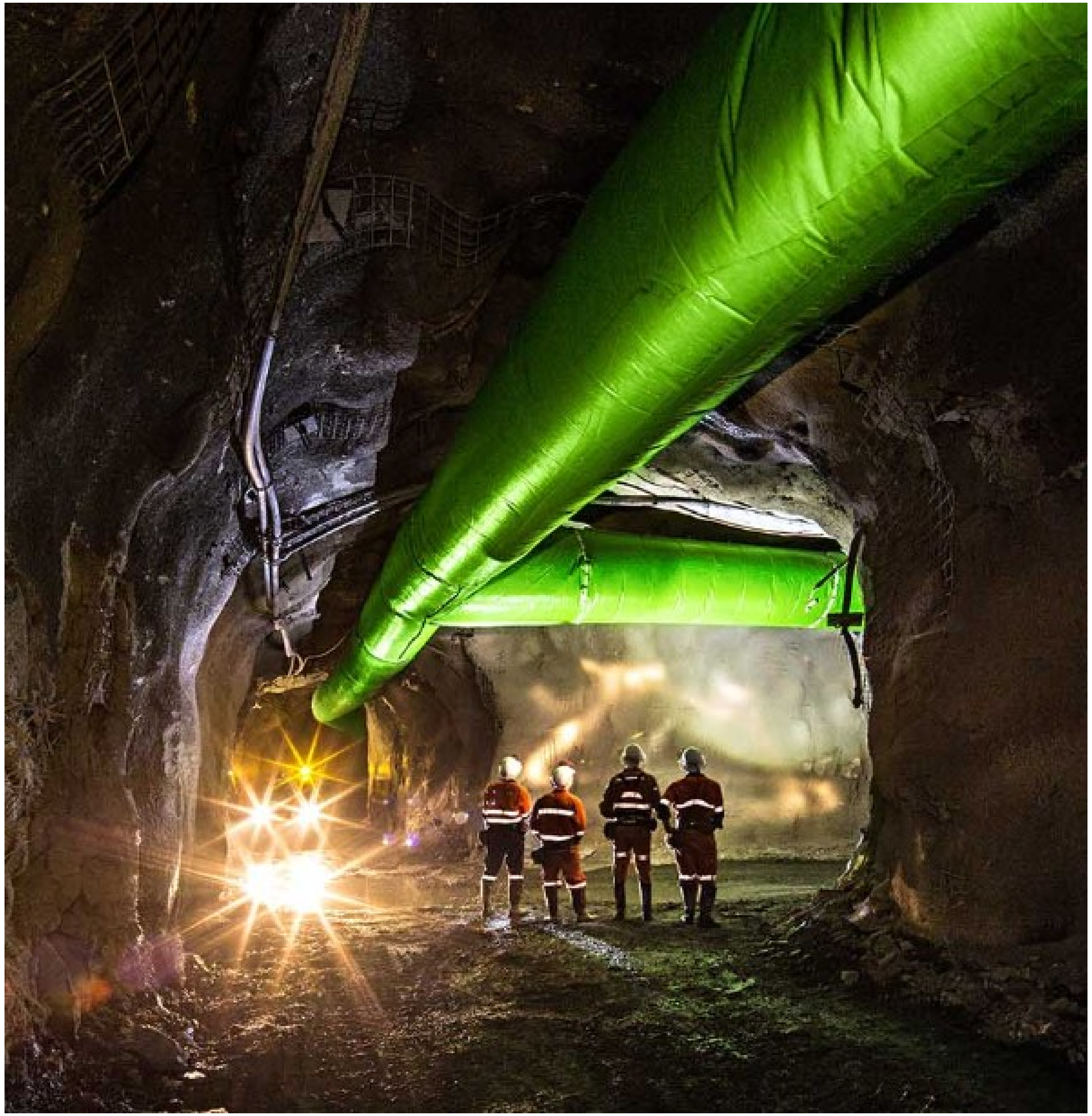
Implementation of CANMET Ventilation Rates and Regulation 854 Changes

Overview of updates, challenges, and technical solutions



Meeting Program

- Regulatory Changes Affecting Ventilation and Emissions
- Challenges in enacting the regulation changes
- Technical Solutions to enact regulation changes
- Validation of Technical Solution Approach
- Social Challenges and Stakeholder Concerns

Regulatory Changes Affecting Ventilation and Emissions

Section 183.1: Airflow Rates for Diesel Equipment

Certified Equipment

Diesel equipment certified in accordance to CSA M424.2 must maintain airflow matching the ventilation rate on the certificate of homologation provided by CanmetMINING.

Non-Certified Equipment Airflow

Non-certified equipment requires airflow of 0.06 cubic meters per second per kilowatt, known as the 100 CFM rule.

Modified Equipment Airflow Determination

For modified equipment (e.g. equipped with a DPF) not recertified, non-certified equipment airflow applies.

Section 183.2: Occupational Exposure Limit for Elemental Carbon

Previous Exposure Limit

The former limit was 0.4 milligrams per cubic meter of air measured as total carbon.

Current Exposure Limit

The updated limit is 0.12 milligrams per cubic meter of air measured as elemental carbon, 30% of former level.

Challenges in Enacting the Regulation Changes

Impact of CANMET Ventilation Rates and Emission Reduction Requirements

Potential Reduction in Ventilation

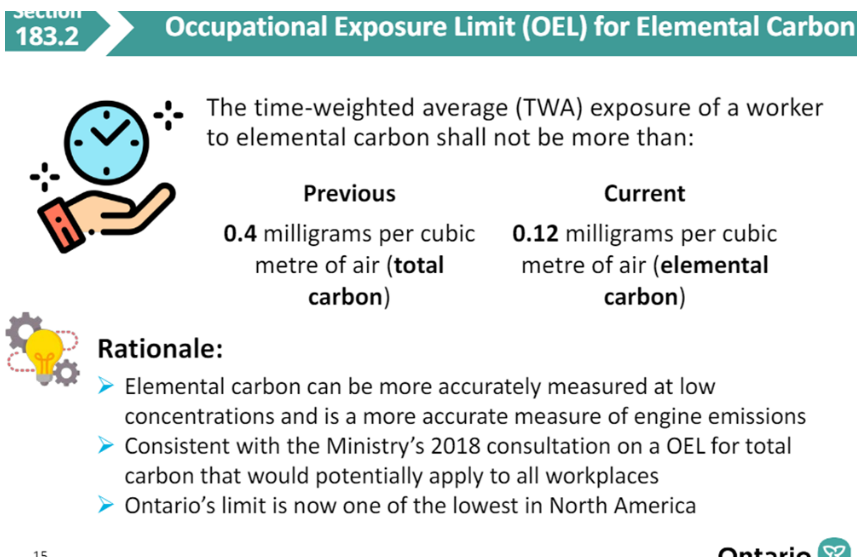
Regulation 854 allowed use of CANMET tested CSA M424.2 ventilation rates, lowering required airflow for diesel equipment.

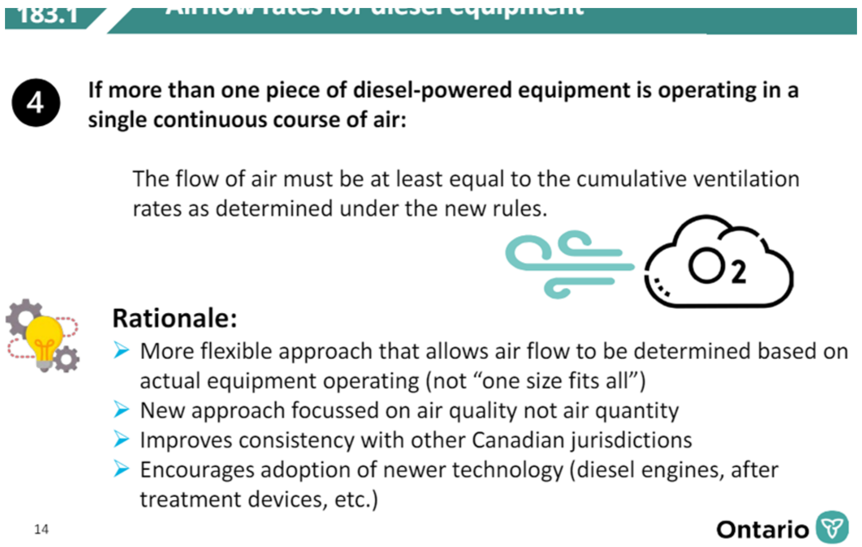
Emission Reduction

Elemental carbon emissions in the workplace were reduced from 0.4 to 0.12 (or 30% of former levels) and prompted the installation of DPFs on our equipment

Regulatory Conundrum for our operations

When engine and DPF combinations lacked tested M424.2 ventilation rates, the required ventilation rate reverts to 100 CFM/BHP.





How did we address the Conundrum

The new regulations provide us with a guide in the case of equipment being modified with a DPF

Ministry of Labour, Immigration, Training and Skills Development

Section 183.1 **Airflow rates for diesel equipment**

3 **If equipment is modified with a DPF or after-treatment device, but not certified or recertified under CSA M424.2 after modification:**

The employer may determine a suitable flow of air, in consultation with the JHSC or HSR, if any, that is based on:

- The applicable rates for the equipment prior to modification,
- Good engineering practices, and
- The results of testing, including emission levels produced after the installation of the DPF or after-treatment device.

Any DPF or after-treatment device is used on diesel equipment underground must be maintained in accordance with the manufacturer's recommendations.

Ontario

Technical Challenges

Creating a process for determining the suitable airflow rate was essential to allowing us to use the CANMET tested CSA Ventilation Rate.

The process was created around addressing the points in the regulation

- What applicable rates for the equipment prior to modification would we apply?
- What were the good engineering practices?
- What would we test and how would we set limits

And keeping to the following principles

- The gaseous emissions after the DPF can never exceed the limits for CO and NO_2 as stated in regulation 854
- Their should be an overall net benefit with the installation
- The gaseous emissions after the DPF should, in general, be unaltered or lower than the gaseous emissions without a DPF
- The DPF should considerably lower the amount of DPM emitted from the tailpipe

Technically applying the Principles

[redacted]

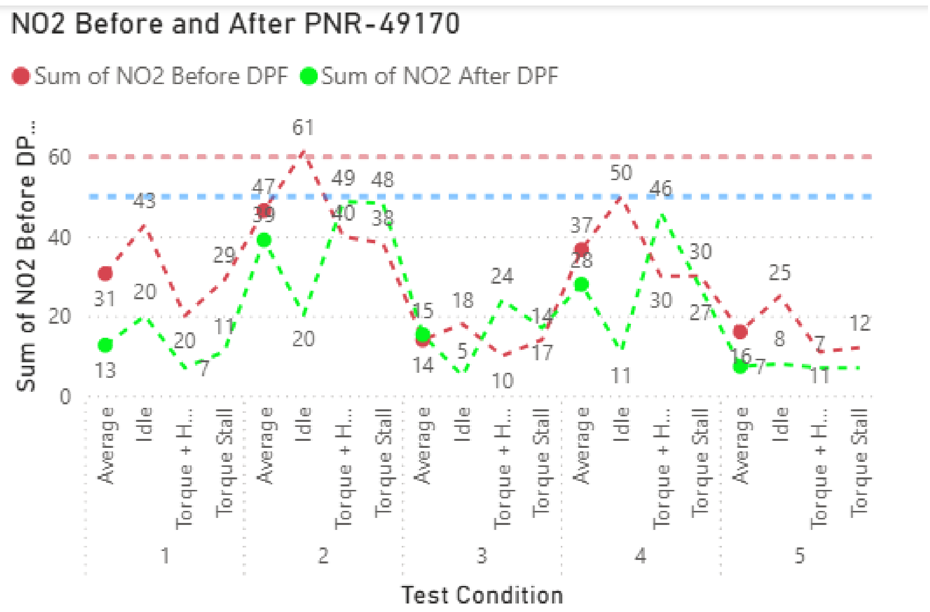
Applicable Rates

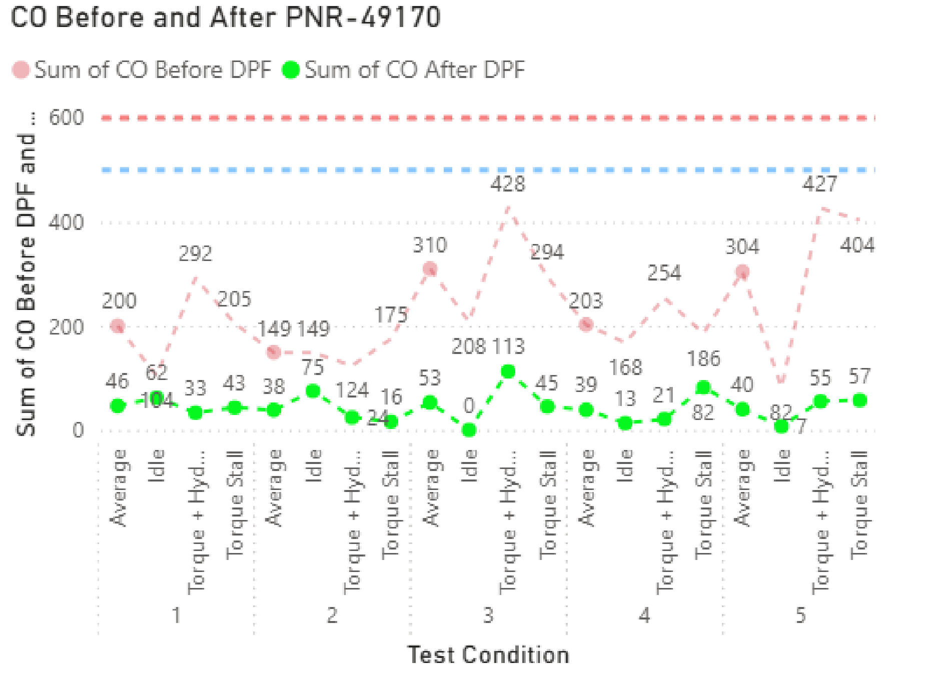
- CSA ventilation rates (before installation of DPF)
- CO, NO_2 Limits as set forth in Reg 854 and Vale

Principle that applies and its application:

The gaseous emissions after the DPF can never exceed the limits for CO and NO_2 as stated in regulation 854

- CO, CO_2, NO, NO_2, and NO_X Emissions to meet or fall below current Regulatory and/or Vale requirements (Vale Emissions requirements for CO and NO_2 are lower than regulation 854.





Good Engineering Practices and Testing Methods

Application of Proven Techniques

Use existing, proven engineering concepts and techniques to determine if there is a net benefit of installing a Diesel Particulate Filter (DPF).

Exhaust Quality Index (EQI)

Compare the Exhaust Quality Index before and after DPF installation to assess exhaust improvements effectively.

Particle Filter Testing Methods

Implement VERT testing methods for particle filter systems to compare exhaust gas after-treatment performance.

MAnufacturer's ProTocol
for
Exhaust Systems Testing
(MAPTEST)

Document Number MMSL 97-064 (CR)
September 1997

DEEPROC POSITION REGARDING SYSTEM EVALUATION CRITERIA:

1) Any reduction in the concentration of a diesel exhaust pollutant is deemed by DEEPROC to be beneficial.

2) Irrespective of variations in individual pollutants, an overall reduction in the value of the Exhaust Quality Index (EQI), is deemed beneficial (see EQI background description in Appendix I; & definition on p. 5).

3) In applications where the engine is 'certified', the addon system performance should not cause an increase in the concentration of any individual pollutant above that specified in the pertinent certification standard.

CALCULATION OF EMISSIONS SYSTEM EFFECTIVENESS (ESE):

Step 1:
For each set of engine operating conditions, the comprehensive emissions quality will be calculated using the Exhaust Quality Index (EQI) criterion in order to provide a universally applicable basis for performance assessment of engine and exhaust treatment systems. It should be noted that higher values of the Index correspond to lower values of emissions quality.

The EQI equation is defined as follows:

$$EQI = \frac{CO}{50} + \frac{NO}{25} + \frac{DPM}{2} + 1.5\left[\frac{SO_2}{3} + \frac{DPM}{2}\right] + 1.2\left[\frac{NO_2}{3} + \frac{DPM}{2}\right]$$

where the gases are in units of ppm and DPM in mg/m^3 of dry exhaust gas.

Principle

There should be an overall net benefit with the installation

Exhaust Quality Index

MAnufacturer's **Pro**T**o**col for **E**xhaust **S**ystems **T**esting (**MAPTEST**)

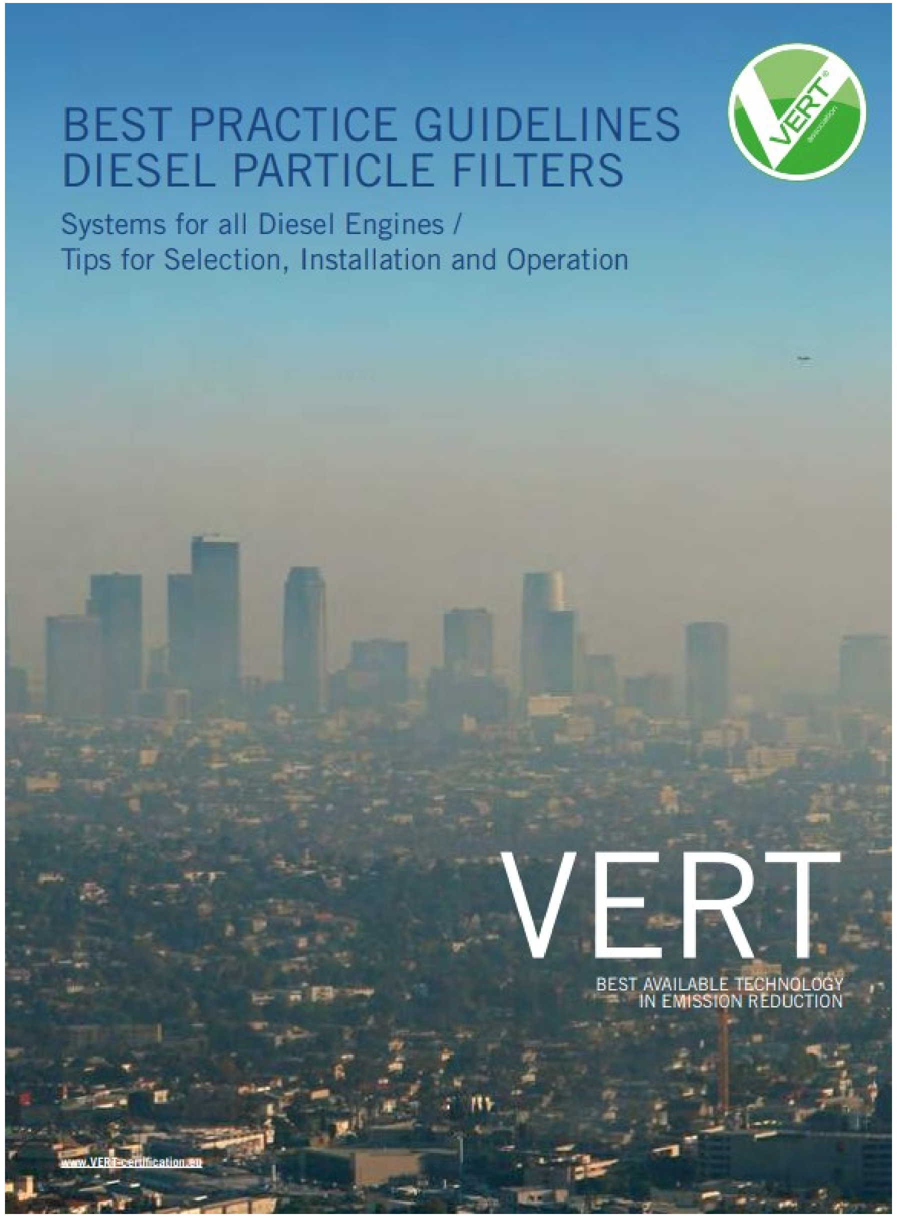
EQI was formerly used in the CSA M424.2 – 16 calculation to determine ventilation Rate

Method

- CO, NO, DPM, NO_2 are measured before and after the DPF and applied to the EQI equation

How do we use EQI to apply the principle

- If the EQI $_{after}$ is less than EQI $_{before}$ there is a net benefit



Principle

- The gaseous emissions after the DPF should, in general, be unaltered or lower than the gaseous emissions without a DPF

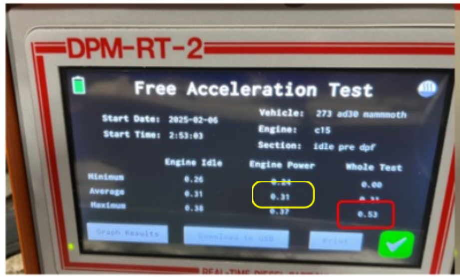
Vert Basis

Prohibition of "relevant" increases: The VERT standards mandate that, compared to a baseline engine, there must be no "relevant" increase in specific toxic compounds in the treated exhaust gas.

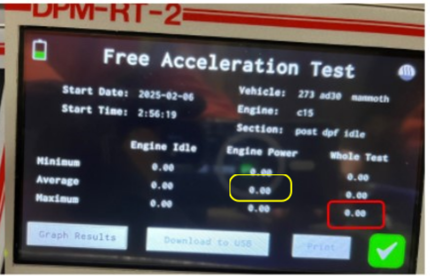
How do we use the VERT basis to apply the principle

- **For Nitrogen Dioxide (NO2):** A limit is placed on the average increase of NO2 relative to the baseline nitrogen monoxide (NO) emissions. For systems certified after 2016, the NO2 increase cannot exceed 20% of the upstream NO value. This is mathematically expressed as:
    - $(NO_{2After\ DPF} – NO_{2Before\ DPF}) / NO_{After} < 20\%$
- Additionally, we placed limits on:
    - The increase on NO_2 relative to the upstream NO_X value ($NO_X = NO_2 + NOx$) to no more than 5%. This is mathematically expressed as:
        - $(NO_{2After\ DPF} – NO_{2Before\ DPF}) / NOx_{After} < 5\%$
    - The increase in CO relative to the upstream CO value to no more than 5%. This is mathematically expressed as:
        - $CO_{\ After\ DPF} – CO_{\ Before\ DPF}) / CO_{\ After\ DPF} <5\%$

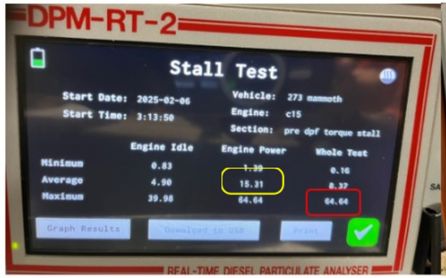
Idle DPM Test -Pre DPF



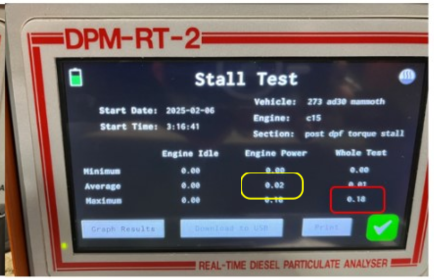
Idle DPM Test – Post DPF



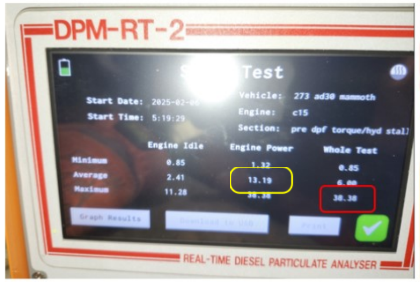
Torque Stall – Pre DPF



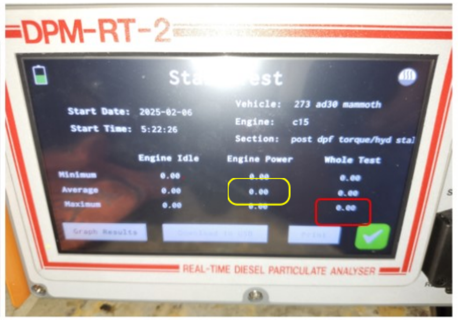
Torque Stall - Post DPF



Torque + Hydraulic Stall DPM Test– Pre DPF



Torque + Hydraulic Stall DPM Test – Post DPF



Principle

The DPF should considerably lower the amount of DPM emitted from the tailpipe

Before and After DPM Testing

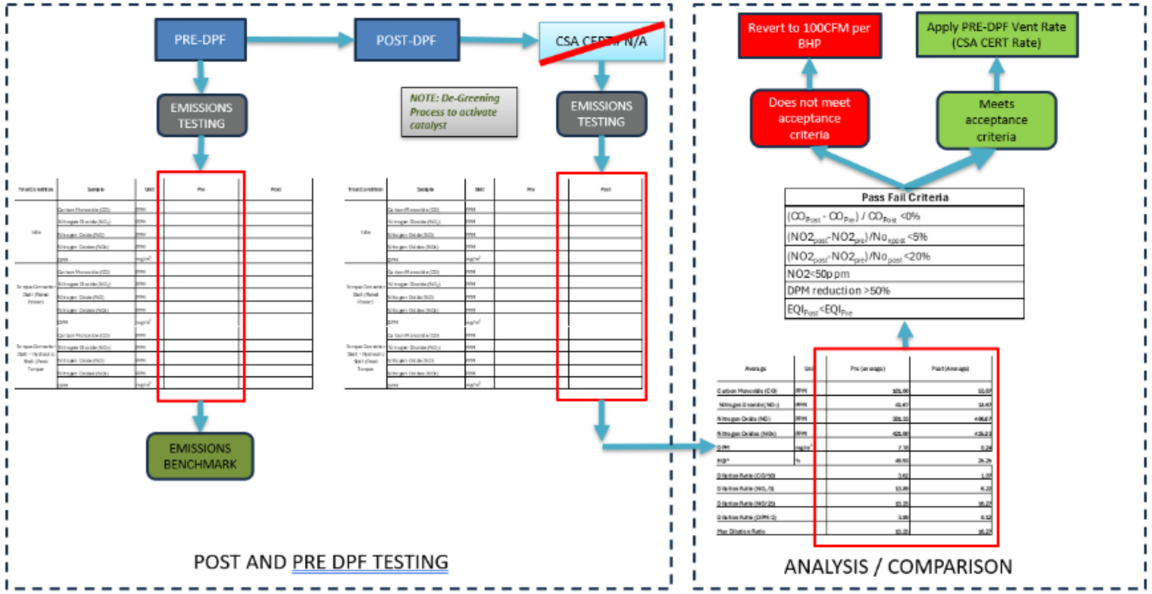
DPM is measured before and after the DPF in mg/m^3

How do we use these measurement to apply the principle

- If DPM after the filter has been reduced by 50% or more then there is a significant reduciton

PROCESS SUMMARY

3.1 FLOW DIAGRAM



NOTE If post DPF results fall outside the acceptance criteria, verify that installation or mechanical defects have not negatively influenced results.

PURPOSE

When a piece of equipment's engine exhaust system has been modified with a diesel particulate filter or similar after-treatment device, the CSA Ventilation rating for that engine is no longer valid and, at a minimum, we would revert to the diesel engine ventilation rating of 100 CFM per BHP.

This guideline outlines Vale's requirements for reinstating the original CSA ventilation rate for the new engine/DPF combination, and follows Ontario Regulations 854 section 183.1(1) rule 3, using the following elements:

- Good engineering practice
- Consultation with the JHSC
- Testing results performed on the equipment.
- Consideration of CSA M424.2 or earlier certification rate for the engine with or without an after-treatment device, if available.
- Maintenance of records of
  - the suitable assigned flow of air
  - all testing results,
  - calculations,
  - and any other relevant information used to determine the new airflow rate

OTHER CONSIDERATIONS

This guideline is specific to reinstating the original CANMET vent rate for diesel emissions at the tailpipe (or wherever the emissions are exhausted to the atmosphere) only.

Diesel emissions at the tailpipe are one component of the Airborne Hazard Management Program (AHMP).

The AHMP shall be consulted in its entirety to determine an appropriate total vent rate to maintain workplace air quality.

Test Inputs

Trial Condition	Sample	Unit	Pre	Post
Idle	Carbon Monoxide (CO)	PPM	149	75
	Nitrogen Dioxide (NO_2)	PPM	61.3	20.3
	Nitrogen Oxide (NO)	PPM	517.8	611.7
	Nitrogen Oxides (NOx)	PPM	579.1	632
	DPM	mg/m³	9.46	0.03
Torque Convertor Stall (Rated Power)	Carbon Monoxide (CO)	PPM	175	16
	Nitrogen Dioxide (NO_2)	PPM	38.3	48.3
	Nitrogen Oxide (NO)	PPM	525.5	469.2
	Nitrogen Oxides (NOx)	PPM	563.8	517.5
	DPM	mg/m³	7.28	0.01
Torque Convertor Stall + Hydraulic Stall (Peak Torque	Carbon Monoxide (CO)	PPM	124	24
	Nitrogen Dioxide (NO_2)	PPM	39.9	48.7
	Nitrogen Oxide (NO)	PPM	526.6	513.1
	Nitrogen Oxides (NOx)	PPM	566.5	561.8
	DPM	mg/m³	9.46	0.03

Test Outputs

Average	Unit	Pre (average)	Post (Average)
Carbon Monoxide (CO)	**PPM**	**149.33**	**38.33**
Nitrogen Dioxide (NO_2)	**PPM**	**46.50**	**39.10**
Nitrogen Oxide (NO)	**PPM**	**523.30**	**531.33**
Nitrogen Oxides (NOx)	**PPM**	**569.80**	**570.43**
DPM	**mg/m³**	**8.73**	**0.02**
EQI*	**%**	**58.68**	**37.70**
Dilution Ratio (CO/50)		**2.99**	**0.77**
Dilution Ratio (NO2/3)		**15.50**	**13.03**
Dilution Ratio (NO/25)		**20.93**	**21.25**
Dilution Ratio (DPM/2)		**4.37**	**0.01**

Pass Fail Criteria	Pass / Fail
$(CO_{Post} - CO_{Pre}) / CO_{Post}$ <0%	-290%
$(NO2_{post}-NO2_{pre})/No_{xpost}$ <5%	-1.3%
$(NO2_{post}-NO2_{pre})/No_{post}$ <20%	-1.39%
CO_{Post} < 500 ppm	38.33
NO_{Post} < 700 ppm	531.33
$NO_{2\ Post}$ < 50ppm	39
NO_{XPost} < 750 ppm	570.43
DPM reduction >50%	99.7%
EQI_{Post}<EQI_{Pre}	-21.0

Validation of Implementation Approach

Testing, Expert Review, and Consultation

Expert Internal Review

Internal subject matter experts reviewed the findings to ensure accuracy and adherence to standards.

Test Results Validation

Existing test data derived from DPF trials were applied against specific validation criteria.

External Consultation

Consulted with CANMET for compliance with Regulation 854 requirements to validate methodologies.

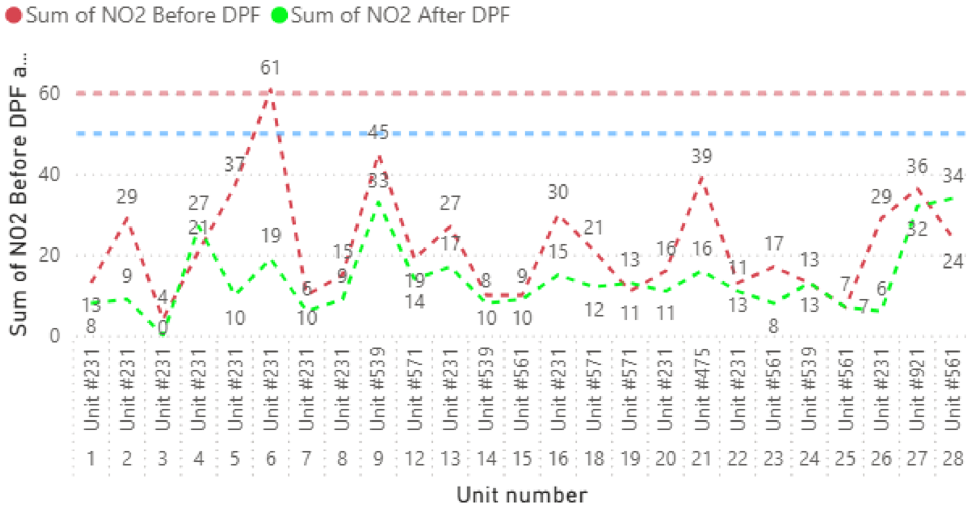
Leadership and Committee Oversight

Process reviewed with senior leadership to ensure organizational alignment and governance.

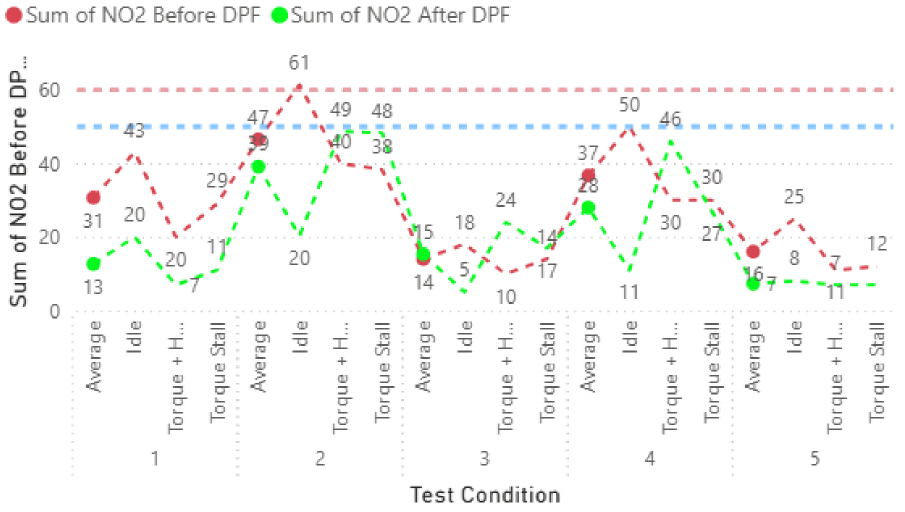
Applicable Rates

NO2, CO

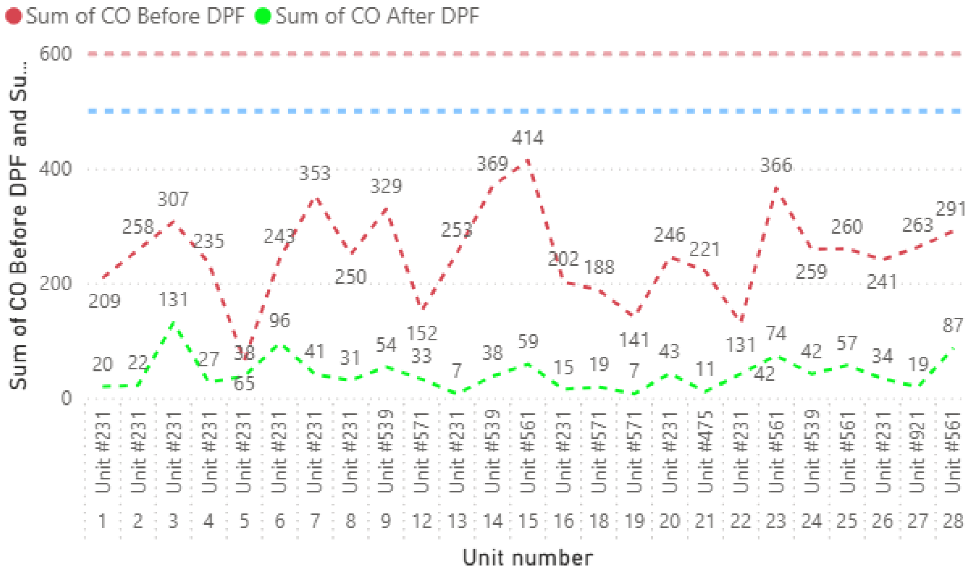
NO2 Before and After DPF Historci



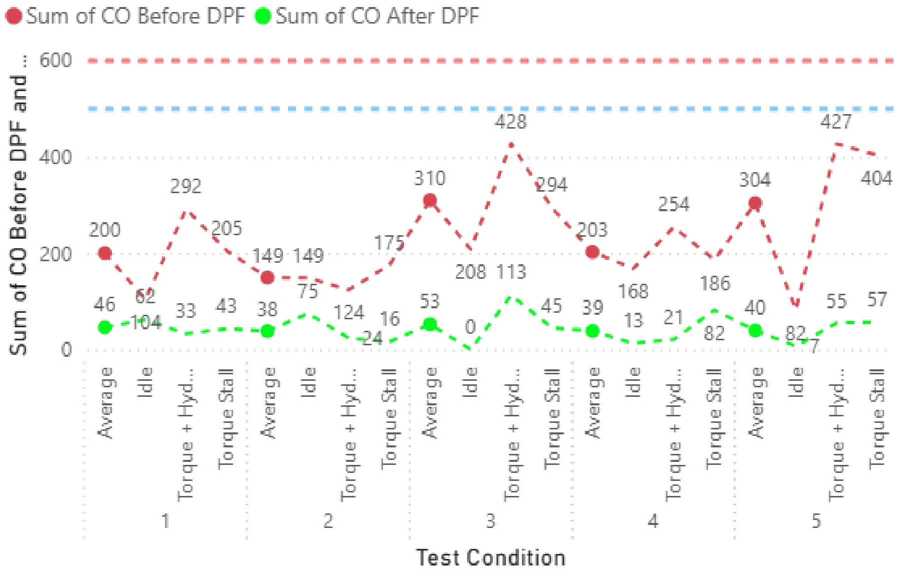
NO2 Before and After PNR-49170



CO Before and After Historic

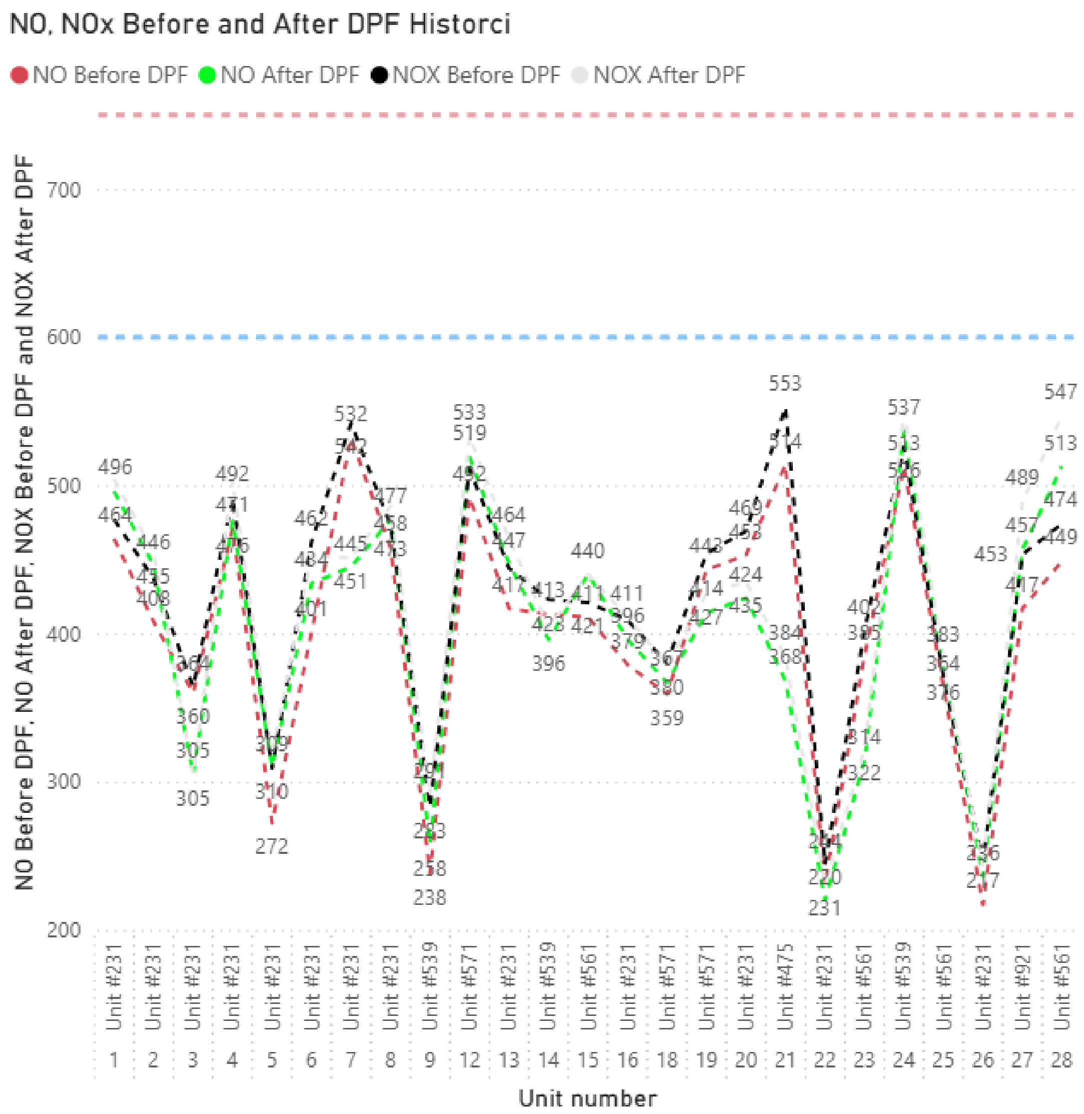


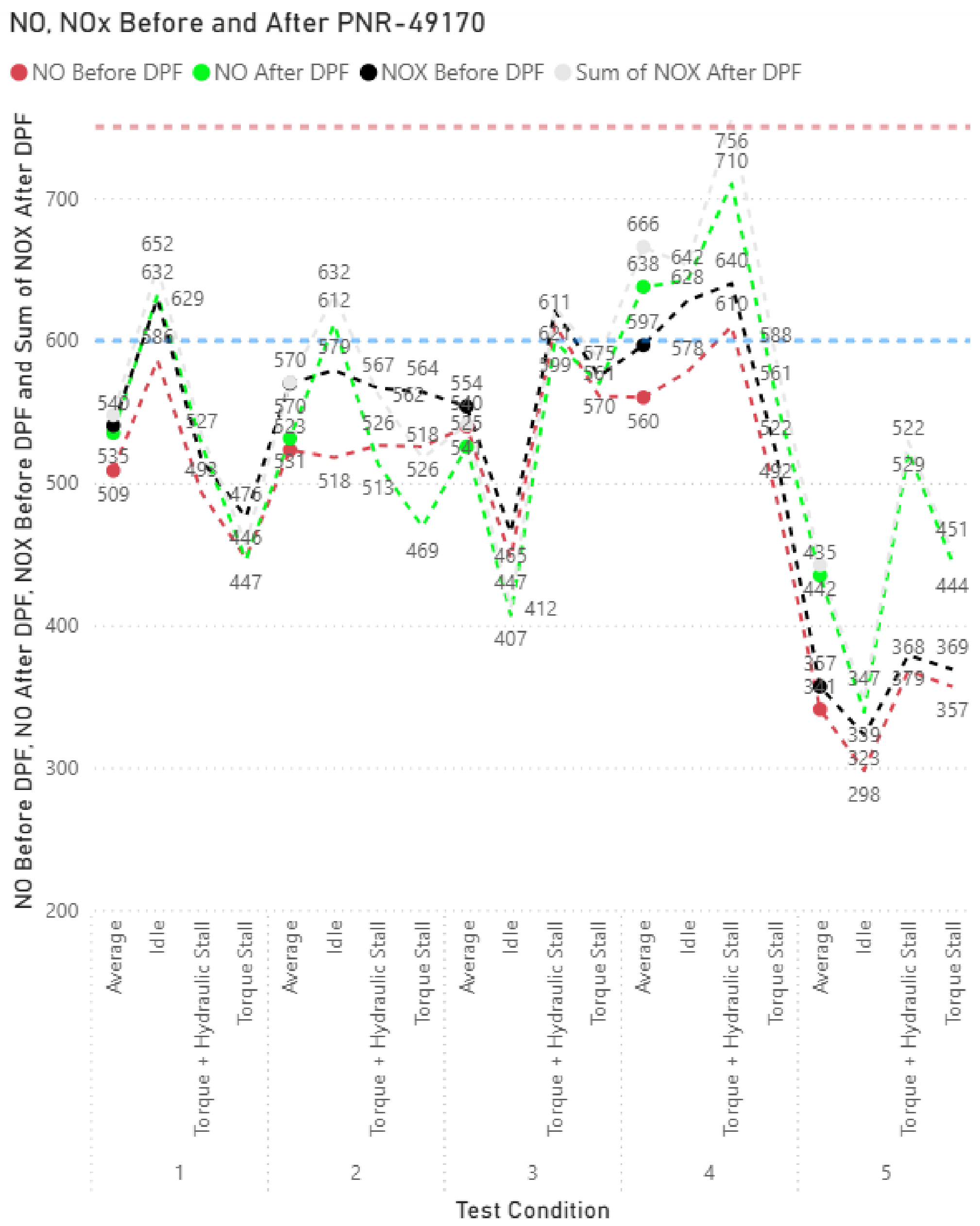
CO Before and After PNR-49170



Applicable Rates

NO, NOx

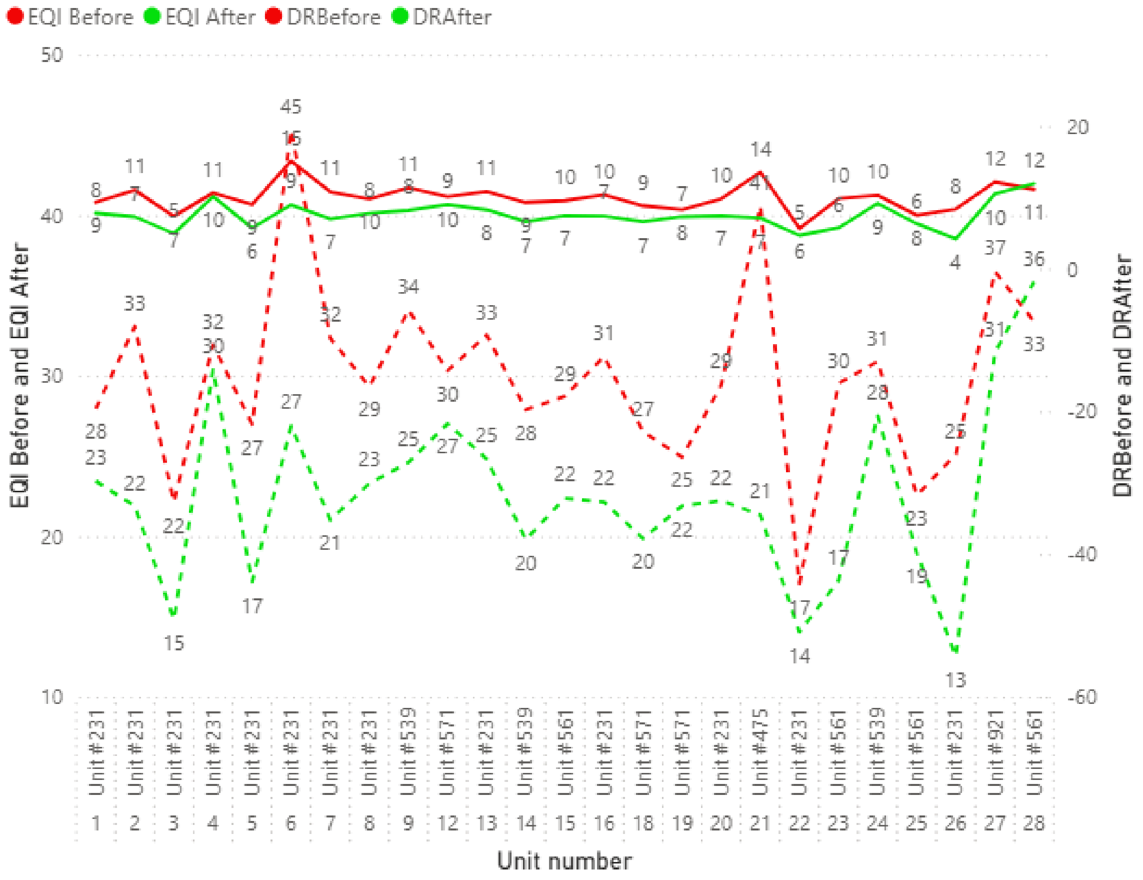




MapTest Criteria Results

E I- Exhaust Quality Index and Dilution Ratio derived from Exhaust Quality Index

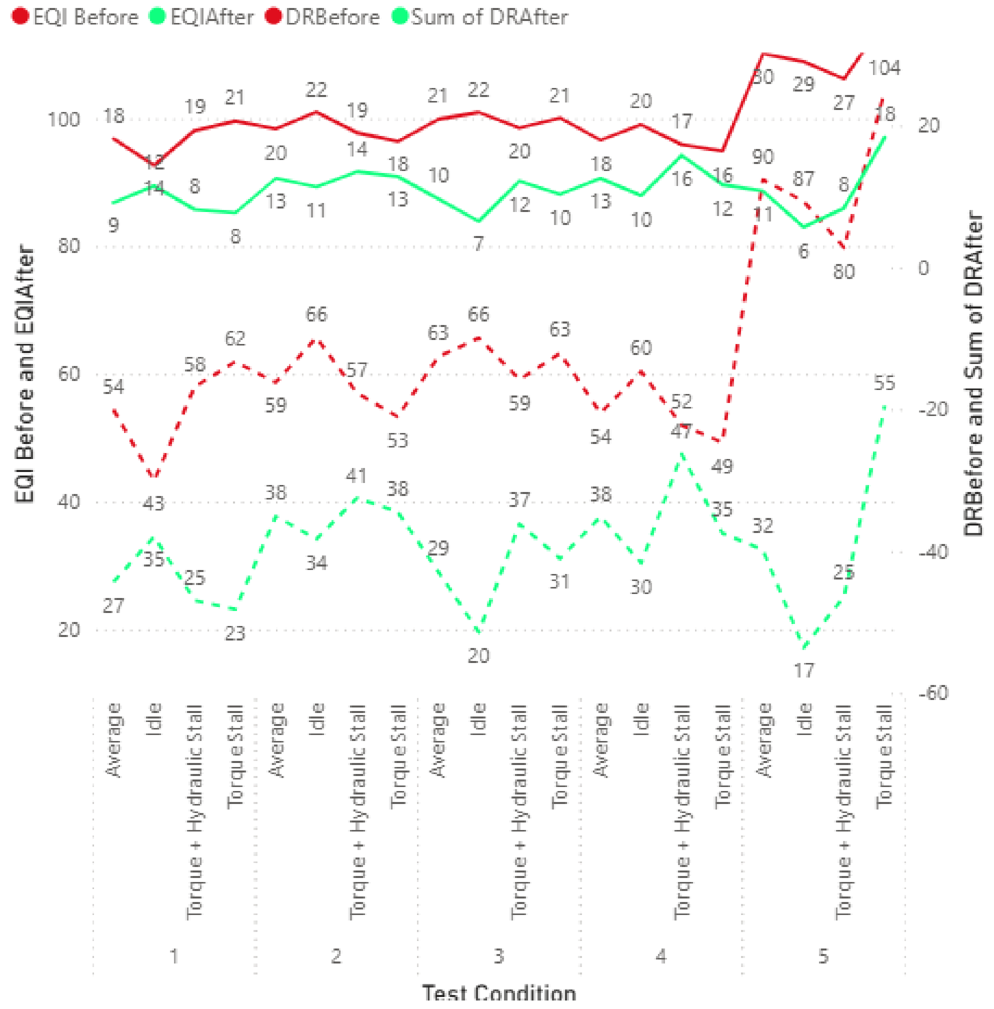
EQI and EQI derived DR Historic



Exhaust Quality Index (EQI)

$$EQI = \frac{CO}{50} + \frac{NO}{25} + \frac{DPM}{2} + 1.5\left[\frac{SO_2}{3} + \frac{DPM}{2}\right] + 1.2\left[\frac{NO_2}{3} + \frac{DPM}{2}\right]$$

EQI and EQI derived DR PRO-04791

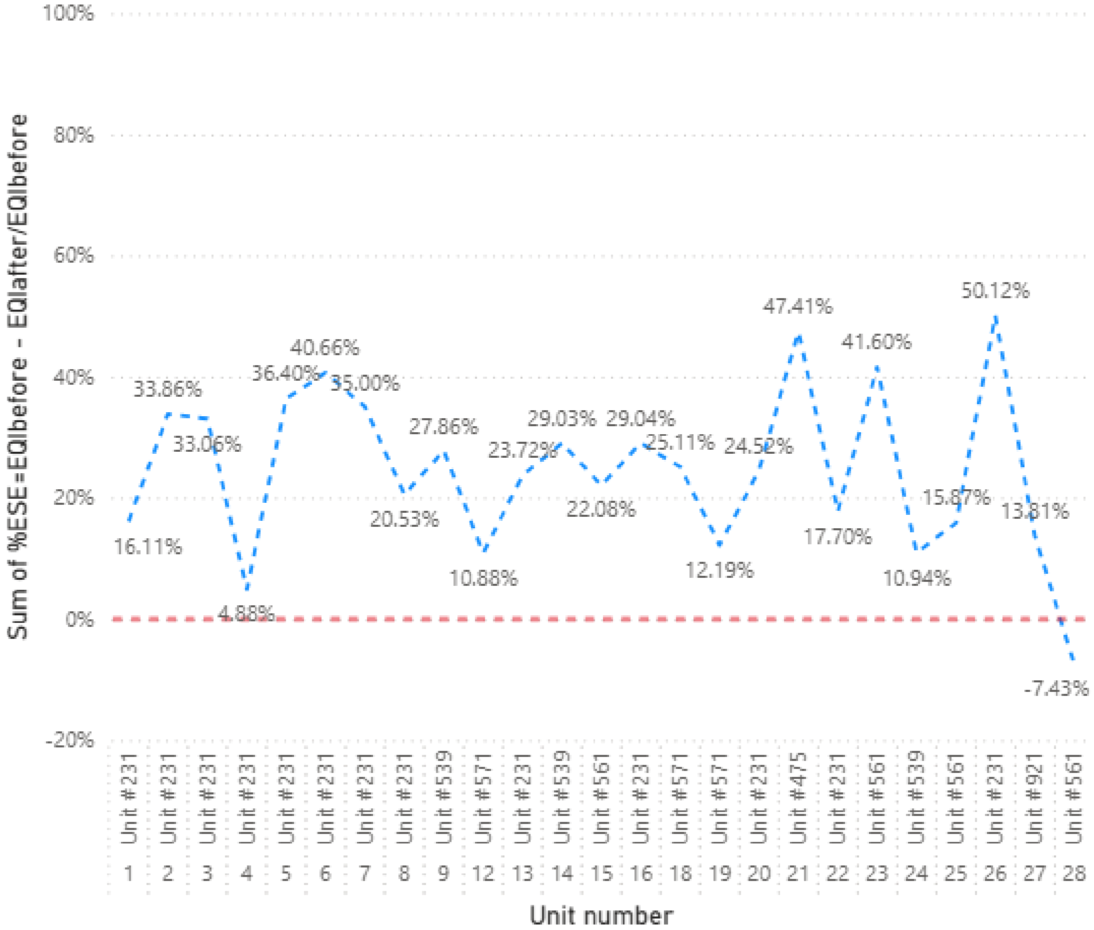


MapTest Criteria Results

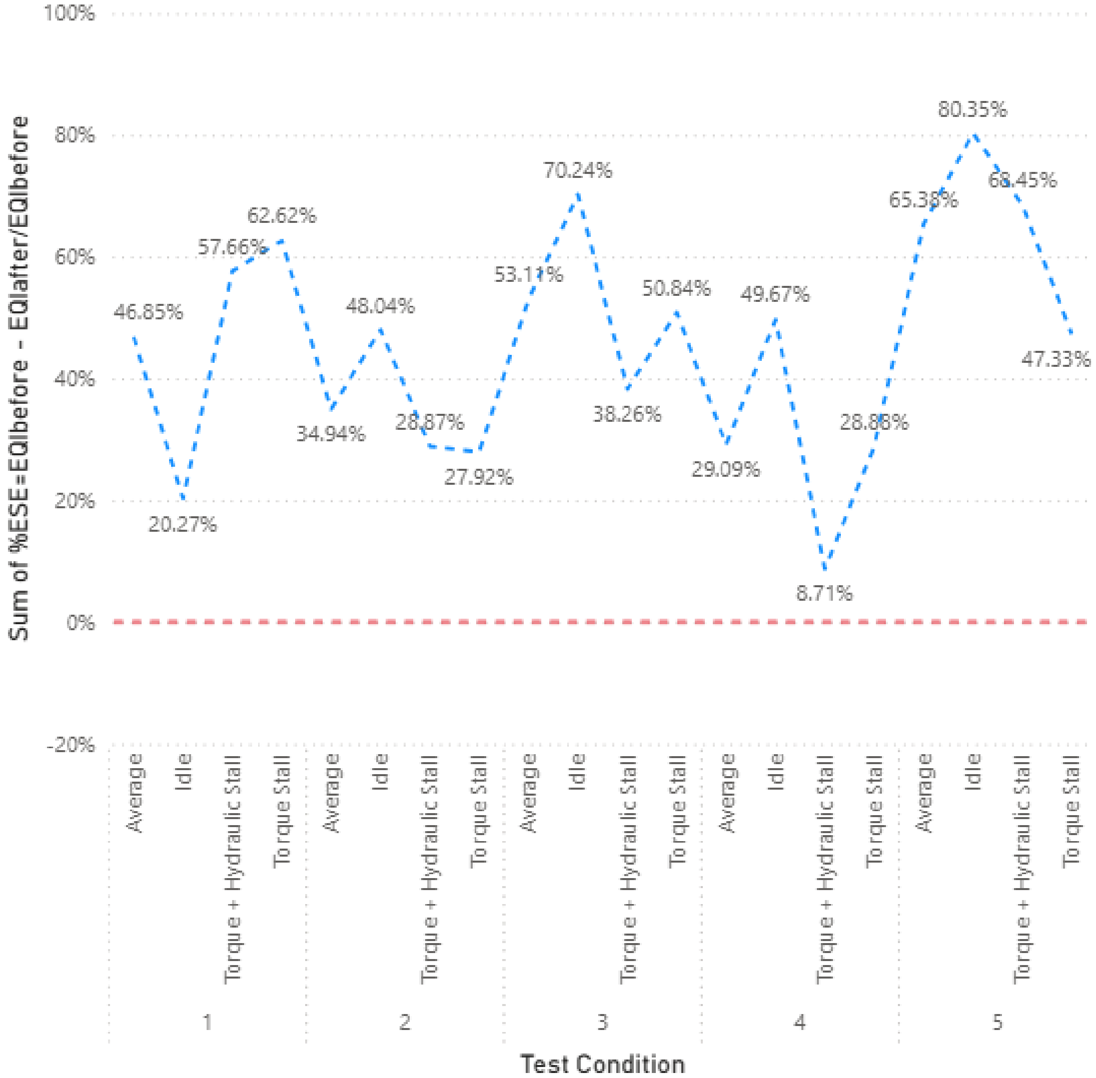
Emissions System Effectiveness(ESE)

$$\%ESE = \frac{EQI_{baseline} - EQI_{addon}}{EQI_{baseline}} x100$$

%ESE Historic



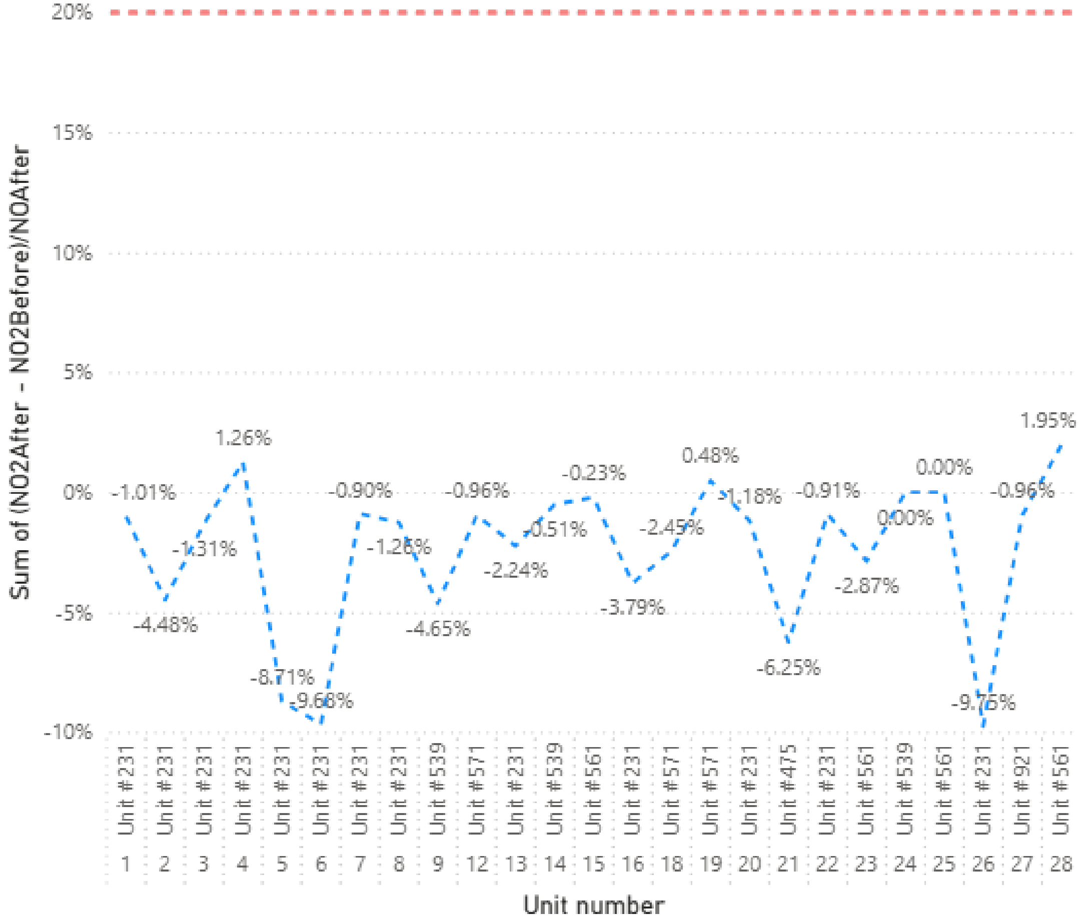
%ESE PNR-04791



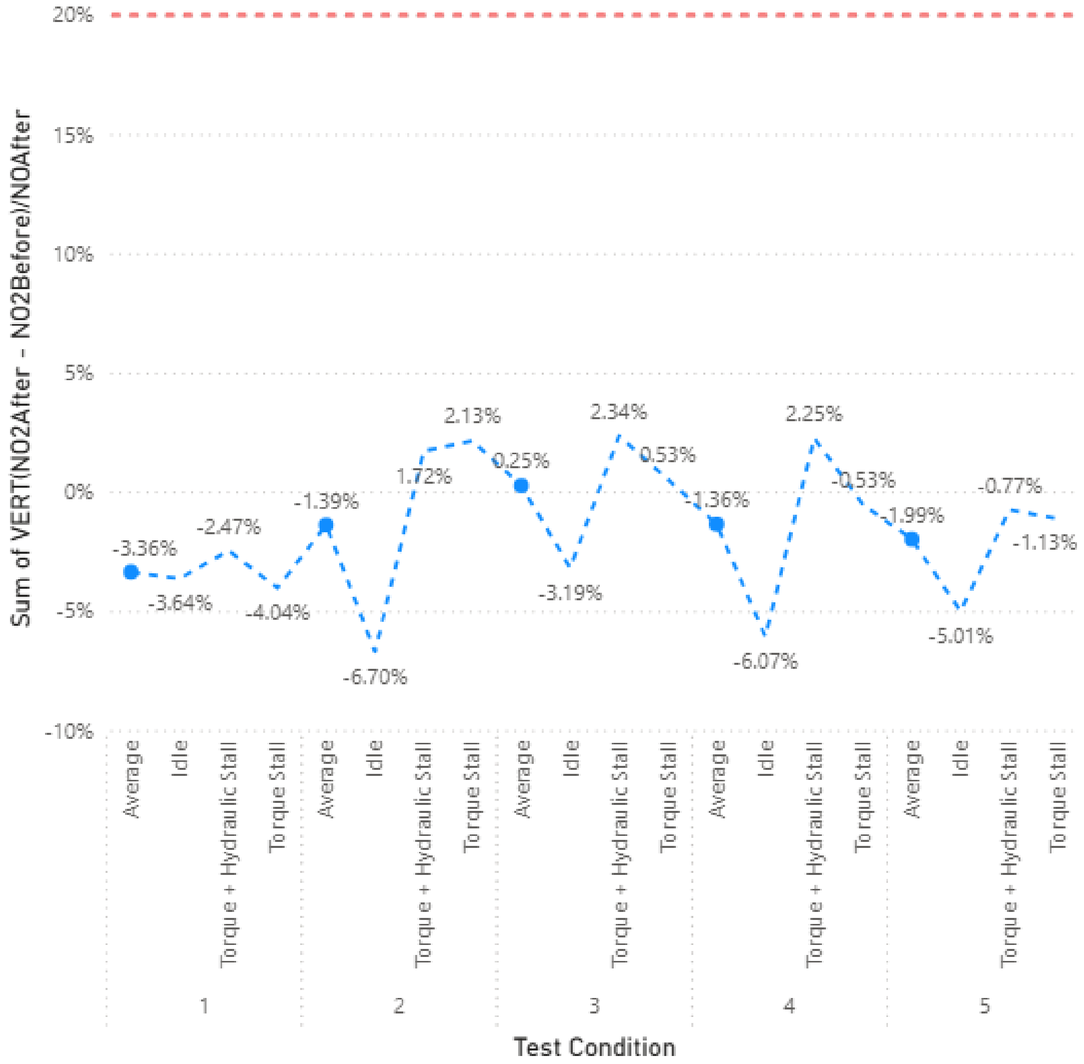
Vert Criteria

$(NO_{2\,After} - NO_{2\,Before}) / NO_{After\,DPF} < 20\%$

VERT (NO2after-NO2before) / NOafter <20% (Historic Testing)



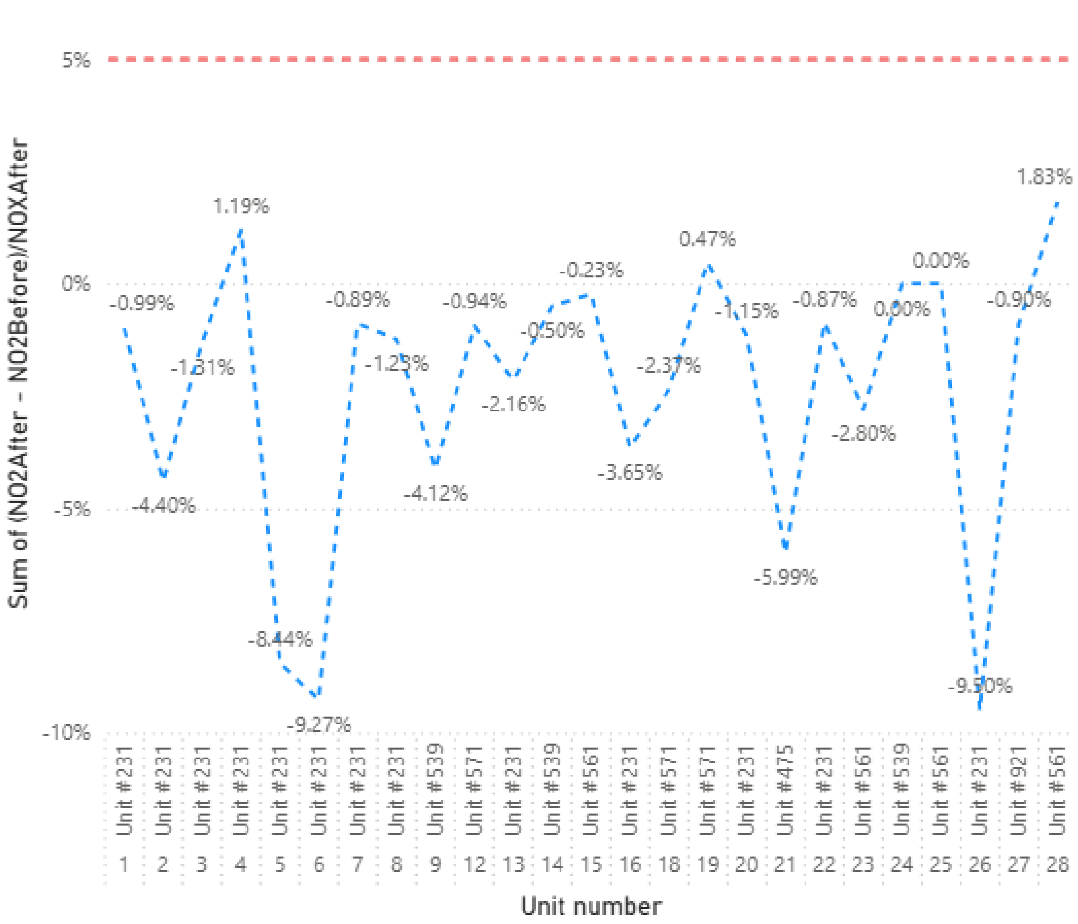
VERT (NO2after-NO2before) / NOafter <20% (PNR-49170 Testing)



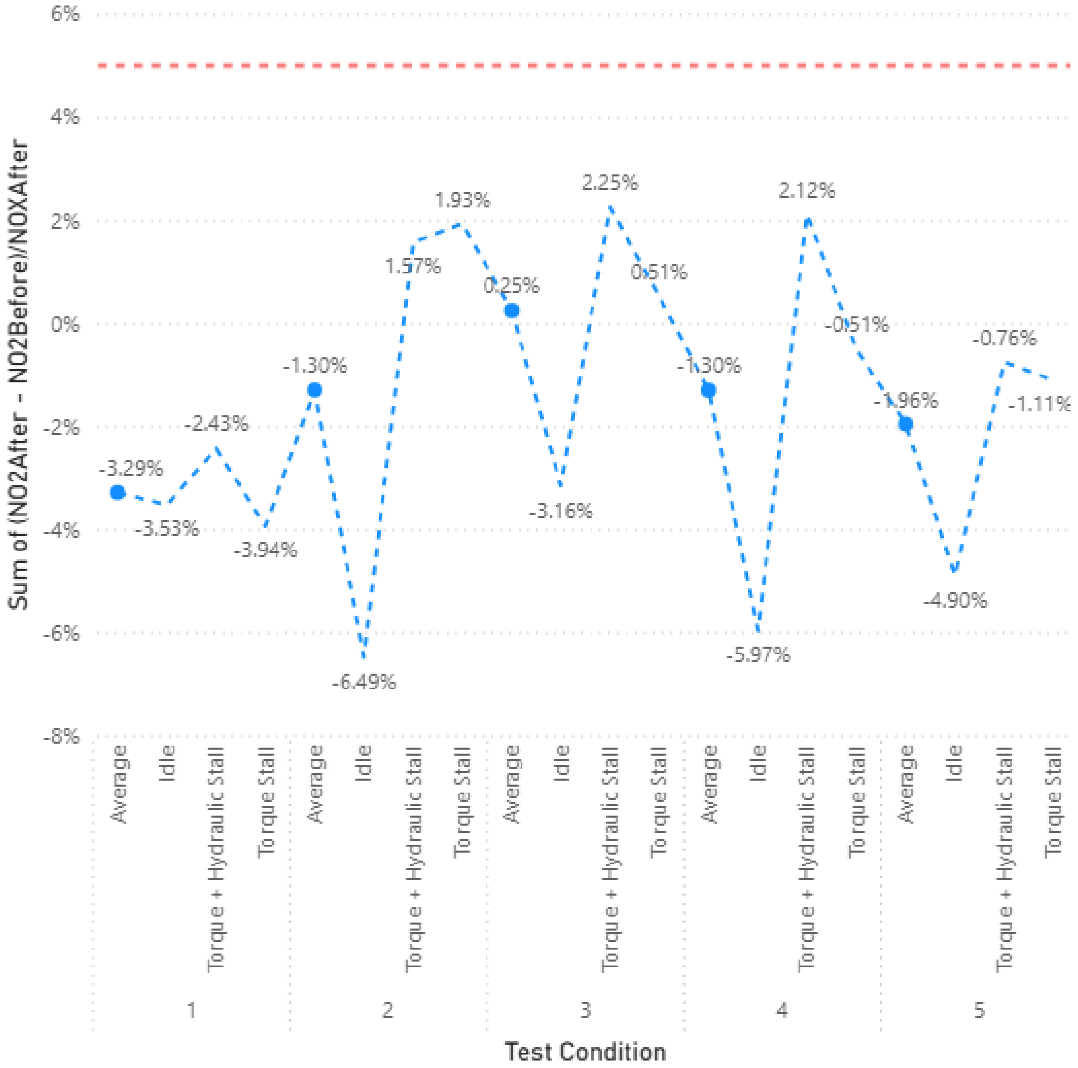
Vert Criteria

$(NO_{2\ After} - NO_{2\ Before}) / NOx_{After\ DPF} < 5\%$

(NO2after-NO2before) / NOx after <5% Historic

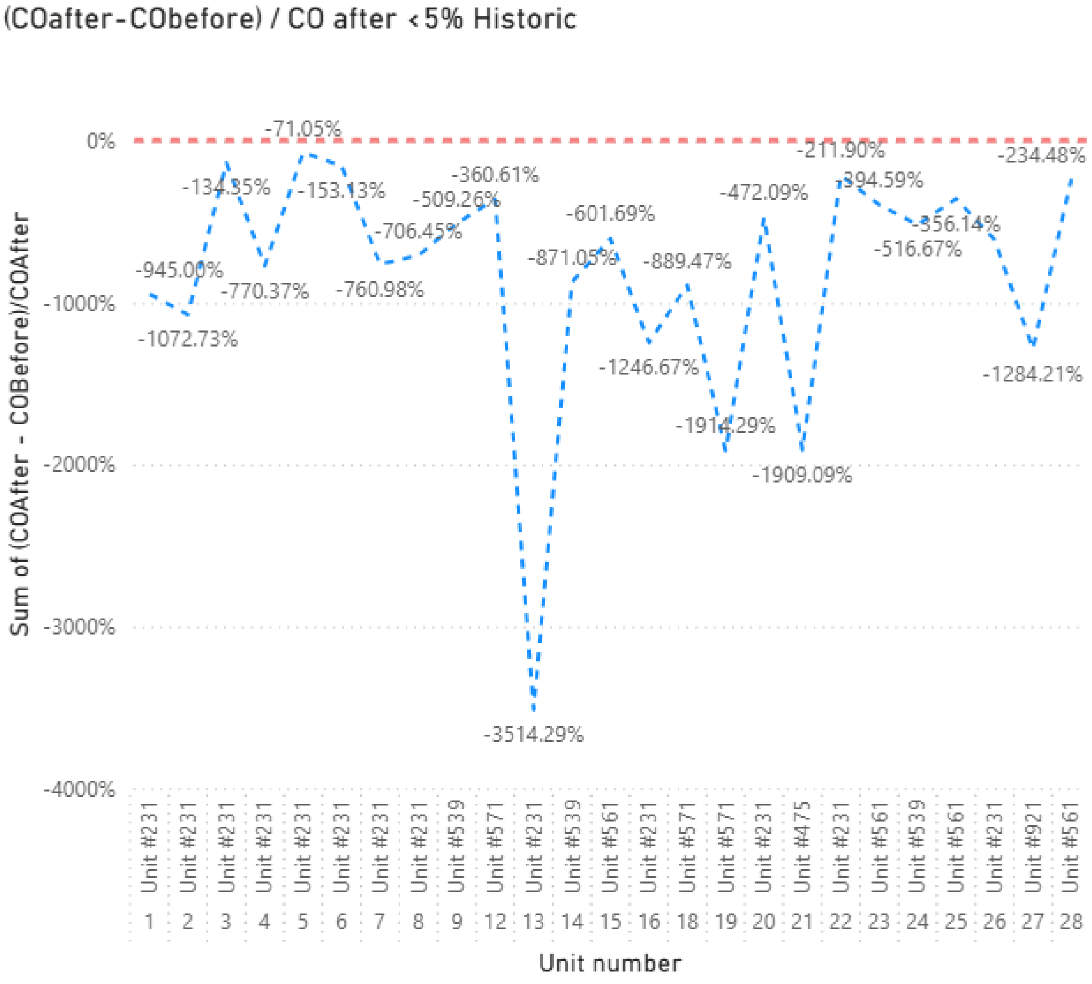


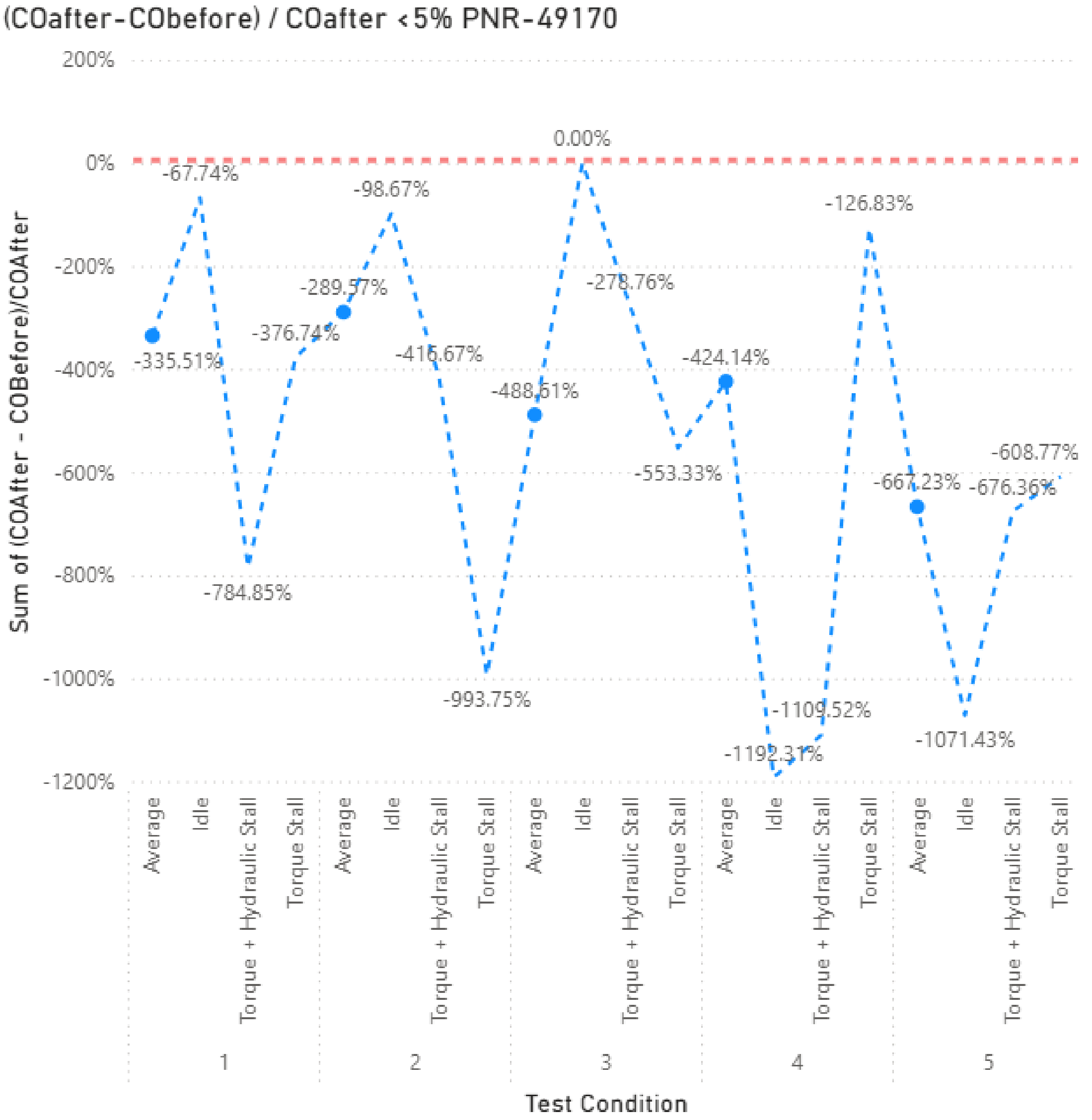
VERT (NO2after-NO2before) / NOxafter <5% PNR-49170



Vert Criteria

$(CO_{After} - CO_{Before}) / CO_{After\ DPF} < 5\%$





Social Challenges and Stakeholder Concerns

Perceptions and Concerns Regarding Ventilation and Contaminants

Contaminant Control Concerns

Concerns exist about managing dust and heat contaminants effectively with lowered ventilation rates

Microparticle Risks

There are worries about the presence and control of harmful micro particles in the mining environment.

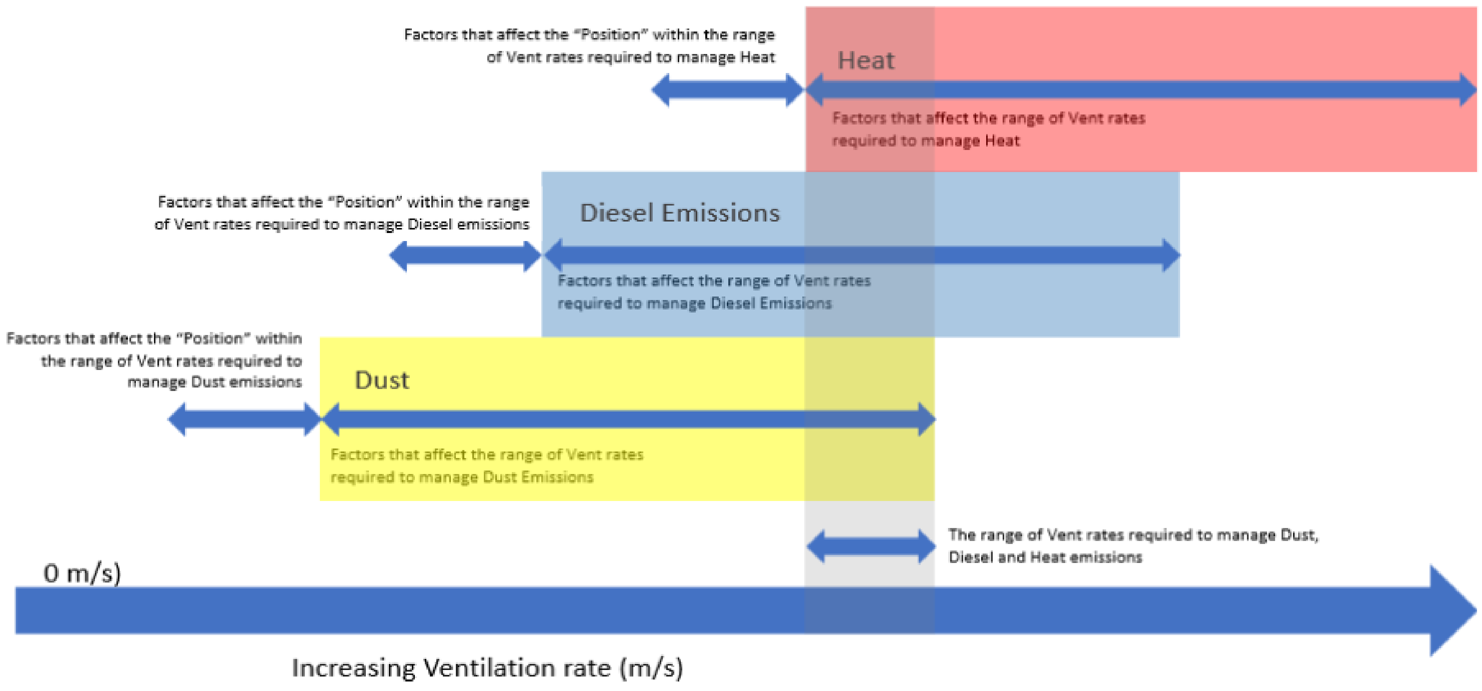
Decoupling Dust Control from Diesel Vent Rate

Contaminant Control Concerns

Dust control using ventilation is not effective, We have mechanical means to control dust like water sprays

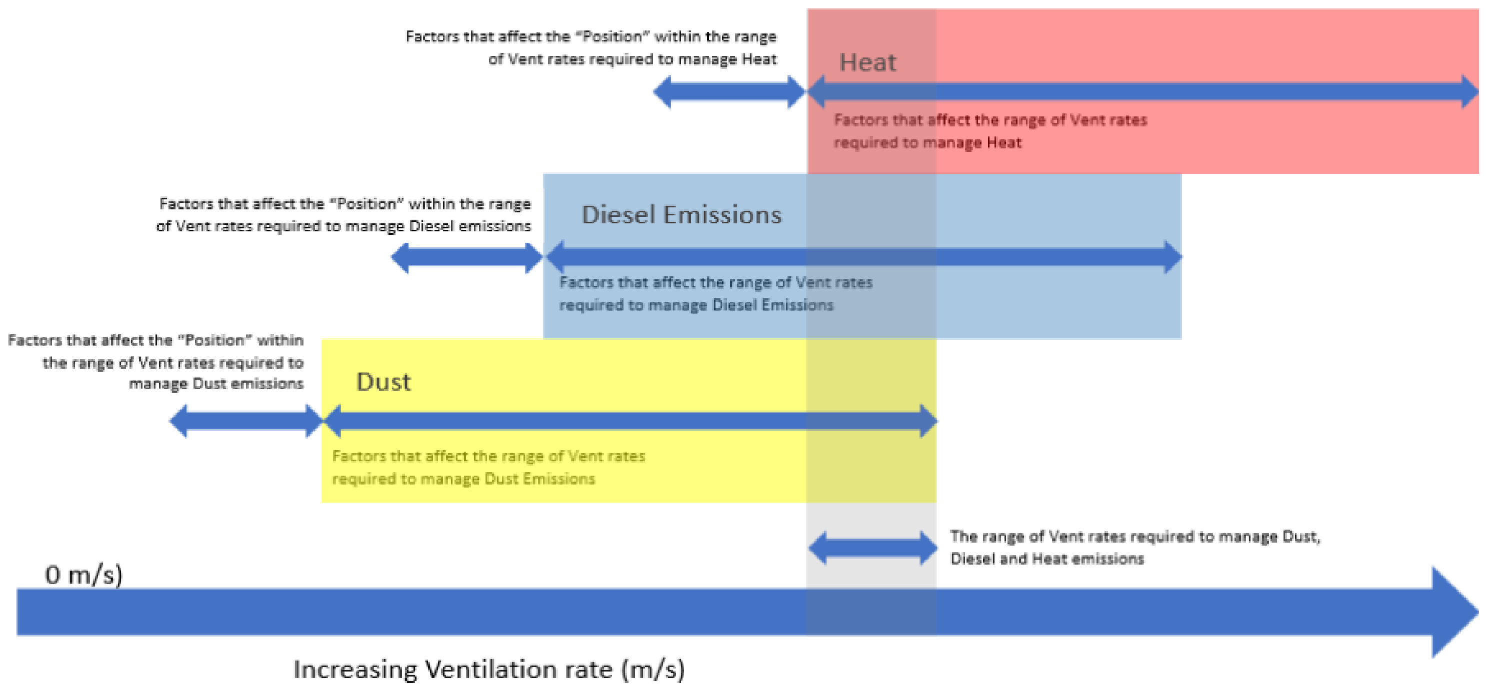
Proper roadbed material, Sweepers, vacuuming, Petrotac spraying of high travel areas, etc.

Ventilation Rate "Sweet" Spot (Why Vent Rate Alone cannot manage Dust and Heat)



Contaminant Control Concerns

Ventilation Rate "Sweet" Spot (Why Vent Rate Alone cannot manage Dust and Heat)



Decoupling Dust Control from Diesel Vent Rate

Dust control using ventilation is not effective, We have mechanical means to control dust like water sprays

Proper roadbed material, Sweepers, vacuuming, Petrotac spraying of high travel areas, etc.

Airborne Hazards Management Program

Airborne Hazards

Diesel Emissions | Heat | Dust

Components of an Airborne Hazard Management Program

Vent | Cooling Plant | Mechanical means of dust suppression

Application of Airborne Hazard Management Program

Workplace Monitoring

Diesel Emissions | Heat | Dust

CAN MET Vent Rate | Cooling Plant | Work Rest Regime | Mechanical Dust Suppression Program, Water Sprays, Petrotec, | Vent arrangement – vent dustiest areas last

- The CAN MET Vent Rate is determined using the regime of engine operation that generates the highest emissions.
- Since Diesel engines do not typically operate continually in that regime, the CAN MET Vent Rate is conservative and generally provides more vent than required to address Diesel Emissions throughout a typical operation

- When combined with a disciplined and effective Mechanical Dust Suppression Program, e.g.
  - Water sprays at the typical dust sources,
  - Petrotac and water sprays on road surfaces,
  - etc
- the CANMET Vent rate should provide sufficient vent to control Diesel emissions and possibly provide some contribution to mitigate other airborne hazards

Micro Particle Risks and Mitigation

Fiebig *et al. Journal of Occupational Medicine and Toxicology* 2014, **9**:6
http://www.occup-med.com/content/9/1/6

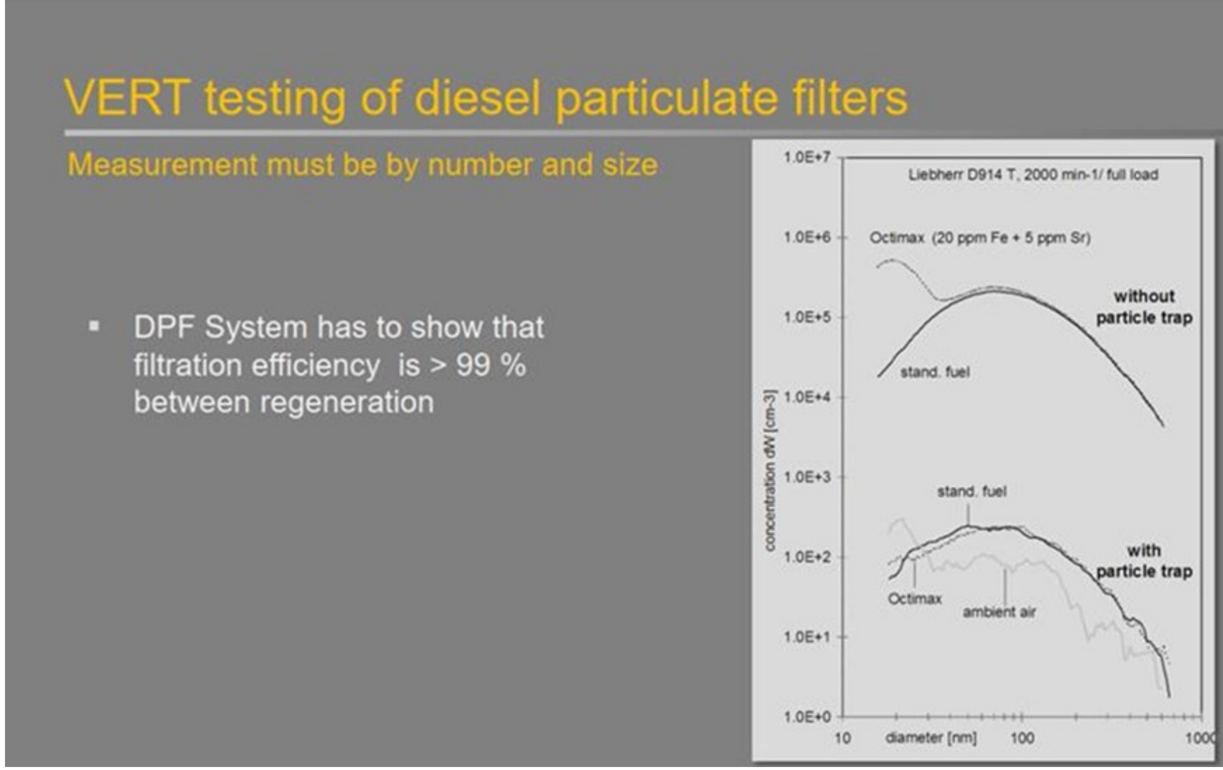
JOURNAL OF OCCUPATIONAL MEDICINE AND TOXICOLOGY

REVIEW **Open Access**

Particulate emissions from diesel engines: correlation between engine technology and emissions

Michael Fiebig*, Andreas Wiartalla, Bastian Holderbaum and Sebastian Kiesow

- Internal engine modifications lead to a clear reduction of the particulate emissions without negative impact on the particulate-size distribution towards smaller particles.
- The residual particles can be trapped in a diesel particulate trap independent of their size or the engine operating mode.
- The usage of a wall-flow diesel particulate filter leads to an extreme reduction of the emitted particulate mass and number approaching 100%
- A reduced particulate mass emission is always connected to a reduced particle number emissions



Fiebig *et al. Journal of Occupational Medicine and Toxicology* 2014, **9**:6
http://www.occup-med.com/content/9/1/6 Page 12 of 18

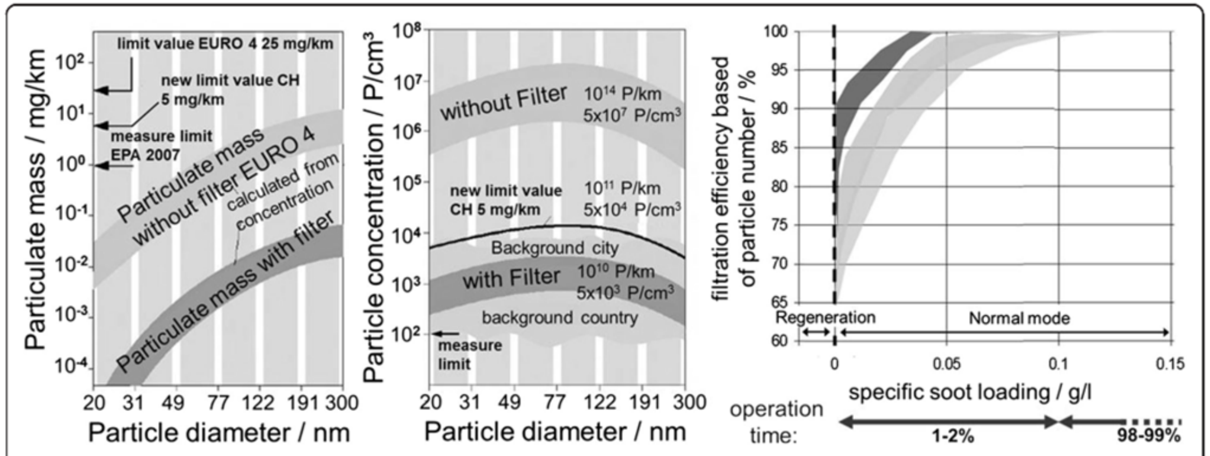


Figure 10 Particle reduction through DPF [68] (left, mid) and particle number reduction based on filter load (right).

Micro Particle Risks and Mitigation

Fiebig *et al. Journal of Occupational Medicine and Toxicology* 2014, **9**:6
http://www.occup-med.com/content/9/1/6

JOURNAL OF OCCUPATIONAL MEDICINE AND TOXICOLOGY

REVIEW **Open Access**

Particulate emissions from diesel engines: correlation between engine technology and emissions

Michael Fiebig*, Andreas Wiartalla, Bastian Holderbaum and Sebastian Kiesow

filtering mechanisms. Due to the overlapping filtration mechanisms, both large as well as small particles can be held back reliably, thus achieving a filtering efficiency of nearly 100% across the entire spectrum of sizes [6]. Since almost all emitted particles are smaller than the pores of the filter substrate, they are not caught in the filter due to their size but mostly by means of diffusion. Since the diffusion speed increases with decreasing particle size, smaller particles are actually separated the most effectively. With rising soot loads, there is a transition from deep filtration in the filter wall down to surface filtration. Both the soot layer stored in the pores as well as the soot cake on the filter wall itself act as a highly effective filtering medium. Due to the low deep filtering capacity of the

cycles as well as for further driving conditions that the particle number for a vehicle with DPF is below that of a vehicle without DPF by several orders of magnitude regardless of the cycle. At a constant speed of 80 km/h, a vehicle with DPF on average emits an approximately 10,000 times lower particle number. The particle number concentration is also within the range of the background level here. Schmidt [67] shows that the particulate mass is reduced by at least 2 orders of magnitudes with a closed DPF on a commercial vehicle engine.

In conclusion, the particulate emissions of advanced diesel engines can be drastically reduced in terms of the particulate mass and the particle number by using closed particulate filters. In-engine measures also lead to a clear reduction in particulate emissions. When measuring particle number and mass, we can see a clear correlation. Reduced particle mass emission is always associated with a reduction in particle number. Statements claiming that advanced engines are emitting a particular high amount of small particles were proven incorrect since they are based on measurement errors. There is no significant increase in small particles in the range of < 30 nm at the engine outlet because of advanced engine concepts. Particulate filters that were universally introduced for passenger cars with emission standard Euro 5 and became the state-of-the-art with Euro VI in commercial vehicles as well, are filtering particles in the entire operating range of the engine across the entire particle size range with high efficiency, which can be explained by the separation principle in the filter.

Diesel particulate filters (DPFs) significantly reduce both the mass and number of particulate emissions from diesel engines, often approaching 100% reduction in emitted particles.

Effectiveness of Diesel Particulate Filters (DPFs)

1. **Mass Reduction**: The use of wall-flow diesel particulate filters leads to an **extreme reduction of emitted particulate mass**, with studies indicating that this reduction can approach **100%**. This is crucial for meeting stringent emission regulations and improving air quality. 1
2. **Particle Count Reduction**: Alongside mass reduction, DPFs also effectively decrease the **particle number emissions**. The correlation between mass and particle count reduction is strong; as the mass of particulate emissions decreases, the number of particles emitted also declines significantly. 1
3. **Particle Size Distribution**: Research indicates that modern diesel engines, when equipped with DPFs, show a clear reduction in particulate emissions without negatively impacting the particulate size distribution. This means that while the total number of particles is reduced, the size of the remaining particles does not shift towards smaller, potentially more harmful sizes. 1

Stakeholder Engagement

- Engaged with JHSC reps to review:
  - the CSA M424.2 Ventilation Rate reinstatement process (PRO-047901)
  - The principles and methods used to create the process
  - The results of the testing against historic and new data

- MOCs (Management of Change)
  - A formal review will be held at each site with stakeholders (Plant Operations, Maintenance, Worker Reps) to:
    - identify implementation risks
    - create/implement appropriate risk mitigation plans.

Conclusion

Canmet Vent Rates and DPM control in mining:

Diesel Particulate Filters can significantly lower the amount of Diesel Particulate emitted in our mining environments. This advantage however, must be considered in concert with potential secondary emissions introduced upstream of the DPF.

Additionally, DPM is only one subset of the airborne contaminants that must be managed in our underground work places. Airborne Hazard Management Plans must account for all airborne contaminants in the underground work places.

Comprehensive Implementation Approach

In order to be truly successful, the adoption of CANMET ventilation rates need to be combined with a multifaceted Airborne Hazard Management Program to control ALL airborne hazards

Addressing Regulatory Challenges

Changes in Regulation 854 provide:

- for safer work environments
- guidance on how to address some challenges associated with the changes

Social and Technical Factors

Multiple Stakeholder Group involvement is the key to allaying social implementation concerns.