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Calibration of Condensation Particle Counter Detection Efficiency Using Mono-Disperse Aerosols

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Presentation Outline

- What is a CPC and how is it used for liquid metrology
- CPC Principle of Operation
- Overview of existing calibration methodology
- Description of novel calibration method
- Data discussion

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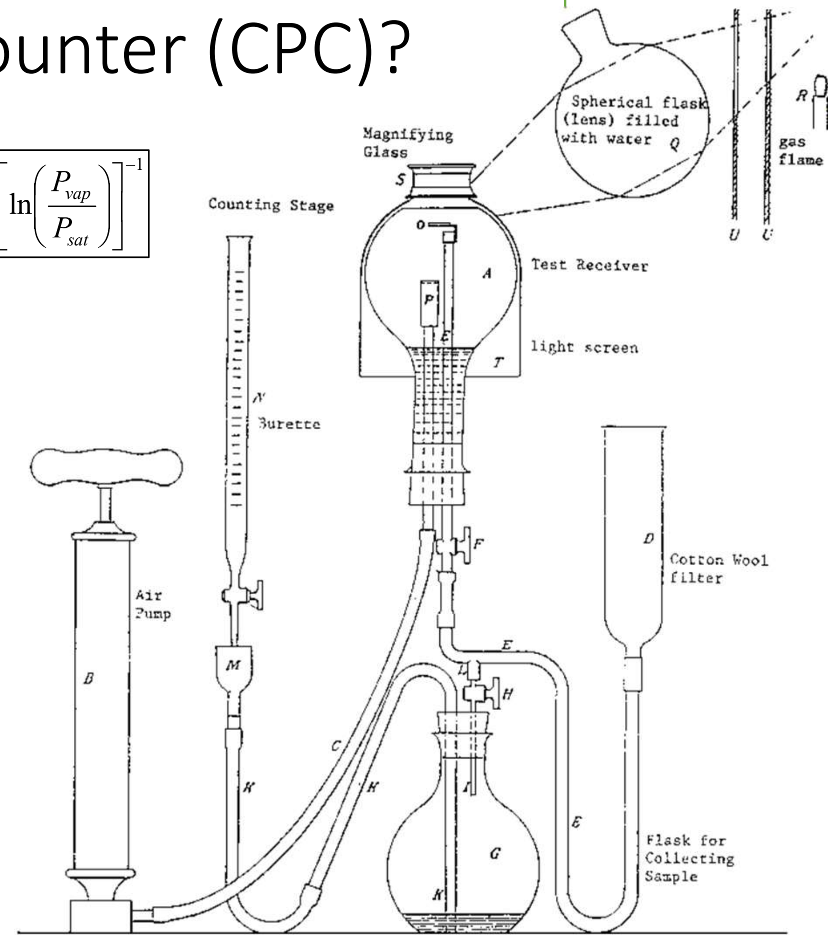
What is a Condensation Particle Counter (CPC)?

- Particles in air are grown to an optically detectable diameter by condensation of a known working vapor
- Condensation happens when:
  - Working vapor is Supersaturated i.e. Vapor pressure, P_{vap} is greater than Saturation Vapor Pressure, P_{sat} at a given gas temperature.
  - The particle size is large enough to overcome surface tension driven evaporation.
- Can be coupled with a nebulizer-aerosolizer to detect particles in liquids

$$Diameter_{Threshold} = \frac{\gamma V_{vap}}{k_B T}\left[\ln\left(\frac{P_{vap}}{P_{sat}}\right)\right]^{-1}$$

$$S = \frac{P_{vap}}{P_{sat}} \propto \frac{1}{D_t}$$



Peter H. McMurry (2000) The History of Condensation Nucleus Counters, Aerosol Science & Technology, 33:4, 297-322, DOI: 10.1080/02786820050121512

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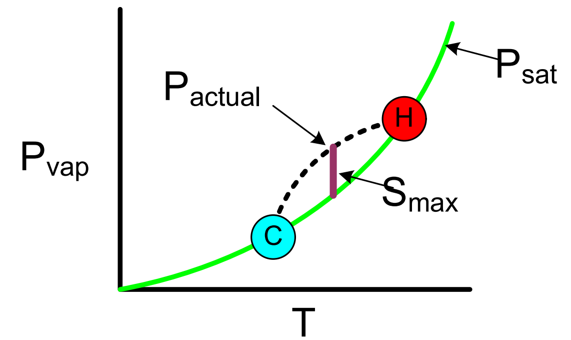
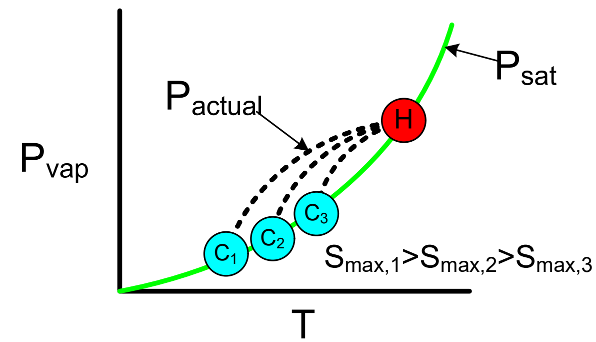
How does a CPC operate?

- Saturator
  - Aerosol passes through conduit with warm walls wetted with working fluid
- Condenser
  - Saturated aerosol passes laminarly through a conduit with cold walls. For working vapors with Lewis number > 1, vapor will become supersaturated
  - Peak supersaturation, S_{max}, increases with the difference between Condenser and Saturator temperatures
  - Particles larger than a threshold diameter will grow to an optically detectable size
- Threshold Scanning
  - Condenser is cycled through several set temperatures
  - Each temperature provides a new minimum detected size
  - Temperatures need calibration to ensure consistent operation between devices





$$Le = \frac{\propto (thermal\ diffusivity, air)}{D\ (mass\ diffusivity, vapor)}$$

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The CPC Transfer Function

$$N = \int_0^\infty \frac{dn}{dD_p} \eta_A(D_p, T_{Sat} T_{Cond}) \eta_T(D_p, Q, L)\, dD_p$$

- N is the concentration measured by the CPC
- n is the true particle concentration
- D_p is the particle diameter
- η_A is the fraction of particles that are activated (i.e. grown to a larger size through condensation)
- η_T is the fraction of particles that are not lost to the conduit walls via diffusion
- T_{sat} and T_{cond} are the saturator and condenser temperatures
- Q is the CPC flow
- L is the effective length of the transport conduit prior to activation (after which transport losses are negligible).

Objective: Determine T_{cond} to achieve a target η_A for a given diameter

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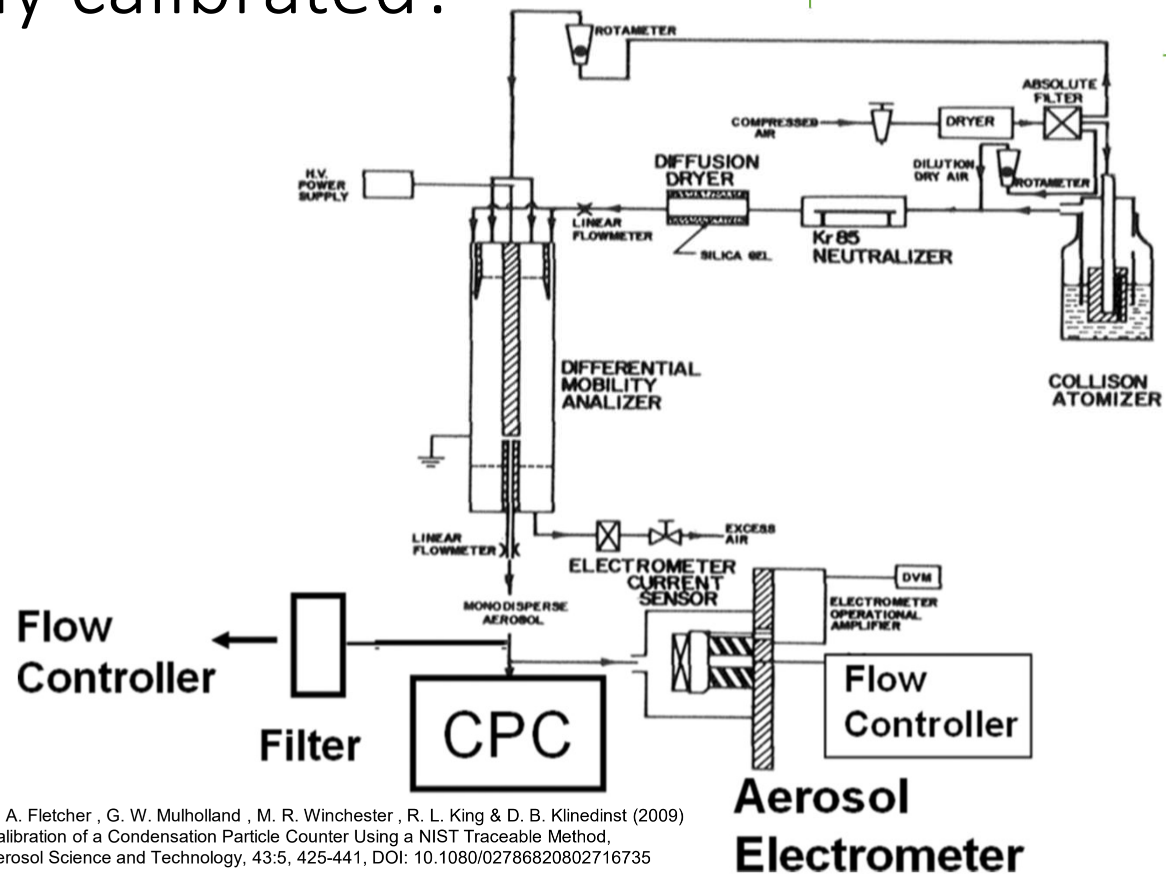
How are CPC traditionally calibrated?

- Aerosol Generation and Conditioning
  - Polydisperse aerosol generated using atomizer, tube furnace, or electrospray
  - Charge conditioners apply a known charge distribution to the aerosol
- Aerosol size selection
  - Differential Mobility Analyzer (DMA) isolates particles of a desired size
  - Only charged particles exit the DMA
- Reference Detector (Electrometer)
  - Faraday Cage Aerosol Electrometer measures the current from the charged particles and converts to a concentration



R. A. Fletcher , G. W. Mulholland , M. R. Winchester , R. L. King & D. B. Klinedinst (2009) Calibration of a Condensation Particle Counter Using a NIST Traceable Method, Aerosol Science and Technology, 43:5, 425-441, DOI: 10.1080/02786820802716735

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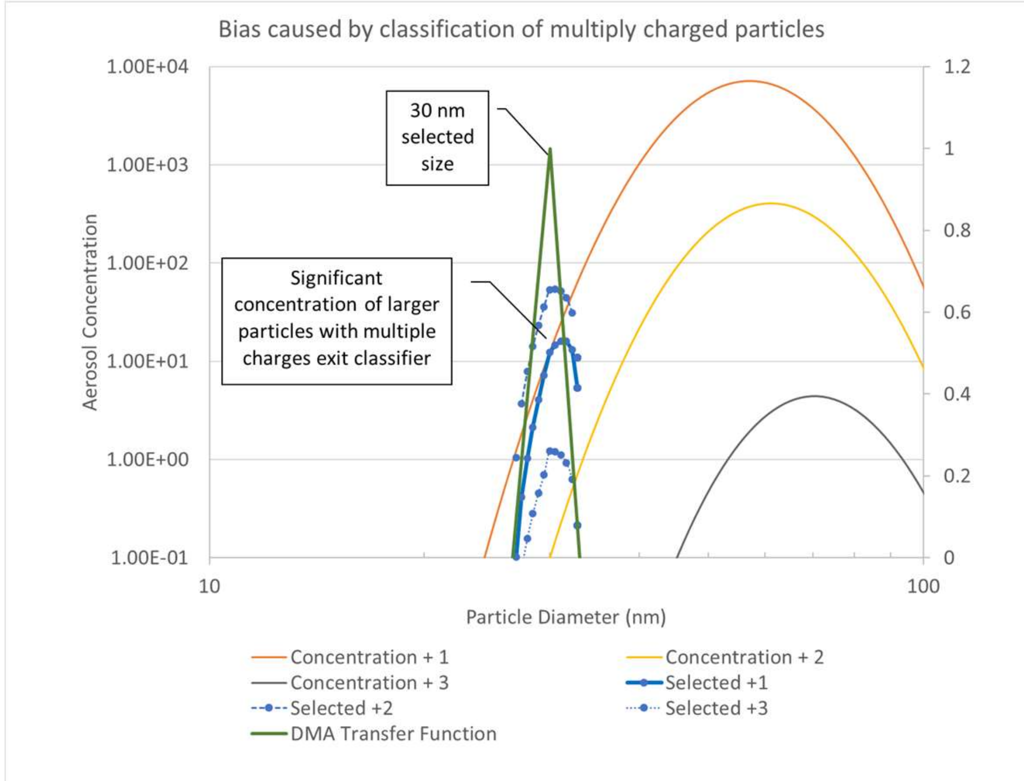
Why are traditional calibration methods tricky?

- Aerosol Generation and Conditioning
  - Polydisperse aerosols skew the challenge aerosol
  - Imperfect charge conditioners skew selection and detection
- Aerosol size selection
  - Transfer function of DMA introduces error due to the range of particle sizes that exit at a given voltage
  - DMAs allow large, multiply charged particles to pass through
- Reference Detector
  - Faraday cage aerosol electrometers unable to distinguish multiply charged particles from singly charged
  - Transport losses in sample tubing and within the reference detector introduce an offset



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Goals for a new approach to Calibrating CPCs

- Repeatable
  - Improve agreement between instruments
- Accurate
  - Eliminate artifacts e.g. Charge, Transport, Polydispersity
  - Prove measurement capability
- Practical
  - Limit the complexity of the instrumentation
  - Reduce potential errors

Objective: Determine T_{cond} to achieve a target η_A for a given diameter

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The new approach to Calibrating CPCs

- Use monodisperse particles for challenge aerosol
  - Eliminates polydispersity artifacts
  - Calibration diameters are limited to available materials
- Use a "boosted" CPC as reference detector
  - Tuned for 100% detection of all challenge particle sizes
  - Eliminates charge artifacts
  - Allows for lower challenge concentrations compared to electrometers
- Decouple the transport and activation efficiencies
  - Avoids correcting for transport losses
  - Improves repeatability and accuracy

Objective: Determine T_{cond} to achieve a target η_A for a given diameter

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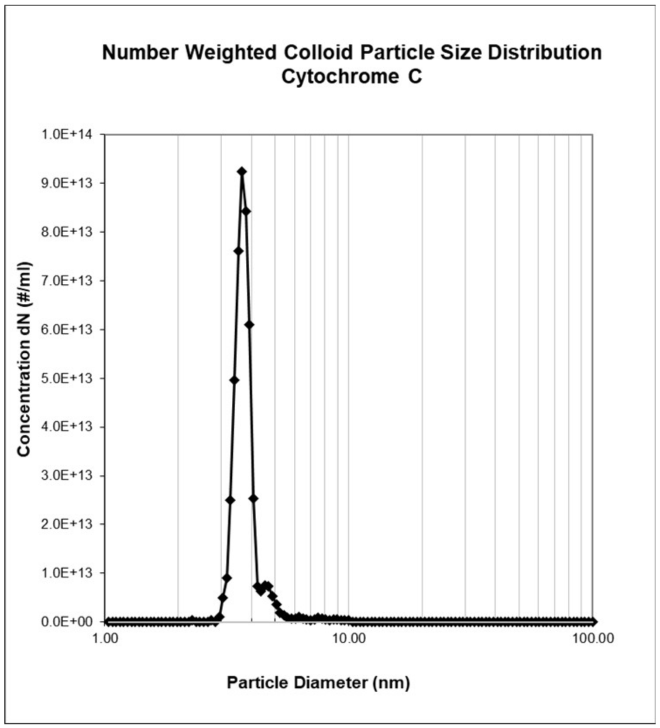
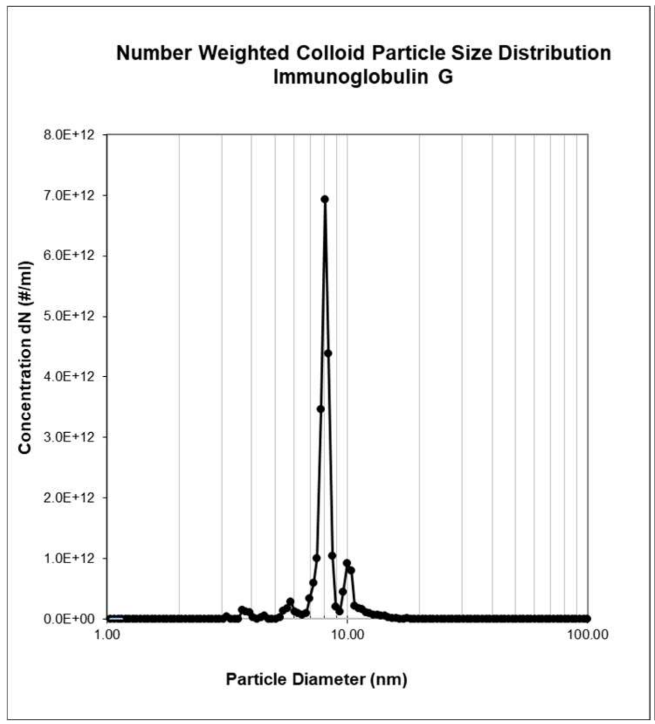
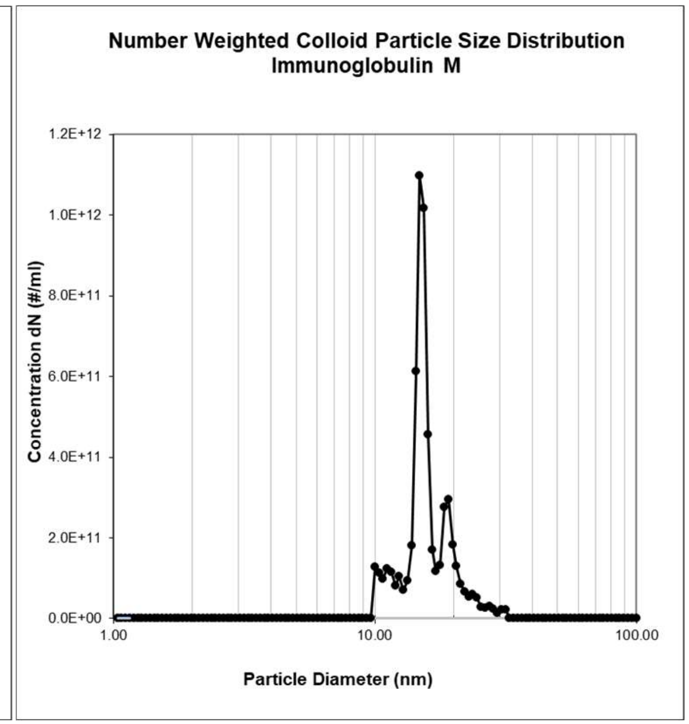
Selecting the challenge aerosol

- Proteins used because they are naturally a fixed molecular weight and are readily available
- Ctyochrome-C ~3.3 nm, Immunoglobulin G (IgG) ~ 8nm, Immunoglobulin M (IgM) ~ 15nm







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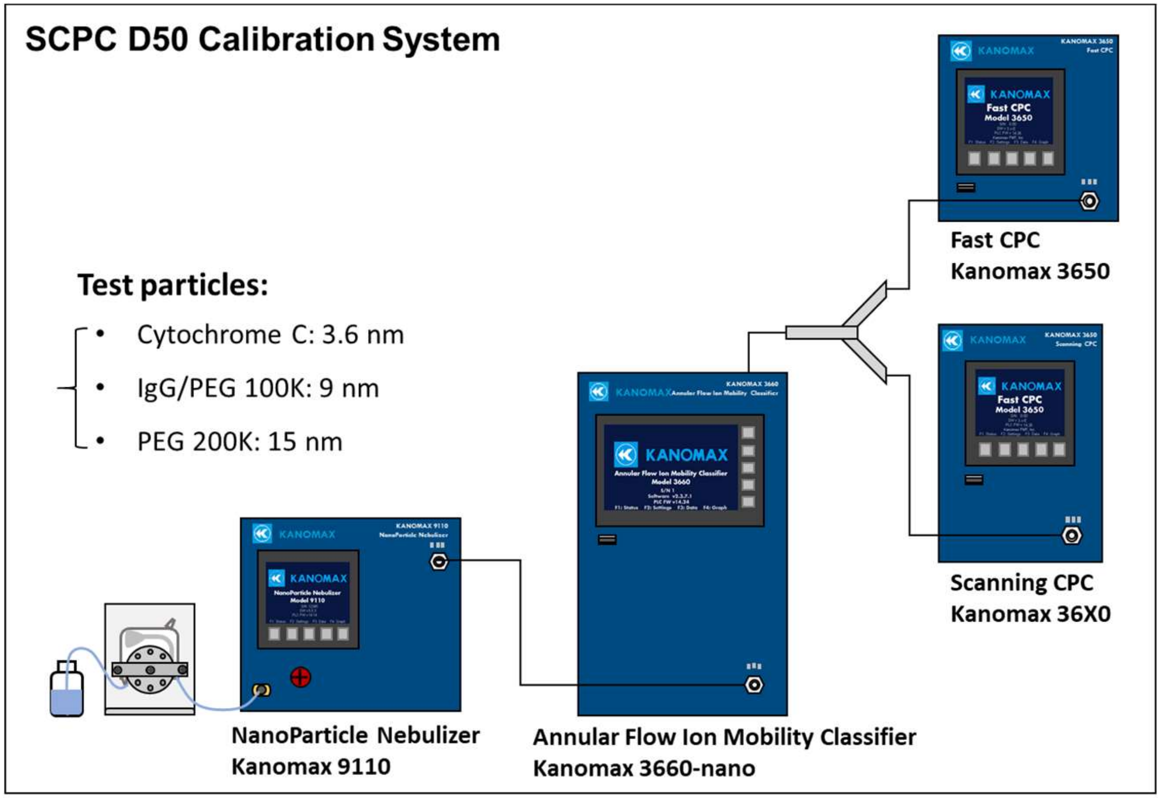
The Experimental Setup

- Challenge particles are aerosolized
  - Large proteins dissolved in UPW
  - Three solutions prepared and are paired with a multi-channel peristaltic pump
  - Size distribution measured by boosted CPC to verify system operation
- Aerosol passes through an Annular Flow Ion Mobility Classifier (AFIMC)
  - Same principle of operation as a Differential Mobility Analyzer
  - Classifier is used to isolate monomers from multimers
  - Transfer function can be relatively broad
  - Boosted FastCPC used as reference



Collecting the data

- Software controls pump and classifier voltage
  - Select vial and flowrate
  - Set the classifier voltage to the isolate the particle size being aerosolized
- Software adjusts condenser temperature of CPC under calibration and reads concentration data from both CPCs
  - Temperature range is selected to extend from η_A < 10% to 100% (the asymptote)
- Following a measurement software moves to next vial/size

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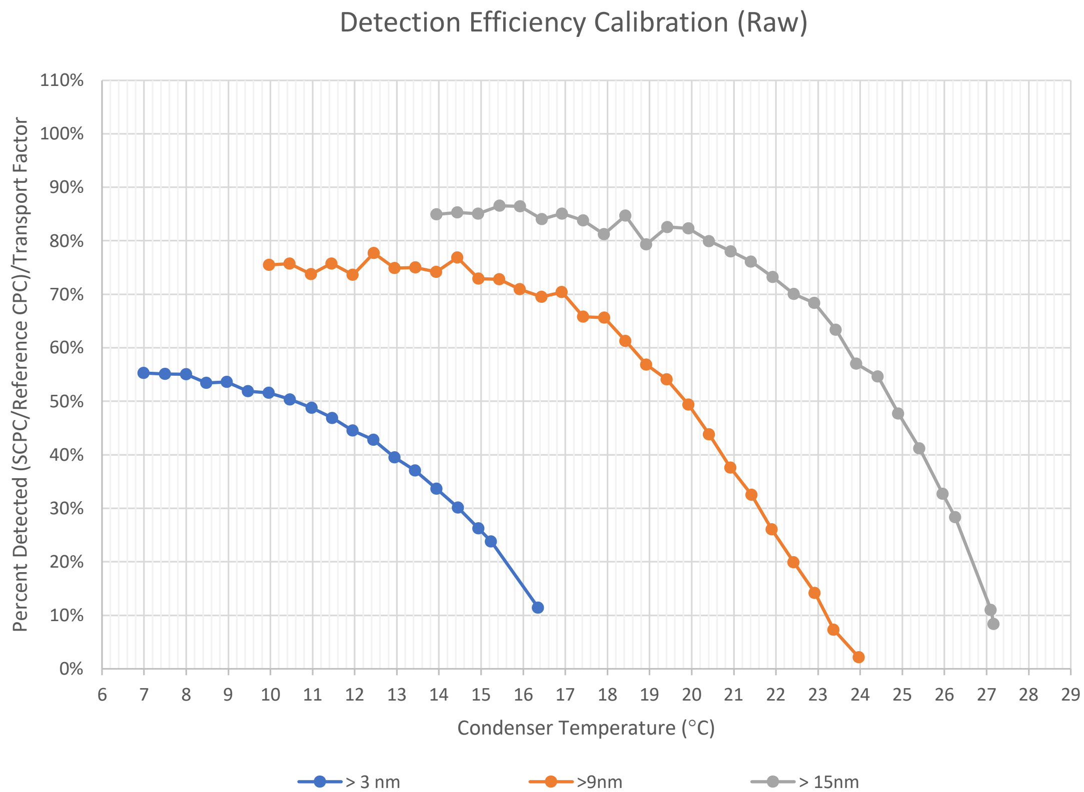

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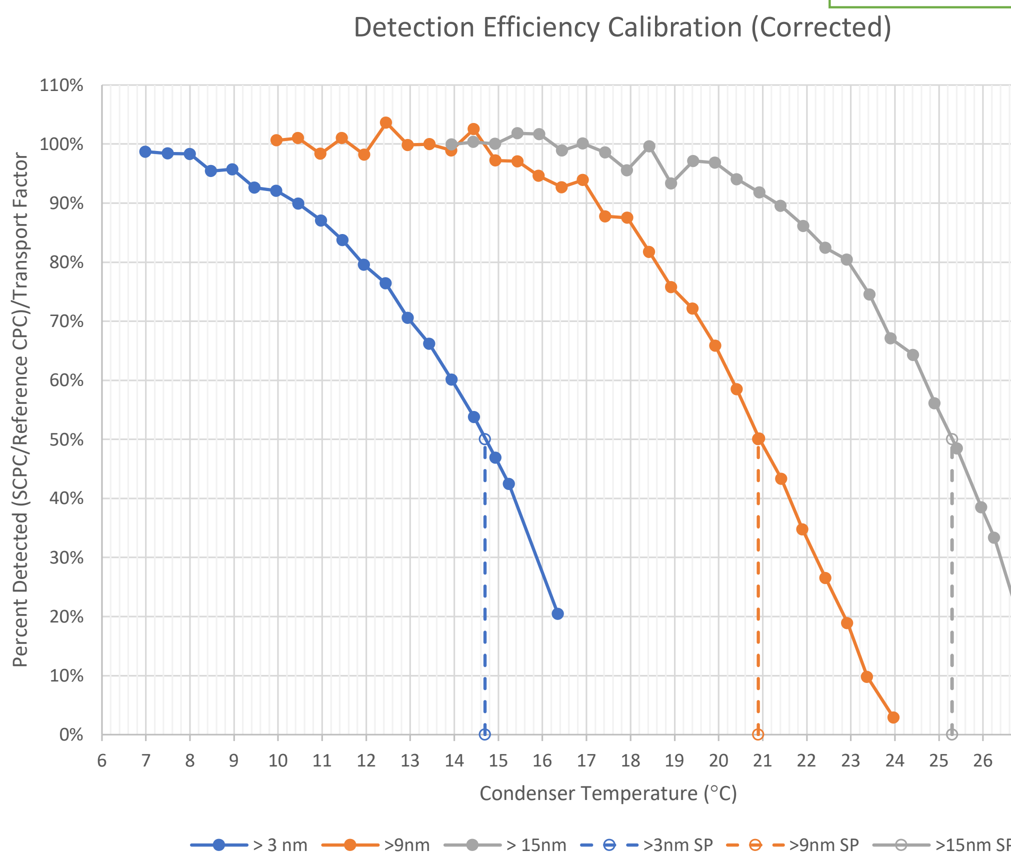
Analyzing the data

- Determine the Transport Factor and scale data
  - Ratio of transport efficiencies between test and ref: $TF = \eta_{T,test} / \eta_{T,ref}$
  - $(N_{test}/N_{ref})\ /TF = 1.$
- Determine T_{cond} for each size
  - To set the 50% detection efficiency find T_{cond} where $(N_{test}/N_{ref})\ /TF = 0.5.$
  - 50% detection selected to minimize bias to smaller sizes. Note: industry standard is to specify minimum detected size (1%-10% detection efficiency)



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Key Takeaways

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- Traditional methods for calibrating operating temperatures for Condensation Particle Counters have several sources of error
  - Differences in transport efficiencies between reference and test instrument
  - Skewing due to the shape of the challenge aerosol distribution
  - Over-counting due to multiply charged particles
- Calibrating CPCs using monodisperse particles and temperature stepping mitigates these sources of error

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Thank you to the R&D team at Kanomax FMT for their contributions to many aspects of this work

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Note: principle concepts of the described method are patent pending

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