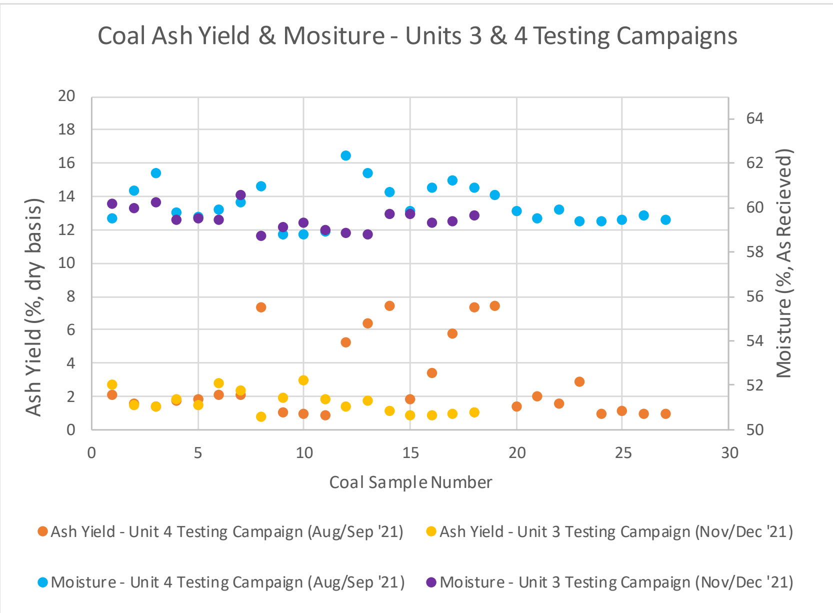
3.1 PM Program Testing Campaigns

A total of 77 stack tests were completed for TPM, PM_{10} and $PM_{2.5}$ as summarised below:

- Unit 4 (Flue 1 & 2, Discharge Point 4):
    - August 2021: A total of 4 tests were conducted for NPI monitoring (2 per flue)
    - August – September 2021: A total of 15 tests were conducted for Flue 1 Opacity Monitor correlation purposes, plus a further 6 additional tests
    - August – September 2021: A total of 16 tests were conducted for Flue 2 Opacity Monitor correlation purposes
- Unit 3 (Flue 1 & 2, Discharge Point 3):
    - November 2021: A total of 4 tests were conducted for NPI monitoring (2 per flue)
    - November 2021: A total of 16 tests were conducted for Flue 1 Opacity Monitor correlation purposes
    - November – December 2021: A total of 16 tests were conducted for Flue 2 Opacity Monitor correlation purposes

Coal analyses conducted on grab samples collected during the Unit 4 testing campaign shows typical variability (see Figure 6), with an average ash content of ~3% (dry basis) from the analysis of 27 coal samples collected from Unit 4 over 8 days, with a minimum of 0.9% (dry) up to a maximum of 7.5% (dry). However, coal analyses conducted on grab samples collected during the Unit 3 testing campaign showed less variability (also see Figure 6), with ash yield averaging 1.6% (dry), with a minimum of 0.8% (dry) and a maximum of 3% (dry) from 18 samples. Periods of low ash coal also tended to correspond to lower moisture coal, indicating higher quality coal for combustion. Over shorter periods, there is potentially even greater variability.

Figure 6: Coal ash content variability during Emissions Monitoring Program testing campaigns



3.2 PM_{10} and TPM Relationship

To better understand the relationship between particle size and TPM emissions downstream of the EDPs, measured emission concentrations of PM_{10} are plotted against TPM, as shown in Figure 7 (Unit 4) and Figure 8 (Unit 3). Linear regression correlations relating PM_{10} to TPM for each individual flue (2 flues per Unit) and for all data (from both flues for each Unit) were obtained using the Microsoft Excel spreadsheet trendline "best fit" linear regression tool.

Figure 7: Correlations between PM_{10} and TPM for Unit 4

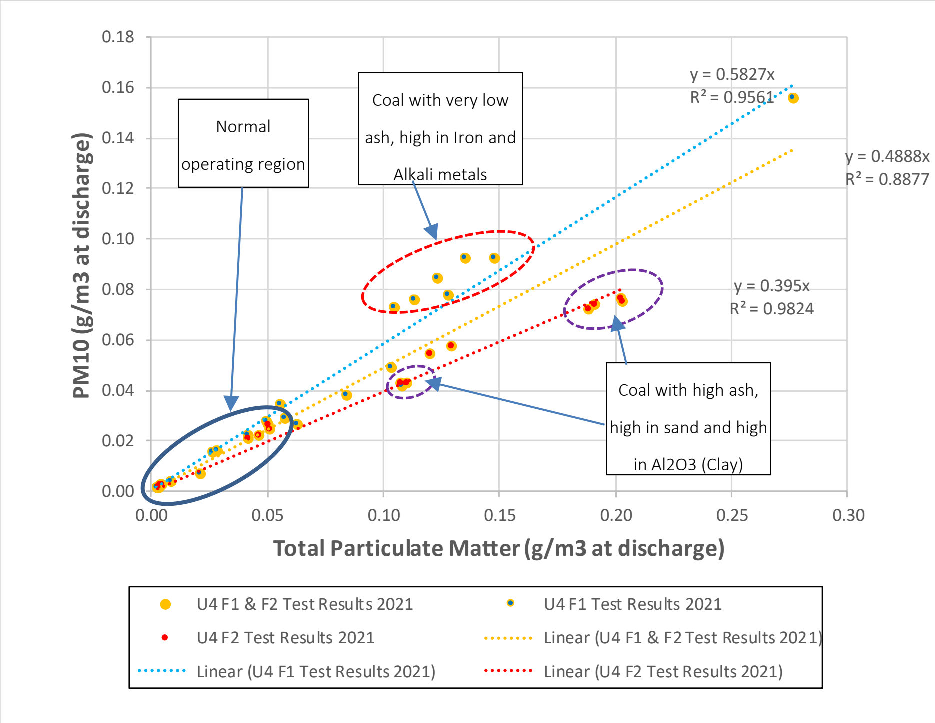
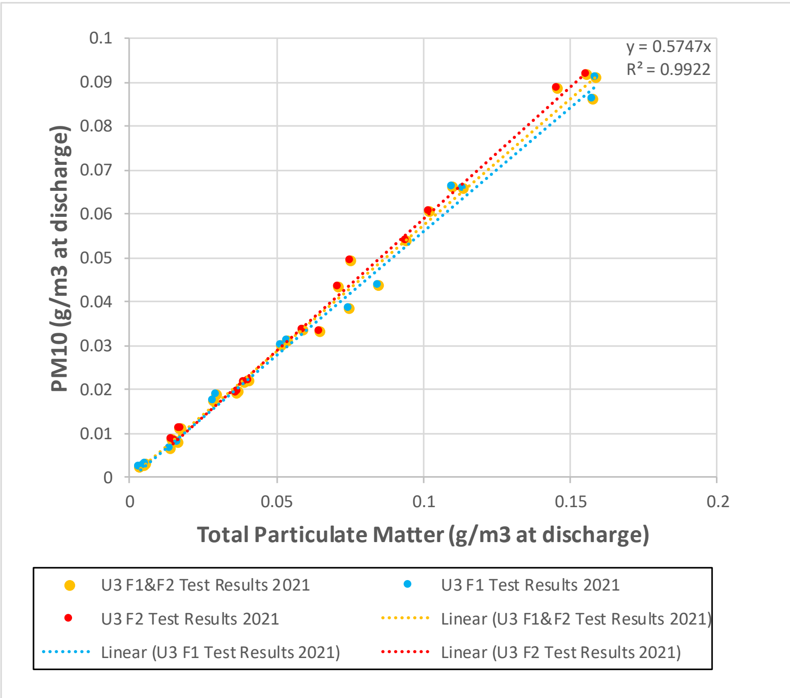


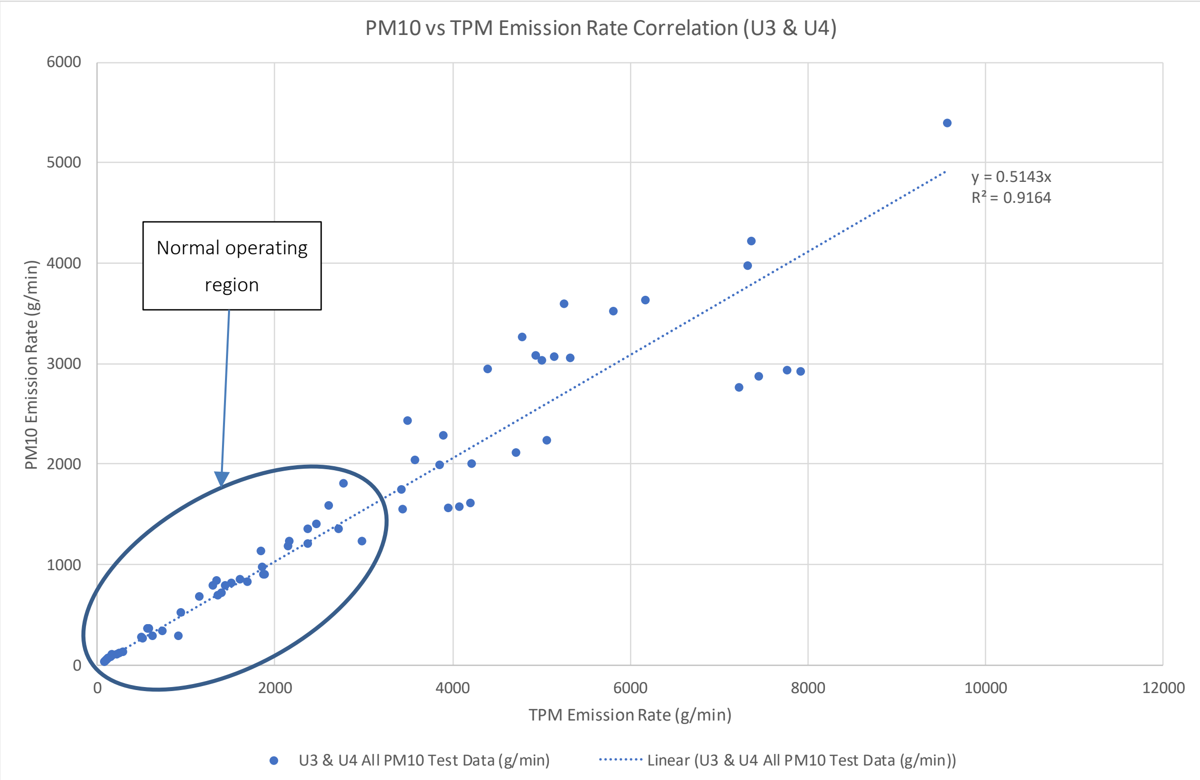
Figure 8: Correlations between PM_{10} and TPM for Unit 3



A significant number of measurements associated with PM_{10} emissions from Unit 4, Flue 1 and 2, were found to diverge from the individual trendlines, while the results for Unit 3 showed much less divergence over a range of TPM emission rates. The divergence observed for Unit 4 becomes more pronounced at higher TPM emission rates. Also of note are the significantly different correlations between both PM_{10} and TPM emissions from Unit 4 Flues 1 & 2 individually (i.e. 0.5827 for Unit 4 Flue 1, 0.395 for Unit 4 Flue 2) and for all Unit 4 data combined (i.e. 0.4888), and between and PM_{10} and TPM emissions from Unit 3 Flues 1 & 2 combined (i.e. 0.5747 for all data for Unit 3).

Figure 9 presents a correlation between PM_{10} and TPM emission rates with all measurements from Units 3 and 4 combined. This chart highlights the potential for increasing divergence of measurements at higher TPM emission rates. The best-fit correlation coefficient for all data combined for Units 3 & 4 is 0.5143 and is clearly influenced by the large number of results in the 0 – 3000 g/min TPM emission range, which is well away from the 90th percentile region (i.e. closer to the Licence limits for TPM, $PM_{2.5}$ and PM_{10}).

Figure 9: Correlation between PM_{10} and TPM emission rates with all measurements for Unit 3 & 4



3.3 $PM_{2.5}$ and TPM Relationship

Measured emission concentrations of $PM_{2.5}$ are plotted against TPM, as shown in Figure 10 (Unit 4) and Figure 11 (Unit 3). Linear regression correlations relating $PM_{2.5}$ to TPM for each flue and for all data (from both flues) were once again obtained using the Microsoft Excel spreadsheet trendline "best fit" linear regression tool. As can be seen, a significant number of measurements associated with $PM_{2.5}$ emissions were found to diverge from the individual trendlines for both Units 3 and 4. Best fit correlations relating $PM_{2.5}$ to TPM were best when developed on an individual flue basis, rather than using all available measurements for each Unit (i.e. 0.2696 for Unit 4 Flue 1 compared to 0.1105 for Unit 4 Flue 2, or 0.19 for all measurements for Unit 4, and 0.3006 for Unit 3 Flue 1 compared to 0.2266 for Unit 3 Flue 2, or 0.2625 for all measurements for Unit 3).

Figure 10: Correlations between $PM_{2.5}$ and TPM for Units 4

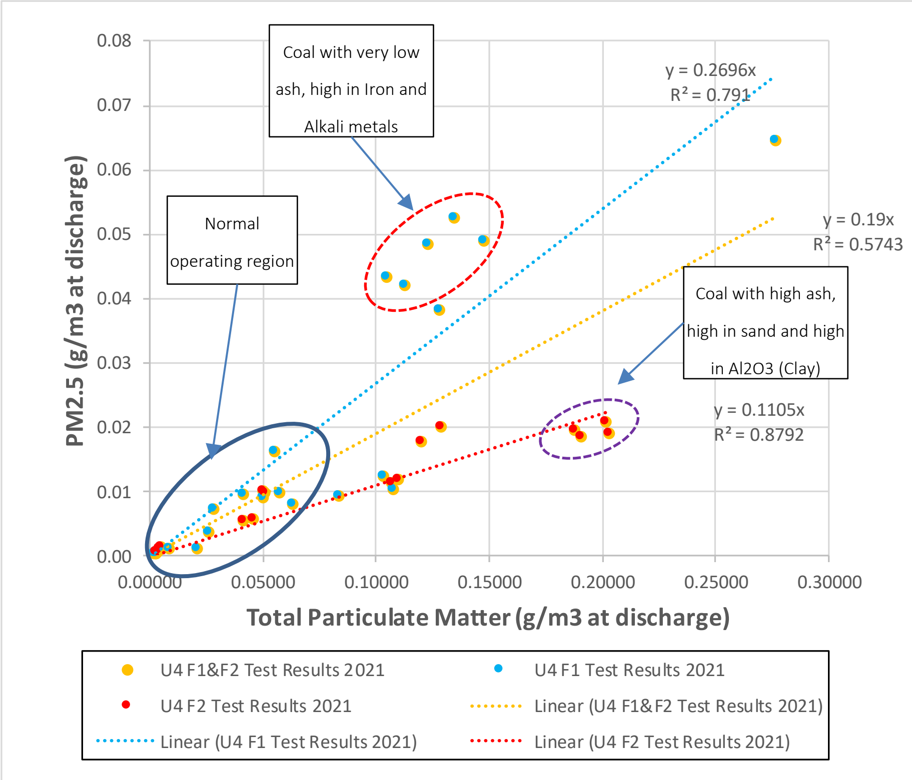


Figure 11: Correlations between $PM_{2.5}$ and TPM for Units 3

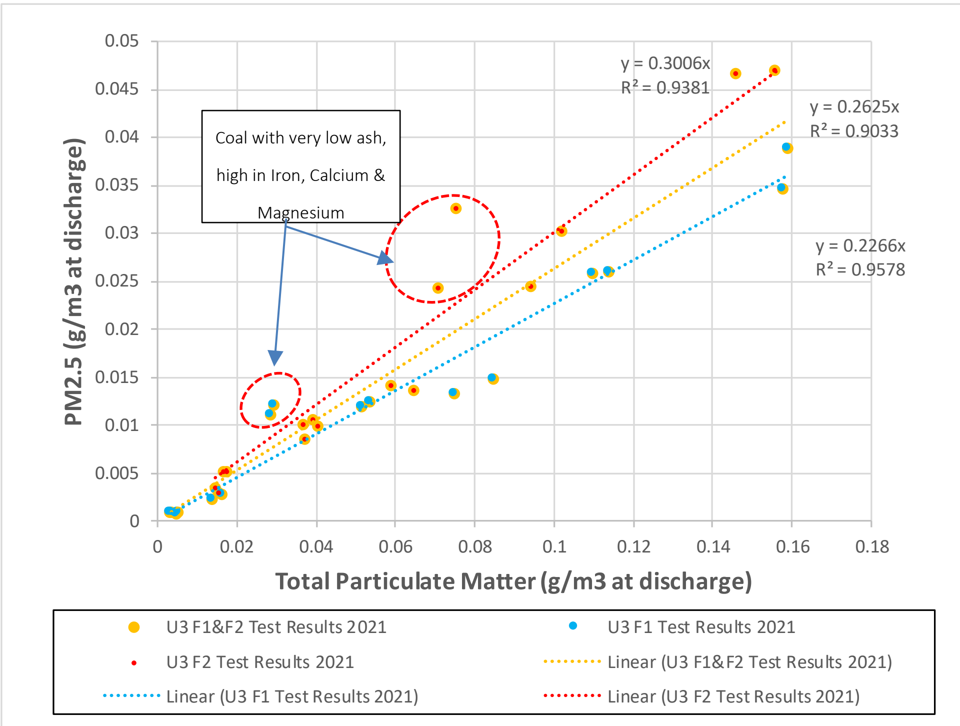
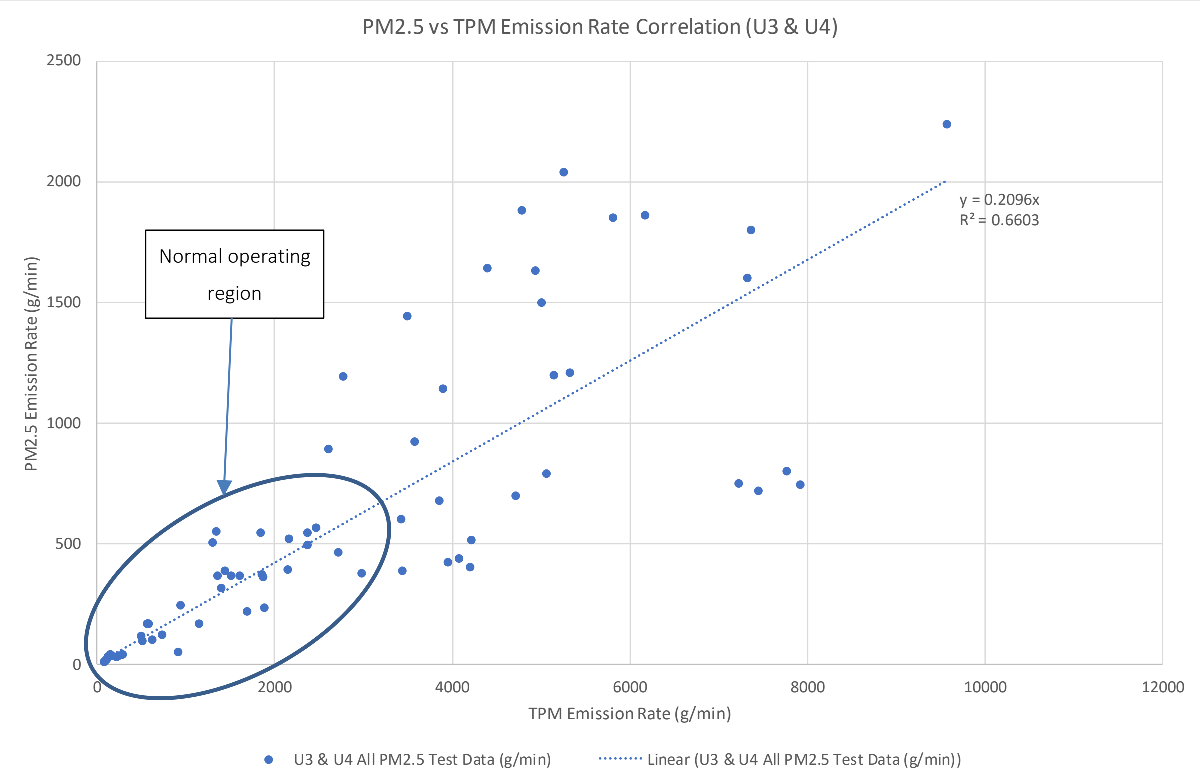


Figure 12 presents a correlation between $PM_{2.5}$ and TPM emission rates with all measurements from Units 3 and 4 combined. The $PM_{2.5}$ correlation shows a much greater level of divergence from the best fit trendline than for the PM_{10} correlation. The best-fit correlation coefficient for all data combined for Units 3 & 4 is 0.2096 and, like the PM_{10} correlation, is clearly influenced by the large number of results in the 0 – 3000 g/min TPM emission range and well away from the 90th percentile region. It is likely that measurement uncertainty contributes to variability in the results, especially for $PM_{2.5}$, due to the smaller concentrations of the finer particulates.

Figure 12: Correlation between $PM_{2.5}$ and TPM emission rates with all measurements for Unit 3 & 4



3.4 Analysis of Correlation Results

As discussed in section 1.1, there are numerous factors which can affect and influence the $PM_{2.5}$ / PM_{10} to TPM correlations. Each of these factors are reviewed in the light of the available data collected during the PM emissions monitoring program, and from historical stack testing campaigns.

3.4.1 Coal Quality

Coal grab samples were taken simultaneously during the stack testing campaigns for Units 3 and 4 to provide analytical information to assess the potential impacts of coal quality on the collection efficiency of the EDPs, which were being operated under normal conditions for the NPI and compliance tests, and under correlation test conditions for the Opacity Monitor correlation tests.

During the NPI testing period for Unit 4 flues 1 and 2 on 18-19 August 2021, coal quality displayed a typical moisture and low ash content, indicating minimal extraneous ash. The higher aluminium content indicates the possible presence of clay, while alkali content was at the average for the test period. The EDPs performed well and the measured PM_{10} / $PM_{2.5}$ emission results were grouped close to the zero end of the correlations for $PM_{2.5}$ / PM_{10} emissions as a function of TPM emissions as shown in Figure 7 and Figure 10.

At higher TPM emission rates, a greater divergence of measured PM_{10} / $PM_{2.5}$ emission rates was observed for Unit 4 PM_{10} and $PM_{2.5}$ test results and for Unit 3 $PM_{2.5}$ test results. Upon review of the coal analysis data from samples collected from the coal feeders to the mills during the corresponding stack testing periods, it was observed that those data points exhibiting significantly higher measured PM_{10} / $PM_{2.5}$ to TPM emission ratios all occurred when Unit 4 was processing coal with a particular set of characteristics. With reference to Figure 7 and Figure 10, the testing dates corresponding to the most divergent results above the best-fit trendline obtained from the 2021 Unit 4 stack testing campaign results occurred on 24 August 2021 and 1 & 2 September 2021. These results are circled in red in the charts presented in Figure 7 and Figure 10. All the most divergent PM_{10} / $PM_{2.5}$ emission data points above the best-fit trendline coincide with coal qualities exhibiting:

- low moisture and very low ash content i.e. expected to be predominantly inherent ash only, rather than extraneous ash associated with sandy interseam material or overburden;
- high iron content (as Fe_2O_3);
- high alkali metals content (as MgO, Na_2O and CaO);
- high in sulphates (SO_3); and
- low silica (SiO_2).

Similar observations are made in relation to the results from the Unit 3 testing campaign and specifically for the emission measurements for $PM_{2.5}$ taken on the 29th of November 2021 and the 1st of December 2021. Once again, the measured results that exhibited significant divergence from the trendline (i.e. higher than expected emission rates) were found to coincide with coal supplies that were very low in ash, low in moisture and relatively high in alkali metals, as indicated in Figure 11.

With reference to Figure 7 and Figure 10, the testing dates corresponding to the most divergent results below the best-fit trendline obtained from the 2021 Unit 4 stack test results occurred on 25-27 August 2021. These points are circled in purple in the charts presented in Figure 7 and Figure 10. All the most divergent PM_{10} / $PM_{2.5}$ emission data points below the best-fit trendline coincide with coal qualities exhibiting:

- high ash content i.e. expected to be predominantly from interseam material or overburden inherent ash only, rather than extraneous ash;
- elevated to high Aluminium content (as Al_2O_3), indicating the presence of clay; and
- high silica (SiO_2).

It was not possible to determine the carbon content of the fly ash collected during the testing campaigns, so the influence of carbon content on EDP performance could not be quantified as part of PM Program.

At low moisture and low ash content, the PM is expected to be finer, being associated with inherent ash rather than extraneous ash (which tends to be larger and heavier) and better combustion i.e. likely lower residual carbon content. The increased quantity of finer particles would be likely to result in higher PM_{10} and $PM_{2.5}$ particle emission rates – as were observed.

3.4.2 EDP Performance

The EDP performance is highly dependent on volumetric flow of gas per unit of precipitator area. When an EDP flow pair is taken out of service during normal operation the inlet and outlet dampers are closed. With no flow through the isolated flow pair, the flow through the remaining flow pairs is increased, while the collection area is reduced. Therefore, if one or more EDP flow pairs are taken out of service, for the same input conditions, it can be expected that there would be an increase in TPM emissions and a larger average particle size. During normal operation, flow pairs out of service due to scheduled maintenance or for repairs will have a similar impact by reducing available collection capacity (both as corona power and collection surface area).

However, there are other factors which influence EDP performance and collection efficiency (such as coal quality and EDP inlet particle size distribution), which are difficult if not impossible to accurately monitor, despite the significant amount of stack test data available from the emissions monitoring program of 2021/22 as well as historical data.

There are many variables that will affect not only collection efficiency but also the collection efficiency of each particle size, which will in turn affect the ratios of $PM_{2.5}$ and PM_{10} to TPM. Attempting to correlate the impacts of EDP performance variables on PM emissions is therefore extremely complex and ultimately impossible given that it is not feasible to measure key parameters such as EDP inlet particle size distribution, coal and coal ash composition continuously in real-time.

3.4.3 Combustion and Boiler Plant Performance

Combustion and boiler plant performance depend on numerous factors, including operating load, coal quality, mills in service and mill performance (which is also related to coal quality and impacts particle size distribution of the PF), burner performance, classifier and swirler performance and secondary combustion air flows. Since the boilers and associated ductwork operate under slight vacuum conditions, air in-leakage, known as tramp air, can add to both combustion air flow and overall flue gas flows. Each of these factors influences combustion conditions, the level of unburnt carbon in fly ash and the particle size distribution at the inlet to the EDPs. When in full load operation, the Unit is operated generally with 7 out of 8 mills in service (occasionally with 6), with 1 on routine outage. Mill throughput is increased by increasing beater wheel speed. Operating with 7 mills in service is preferred (rather than 6) to limit erosion.

Milling performance, in terms of PF size or coal drying is not monitored in real-time at LYA, consequently, the influence of mill performance and pulverised fuel size or drying was not directly monitored during the emissions monitoring program.

3.4.4 Plant Operating Conditions

During stack testing for developing the TPM vs PM CEMS response correlations, it is desirable for the Unit undergoing testing to be operating stably and near to nameplate generation capacity. While such operation means that subtle impacts of variations in generation capacity on TPM emissions may not be directly observed, this is not expected to be detrimental to the development of a correlation, since operation under conditions likely to produce higher emissions are more relevant when assessing the 90^{th} percentile $PM_{2.5}$ and PM_{10} annual frequency distributions. As such, operation at or near to full capacity is considered preferable for correlation development.

Data from the Unit data historian indicates that both Units were operating at or near to nameplate capacity for most of the testing campaigns, with a little more variability (83 – 100% capacity) experienced during the Unit 4 testing campaign compared to the Unit 3 testing campaign (~95 – 100% capacity).

3.5 Using TPM as a Surrogate to Predict Fine and Coarse Particle Emissions

The EPA rightfully acknowledged in the "Support to Comply" guidance in relation to condition LI_DA4.3 the technological challenges of monitoring PM_{10} and $PM_{2.5}$ emissions in real-time. As such, the EPA supports the use of surrogate methods, together with stack testing, to achieve the understood EPA objective of establishing a rolling average real-time calculation of the 90th percentile annual frequency distribution of PM_{10} and $PM_{2.5}$ emissions, for compliance monitoring purposes. Using TPM emission measurements as a surrogate for predicting PM_{10} and $PM_{2.5}$ emissions, which is necessary to establish a meaningful rolling 90th percentile annual frequency distribution for PM_{10} and $PM_{2.5}$ emissions, requires multiple correlations and ideally, minimal correlation uncertainty.

Estimation of the 90th percentile annual frequency distribution of $PM_{2.5}$ emissions requires:

a) A correlation between TPM emission concentration and optical density (as measured by the Opacity Monitors), then conversion of calculated TPM emission concentrations (mg/m^3) to mass emission rates (g/min) using the results of continuous flue gas flow monitoring, and
b) A correlation between TPM mass emission rate and $PM_{2.5}$ mass emission rate.

Estimation of the 90th percentile annual frequency distribution of PM_{10} emissions requires:

a) A correlation between TPM emission concentration and optical density (as measured by the Opacity Monitors), then conversion of calculated PM_{10} emission concentrations (mg/m^3) to mass emission rates (g/min) using the results of continuous flue gas flow monitoring, and
b) A correlation between TPM mass emission rate and the PM_{10} mass emission rate.

These correlations would be required to create the link between optical density, a continuous measure of TPM (monitored in real-time by the opacity monitors) and predicted PM_{10} and $PM_{2.5}$ emissions. However, as discussed in Section 3.4, these correlations cannot accurately account for the numerous variables relating to coal quality, EDP and Unit performance, as many of those variables are not or cannot be accurately monitored in real-time.

To understand the suitability of the correlation for predicting emission rates (g/min) for both PM_{10} and $PM_{2.5}$ the error between the predicted emission rate and the actual measured emission rate was determined and plotted against the measured values, as shown in Figure 13 (PM_{10}) and Figure 14 ($PM_{2.5}$).

As can be seen in Figure 13 and Figure 14, correlation errors between predicted and measured PM_{10} and $PM_{2.5}$ emission rates were lower for Unit 3 than for Unit 4, due to less variability in coal quality and composition during the Unit 3 testing campaign. In addition, correlation errors were significantly smaller for PM_{10} than for $PM_{2.5}$. Using all available analytical data from Unit 3 and 4 testing campaigns, best-fit linear correlation uncertainty/error as a percentage (i.e. the difference between measurement and prediction divided by the measurement x 100%) ranged from +26% to -59% for predicted PM_{10} emission rates, though most results were within an error band of ±20%. However, for predicted $PM_{2.5}$ emission rates, the correlation uncertainty/error ranged from +51% to -264%, though most results were within an error band of +50% and -100%. The largest errors related to Unit 4 measurements and appear to result from the effects of coal quality and composition as discussed in Section 3.4.1.

It is noted that the error is dependent on the variability of key parameters over the testing period. Given the potential for a larger range of plant operation and coal quality variability over an entire year of operation, the correlation error is likely to be substantially higher on an annual basis.

Figure 13: Correlation error for PM_{10} plotted against the measured data for Units 4 & 3

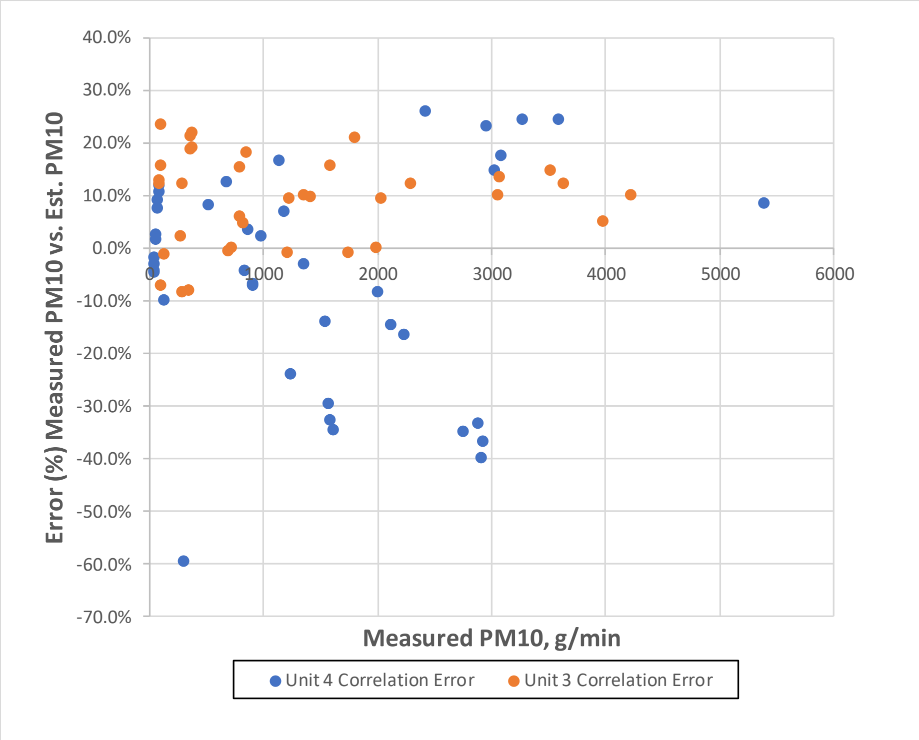
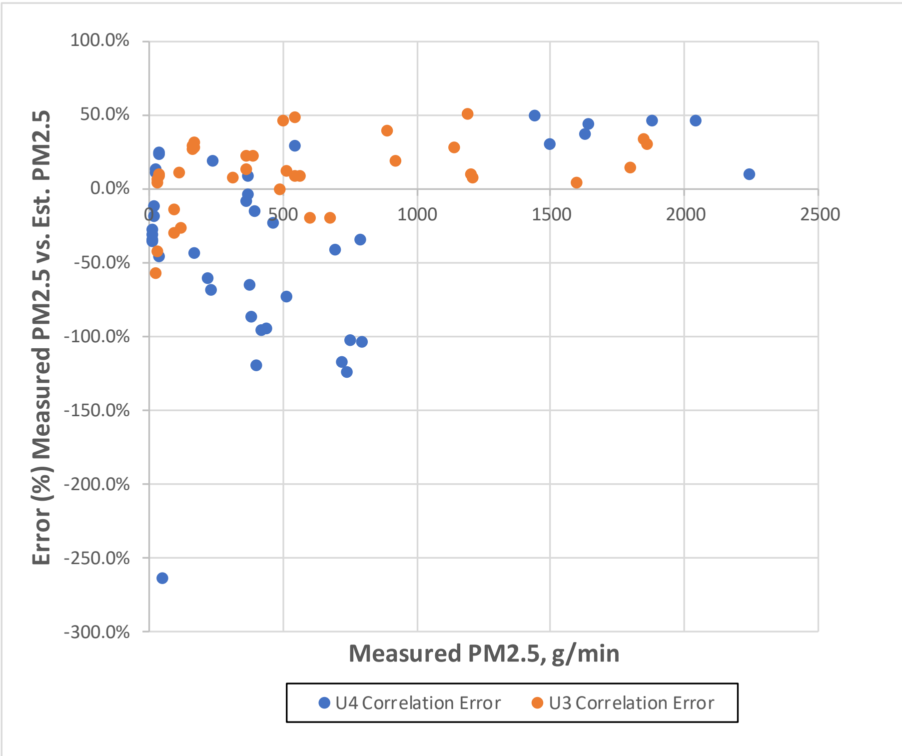


Figure 14: Correlation error for $PM_{2.5}$ plotted against the measured data for Units 4 & 3



3.6 Annual 90th Percentile Distributions

The EPA has acknowledged the technological challenges of monitoring PM_{10} and $PM_{2.5}$ emissions in real-time. As such, the EPA supports the use of surrogate methods, together with stack testing, to achieve the expected EPA objective of establishing a rolling average real-time calculation of the 90th percentile annual frequency distribution of PM_{10} and $PM_{2.5}$ emissions, for compliance monitoring purposes.

To account for the high degree of uncertainty (especially for $PM_{2.5}$), if the EPA were to introduce a rolling annual 90th percentile limit for PM_{10} and/or $PM_{2.5}$ then it would be necessary to assume 'Upper' bound ratios multiplied by the current Licence 90th percentile TPM annual rolling average limit (16,200 g/min).

Figure 15 shows the average equation, 'Upper' bound equation and 'Lower' bound equation for the PM_{10} versus TPM results. The Upper and Lower bounds were set such that 90% of the measured test data is within the Upper and Lower bounds. Therefore, if a rolling annual 90th percentile PM_{10} limit were set, this would be:

Rolling Annual 90th Percentile PM_{10} emission rate = 16,200 g/min x 0.675 = 10,935 g/min

This compares to the current LYA maximum licence limit for PM_{10} of 30,800 g/min. However, for real time monitoring of PM_{10} emissions, the 0.5143 x TPM "best fit" correlation could be used.

Figure 15: PM_{10} to TPM emission rate correlation with Upper Bound ratio

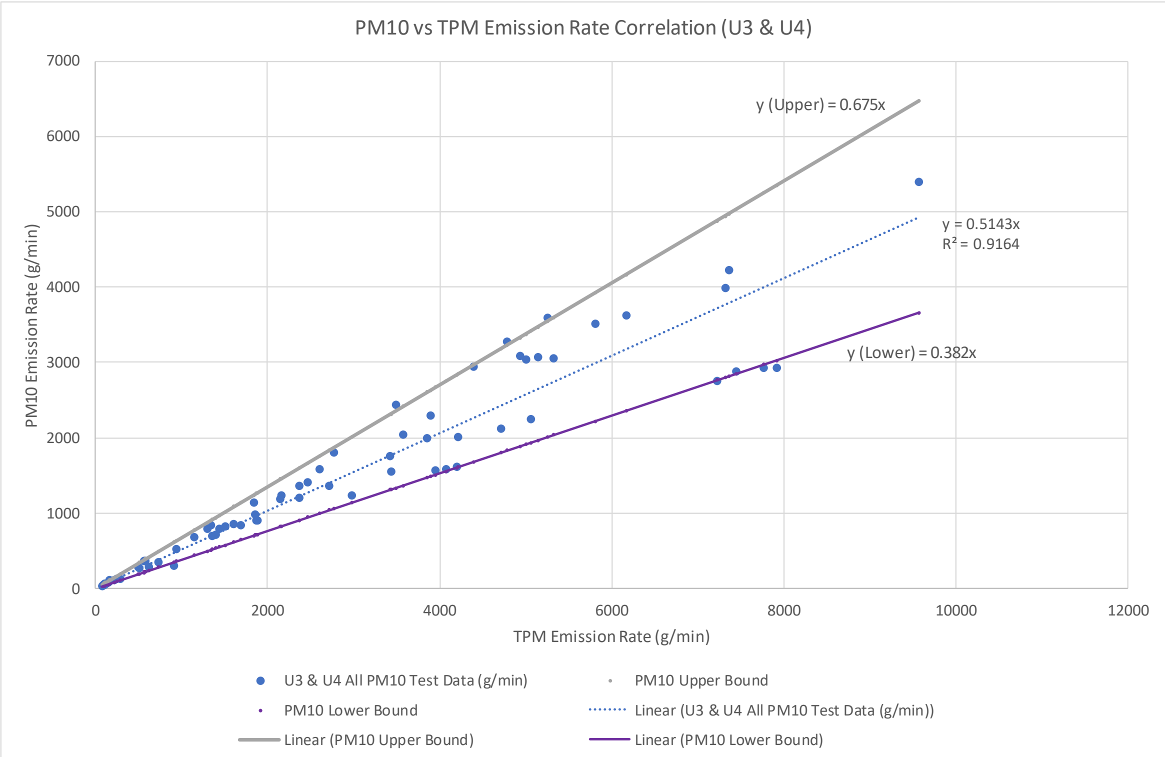
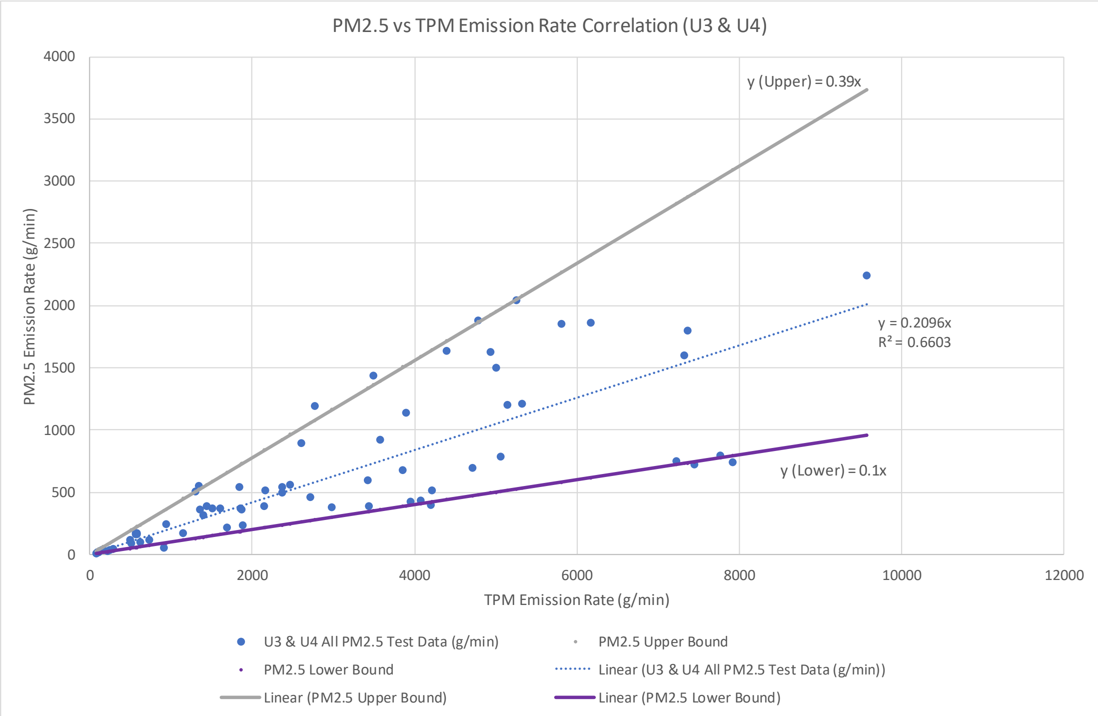


Figure 16 shows the average equation, 'Upper' bound equation and 'Lower' bound equation for the $PM_{2.5}$ versus TPM results. The Upper and Lower bounds were set such that 90% of the measured test data is within the Upper and Lower bounds. Therefore, if a rolling annual 90th percentile $PM_{2.5}$ limit were set, this would be:

Rolling Annual 90th Percentile $PM_{2.5}$ emission rate = 16,200 g/min x 0.39 = 6,318 g/min

This compares to the current LYA maximum licence limit for $PM_{2.5}$ of 15,800 g/min. However, for real time monitoring of $PM_{2.5}$ emissions, the 0.2096 x TPM "best fit" correlation could be used.

Figure 16: $PM_{2.5}$ to TPM emission rate correlation with Upper Bound ratio



Given the large number of variables impacting TPM, $PM_{2.5}$ and PM_{10} emissions at any point in time, the outcomes of the PM Program confirm that it is not feasible to obtain accurate correlations for predicting PM10 and PM2.5 emissions at LYA, using TPM measurements as a surrogate. However, a possible approach to achieve the EPA's understood objective of continuously monitoring emissions of PM_{10} and $PM_{2.5}$ at LYA is as follows:

- For the purpose of establishing a rolling annual 90th percentile PM_{10} mass emission rate limit for LYA, apply a PM_{10} to TPM mass emission rate correlation coefficient corresponding to the Upper Bound (i.e. 0.675 x TPM), based on all available test data for LYA, to the Licence 90th percentile TPM mass emission rate limit for LYA (i.e. 0.675 x 16,200 g/min = 10,935 g/min).
- For the purpose of establishing the rolling annual 90th percentile $PM_{2.5}$ mass emission rate limit for LYA, apply a TPM to $PM_{2.5}$ mass emission correlation coefficient corresponding to the Upper Bound (i.e. 0.39 x TPM), based on all available test data for LYA, to the Licence 90th percentile TPM mass emission rate limit for LYA (i.e. 0.39 x 16,200 g/min = 6,318 g/min).
- For the purpose of determining the rolling 90th percentile for compliance purposes, apply the best-fit (average) PM_{10} to TPM and $PM_{2.5}$ to TPM correlation coefficients obtained from all available test data for LYA (i.e. 0.5143 x TPM for PM_{10} and 0.2096 x TPM for $PM_{2.5}$), to the measured rolling average 90th percentile TPM mass emission rate for LYA.

HRL understands that AGL Loy Yang will discuss these options with the EPA.

4 References

The following Ektimo stack testing reports were referenced by the PM Program:

Ektimo Report No.	Report Title	Comment
R009874	2021 - Dust Meter Correlation Programme, Boiler Unit 4 – Flue 1 & Flue 2, AGL LY	Includes TPM, PM_{10} / $PM_{2.5}$ for Unit 4 - Flue 1 & 2
R009707	2021-22 Financial Year Boiler Unit 4 – EPA Compliance + NPI Monitoring, AGL LY	Includes TPM, PM_{10} / $PM_{2.5}$ for Unit 4 - Flue 1 & 2
R011732	Particulate Matter Assessment, Unit 4 – Flue 1, AGL Loy Yang, Traralgon South	Includes TPM, PM_{10} / $PM_{2.5}$ for Unit 4 - Flue 1
R011866	Dust Meter Correlation Programme, Boiler Unit 3 – Flue 1 & Flue 2, AGL Loy Yang, Traralgon South	Includes TPM, PM_{10} / $PM_{2.5}$ for Unit 3 - Flue 1 & 2