Is opacity monitoring still relevant?

An exploration into opacity versus particulate in-stack monitoring

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What brought this on?

- Ringelmann → % Opacity
- What is the right limit?
- Relationship to particulate concentrations?
- Cases where sites measuring particulate anyway…
- Is opacity monitoring still the right thing to do?

a. The opacity of emissions from the chimney stack from any of the coal-fired boiler stacks shall not be darker than Ringelmann Shade 1 as described in New Zealand Standard 5201:1973 except:

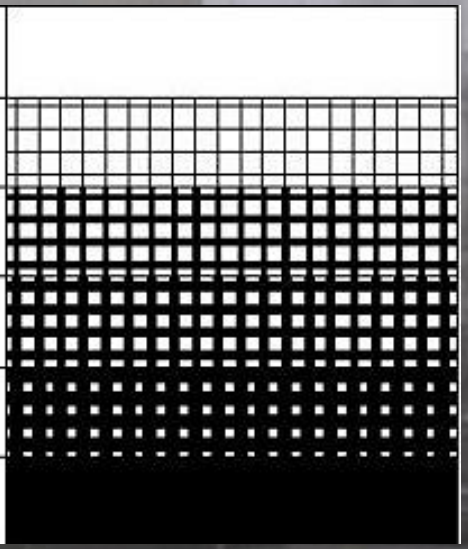
   i. in the case of a cold start for a period not exceeding 30 minutes in the first hour of operation; and

   ii. for a period not exceeding a total of four minutes in each succeeding hour of operation.

b. Obscuration meters shall be fitted in both chimney stacks and shall be operated to provide continuous measurement and recording of obscuration of the discharge. The meters shall be maintained and calibrated by a competent person such that they provide a reliable indication of plume opacity. Boiler operators shall take into account obscuration meter readings when determining compliance with Condition (14)(a). Obscuration records shall be held on site and a summary of these measurements shall be provided to the Canterbury Regional Council as part of the Annual Environmental Report required under Condition (39).

Where monitoring of opacity began

- First standardisation was in 1888 with Ringelmann Charts
- Designed for smoke abatement and enforcement of visible emissions
- London smog event in 1952 indicated health implications
- Health effects of particulate matter are well known

Ringelmann 0	0% opacity – clear	
Ringelmann 1	20% opacity – barely visible	
Ringelmann 2	40% opacity – clearly visible	
Ringelmann 3	60% opacity – somewhat transparent	
Ringelmann 4	80% opacity – barely transparent	
Ringelmann 5	100% opacity – black	

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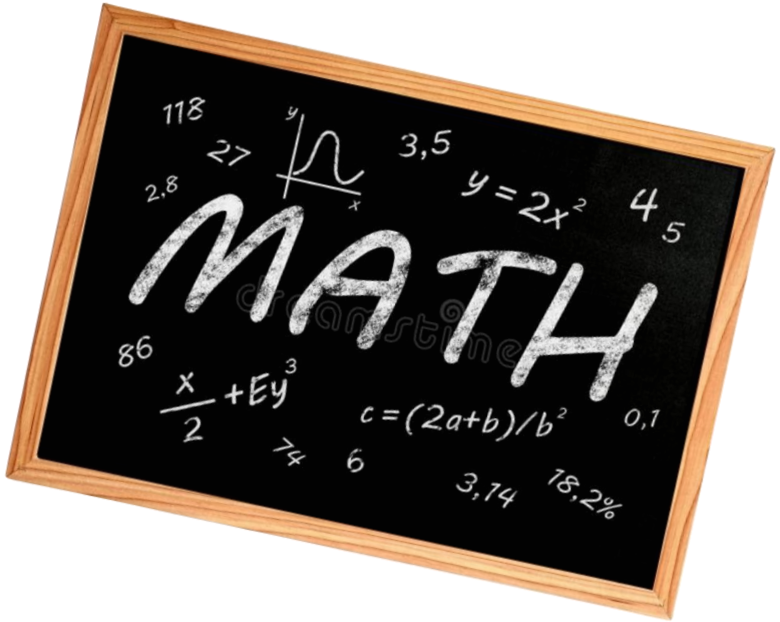
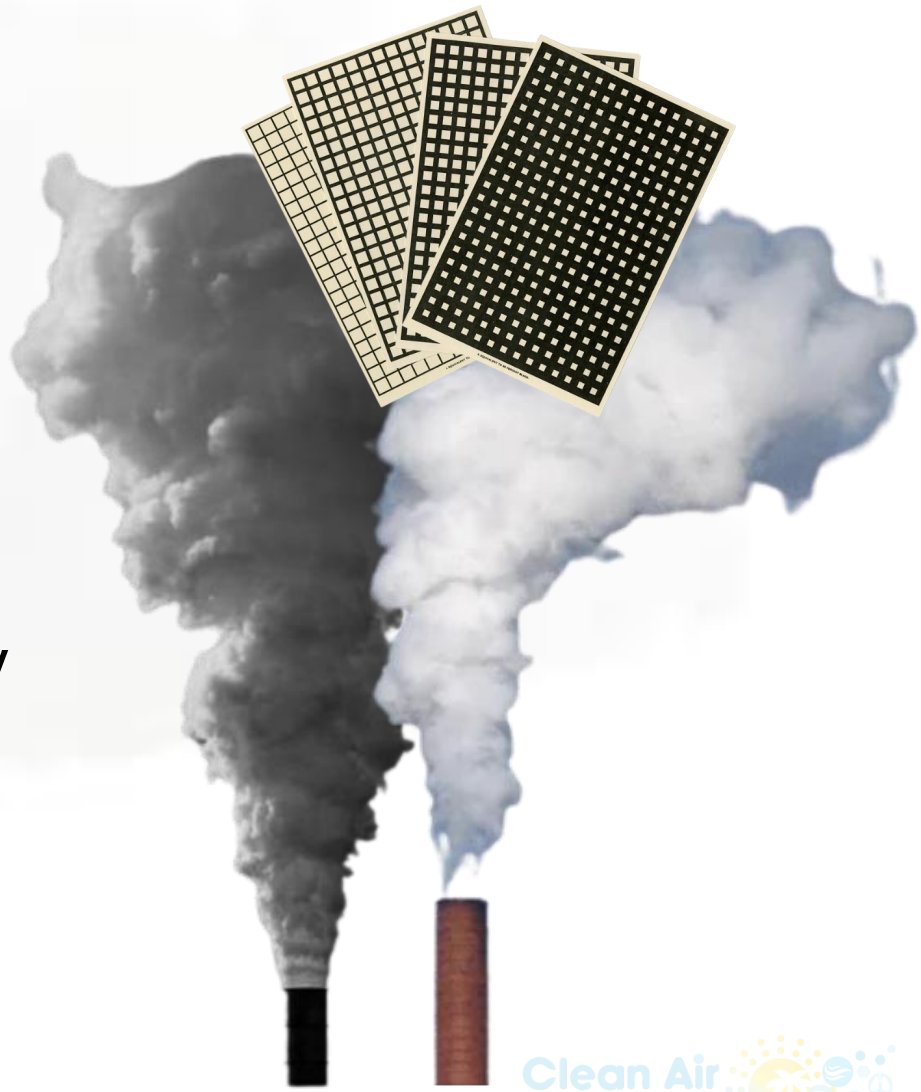
Opacity – PM relationship

- Beer-Lambert law relates opacity to PM concentration:
  - $I = I_0 \exp(-\alpha\ c\ L)$
  - I is transmitted light intensity (light exiting the stack, W/m^2)
  - I_0 is incident intensity (light entering the stack, W/m^2)
  - α is the mass extinction coefficient (m^2/g)
  - c is PM mass concentration (g/m^3)
  - L is the optical path length (stack diameter, m)
  - Fraction of light that is passed, $\frac{I}{I_0} = \exp(-\alpha\ c\ L)$
  - Opacity% = $100\lfloor 1\ -\ \exp(-\alpha\ c\ L)\rfloor$



Ringelmann as a proxy for PM

- Ringelmann Charts repurposed as a proxy for PM loading
- Works well for fossil fuel combustion sources, where unburned carbon is the principal colouring agent.
- Limited by human-subjectivity
- Transitioning towards continuous opacity monitoring systems (COMS)



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Other limitations

- Opacity% = $100\lfloor 1 - \exp(-\alpha\, c\, L)\rfloor$
- Fine particles ($PM_{2.5}$) have a high extinction coefficient per unit mass
- Generate high opacity at relatively low mass concentrations
- Coarse particles may represent significant mass with comparatively modest opacity
- Appropriate for biomass? Plumes generally white, light grey, or near-transparent

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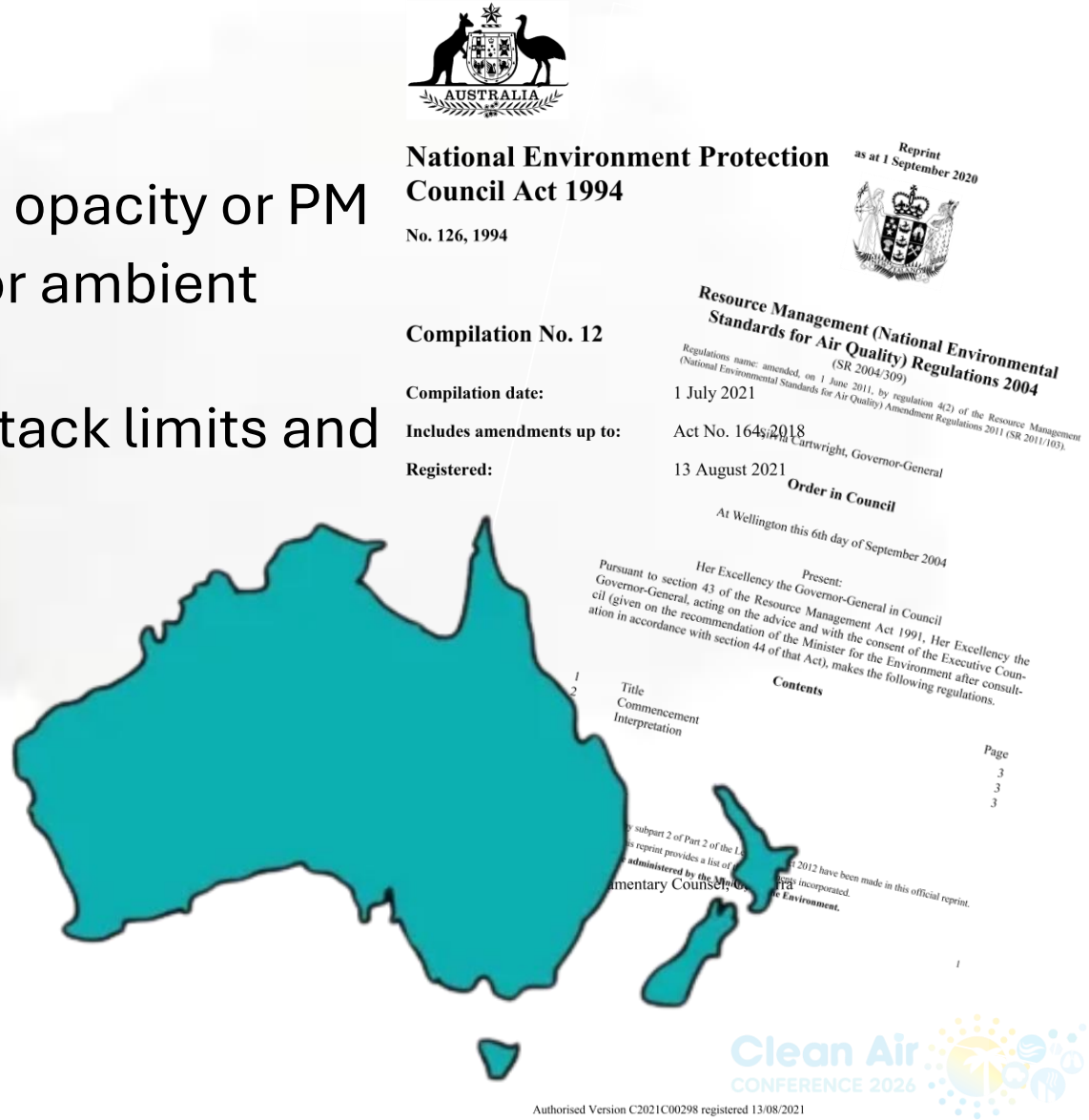
What do the regulations say

- New Zealand,
  - No national requirement to monitor opacity or PM
  - PM standards/guidelines are only for ambient concentrations
  - Rely on Resource Consents to set stack limits and monitoring
  - Source-by-source basis
- Australia
  - Similar principles as New Zealand
  - Licence conditions



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Compilation date: 1 July 2021

Includes amendments up to: Act No. 164, 2018

Registered: 13 August 2021

Silvia Cartwright, Governor-General

Order in Council

At Wellington this 6th day of September 2004

Present:

Her Excellency the Governor-General in Council

Pursuant to section 43 of the Resource Management Act 1991, Her Excellency the Governor-General, acting on the advice and with the consent of the Executive Council (given on the recommendation of the Minister for the Environment after consultation in accordance with section 44 of that Act), makes the following regulations.

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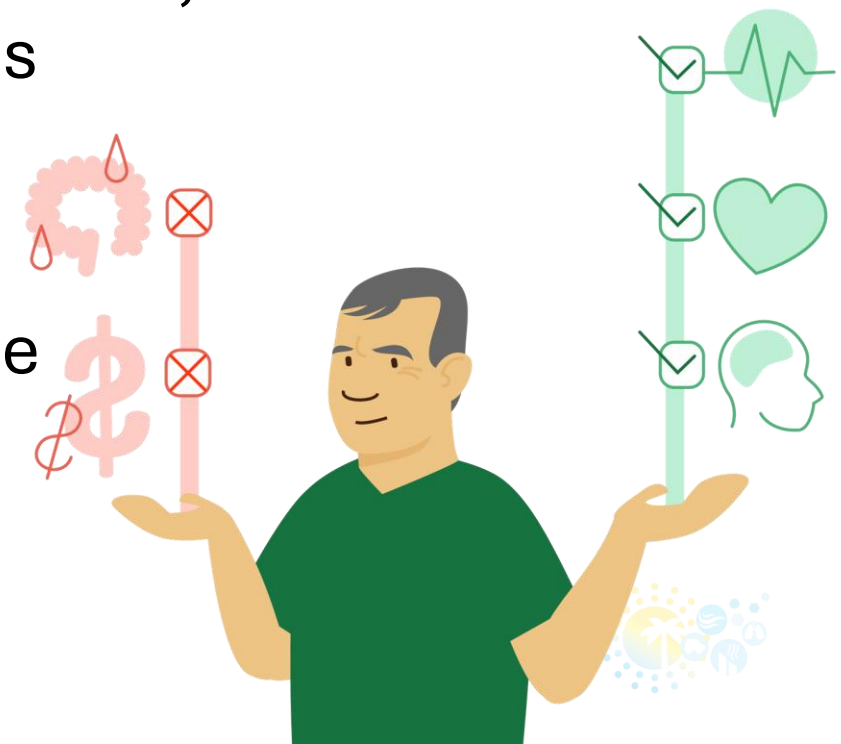
Overseas

- United States
  - Continuous Opacity Monitoring System (COMS) prescribed for major stationary sources including large coal-fired power plants (Clean Air Act Framework).
  - Mandated PM-CEMS for new and reconstructed coal- and oil-fired electricity generating units (2012 Mercury and Air Toxics Standards)
- European Union
  - Requires continuous PM monitoring for large combustion plants, except when fired on natural gas (European Commission 2010).

Benefits and limitations of COMS

- Provide continuous, objective monitoring data
- Valuable for process control
- Well established, relatively low cost
- Dependent PM mass concentration, particle size, plume depth, and natural lighting conditions
- Results may vary by an order of magnitude or more across different source types
- Subject to drift, require regular maintenance



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Opacity limits (in New Zealand)

- Common limits
  - Ringelmann Shade 1 or 40% opacity
- Where does this come from?
  - MfE (1998)* recommended limit Ringelmann Shade 2

Ringelmann Shade	Associated Opacity	In-stack opacity
1	20%	52%
2	40%	64%

The opacity of the boiler flue gases when measured by an optical method in the flue shall not exceed 40 % when measured on an equivalent diameter light path to the stack exit. Exemptions shall be allowed no more than 15 minutes aggregate in any hour and for continuous periods of 3 hours when starting a boiler or shutting down.

The opacity of any discharge to air when measured by photoelectric means, or visually for discharges from the flare and D Block stacks, in accordance with AS3543-1989 shall not equal or exceed a value of 20% for more than two minutes continuously, or for an aggregate of four minutes in any period of 60 minutes.

The opacity of the flue gases when measured by an optical method in the flue shall not exceed forty percent, when measured on an equivalent diameter light path to the stack exit. Compliance with this condition shall be demonstrated by monitoring required under condition 16.

The opacity of emissions from the chimney stack shall not be darker than Ringelmann Shade 1 as described in New Zealand Standard 5201:1973 except:

Particulate limits (in New Zealand)

- Both concentration and emission rates limited
- Relates to the particulate control equipment installed
  - Limited on total suspend particulate
  - More recently TSP or PM10
  - Range from 25 mg/Nm^3 to 250 mg/Nm^3
- So why don't opacity limits vary?

The continuous measurement results (excluding any invalid data) shall be recorded and compared against a monitoring target of 40% opacity, (or 65 mg/m^3 for TSP) for at least 95% of any one day (1.2 hours/day exceedance) and for at least 99% of any one operational year (88 hours/year exceedance).

The opacity or particulate concentration of stack emissions as measured in the common boiler stack shall not exceed 40% (or 100 mg/m^3 particulate or an equivalent limit determined by percentage of full span or scale of the meter readout that is acceptable to Council and has been approved in writing by Council) for more than 2 minutes continuously or for an aggregate of 4 minutes in any period of 60 minutes, except:

Alternatives to opacity

- Many options for continuously monitoring particulate matter (PM-CEMS)
- Use inferential methods that measure a quantity related to dust density
- Often requires site-specific correlation with standard isokinetic reference method measurements
- Can provide direct or near-direct mass concentration data
- Provides a more defensible compliance demonstration when limits are mass based
- More expensive

Conclusions

- Opacity
  - Retains relevance as an operational process control tool
  - Cost-effective compliance instrument where the opacity-PM relationship is well characterised (e.g., coal fired boilers)
  - Limited reliability for sources with variable or light-coloured PM
  - Limited where mass-based compliance is required
- PM-CEMS
  - Superior health-relevant data and regulatory certainty
  - Significantly higher capital and operating costs
  - Warranted for high-impact sources in sensitive airsheds and consistent with international best practice

Questions?

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