PULSE HEIGHT MONITOR TO IMPROVE DATA RELIABILITY OF CONDENSATION PARTICLE COUNTER FOR ENGINE EMISSION APPLICATIONS

Jacob H Scheckman[1], Hans-Georg Horn[2] and Robert Anderson[1]
[1]TSI Incorporated, 500 Cardigan Rd, Shoreview, MN, USA
[2]TSI GmbH, Neuköllner Str. 4, Aachen, Germany

Abstract

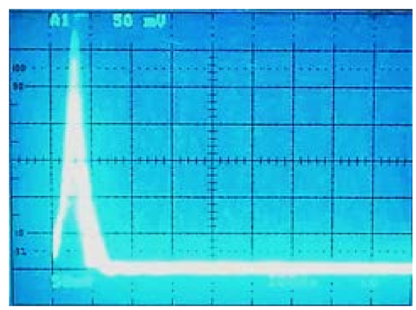
Condensation Particle Counters (CPCs) have been used for measurement of engine emissions either alone or as part of SMPS (scanning mobility particle sizer) systems for many years. With the introduction of the European particle number standards for engine emissions, the usage of CPCs has increased. In a limited number of engine emission applications a drop in CPC concentration has been observed[1]. Advanced signal processing and analysis methods have been developed to monitor CPC measurement performance and ensure data integrity.

A CPC works by condensing a saturated vapor on to particles and growing them into droplets that are large enough to be easily detected using an optical technique. During normal operating conditions, enough vapor is produced such that all particles grow into droplets of approximately the same size. As a result, the light scattering signal produced (i.e. the pulse height) for each droplet is approximately the same. However, if the amount of saturated vapor is insufficient, possibly due to concentration exceeding instrument specification, or due to a contaminated or dirty saturator wick, the resulting pulse heights of detected particles will decrease. By monitoring these electronic signals, it is possible to monitor the "health" or performance of a CPC in order to determine its operating performance. This paper will describe the pulse height monitor and show test results that illustrate how it detects vapor depletion problems that could otherwise results in undercounting of concentration.

Introduction

A Condensation Particle Counter (CPC) grows particles by condensation to make them large enough to detect. When a particle has grown it passes through a laser beam and the scattered light is focused on a photodetector. The photodetector signal is an electrical pulse that is counted as a particle count.

- Height of pulse is roughly correlated to size of grown droplet
- Size of grown droplet is a rough indicator of how much vapor is available
- As vapor is depleted, final grown size is smaller
- If vapor is depleted enough, some particles do not grow to detectable size
- Pulse height drop is a rough indication of depletion of available vapor



Pulse Height Monitoring

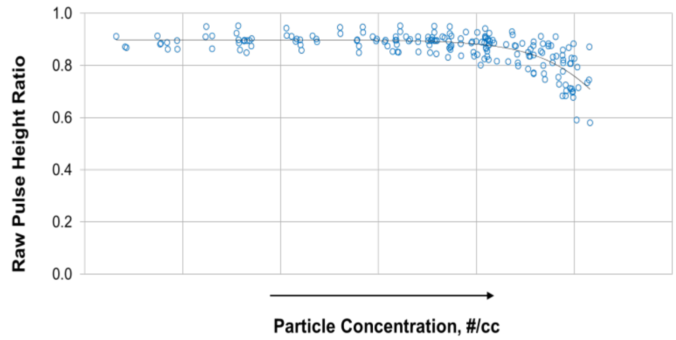
A Trigger Level (V1) is used to decide if the particles have grown sufficiently to be counted. With Pulse Height Monitoring a second, Higher Voltage Trigger (V2) is used, the ratio of V2/V1 is calculated. For the voltage levels chosen for this monitor the ratio is approximately 0.9. When normalized the ratios vary around 1 (100%).

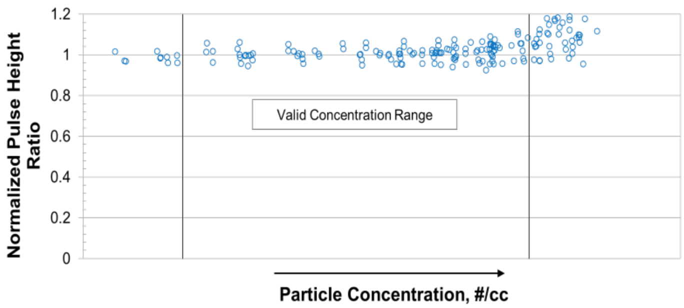
Evaluating Pulse Ratio Data

The main purpose of the pulse height monitoring system is to detect a drop in instrument performance due to vapor depletion. Since system errors and concentration extremes can also cause reduction in the pulse ratio the pulse ratio data is evaluated for validity. If a system error occurs or if the concentration is outside of the valid concentration range that pulse height data is excluded from the data set that is used to determine if an error has occurred due to low pulse height ratio. Examples of system errors are: concentrations above 10^4, temperatures, pressure or laser power readings out of range, or low liquid level.

Pulse Height Ratio Data

The raw Pulse Ratio data shows scatter around approximately 0.9 at lower concentrations and it drops with increasing concentration due to vapor depletion. A nominal curve was fit to the data during development that is used to normalize the data. This normalization helps to avoid false errors at high concentrations. The Y Intercept value on this curve is determined individually during calibration to account for instrument to instrument variability.





Pulse Height Errors

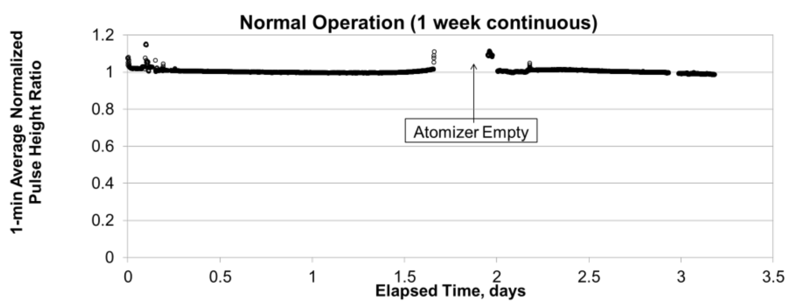
Degradation of the wick, when it occurs, is a gradual progressive process usually due to contamination that reduces the amount of wick available to produce vapor needed to grow particles in the CPC. If the normalized pulse height drops below the error criteria for a sustained time an error flag is generated.

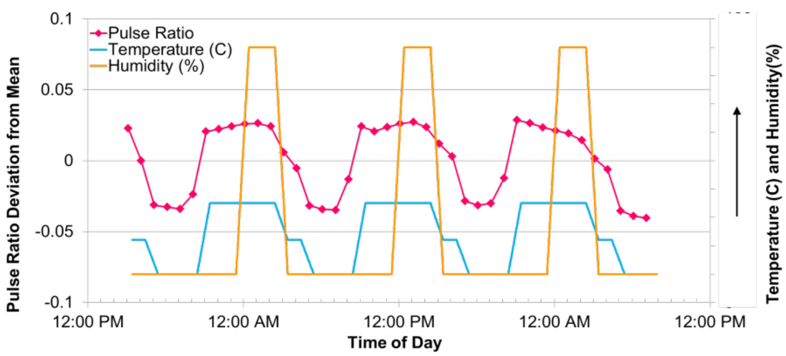
Experimental Test Setup

Various tests were done to evaluate the conditions where pulse heights may vary. The basic setup used an atomized oil solution. Other tests were done with different soot sources and these gave similar results to the lab testing using oil aerosol. With the atomized oil setup several methods were used to simulate degraded performance.

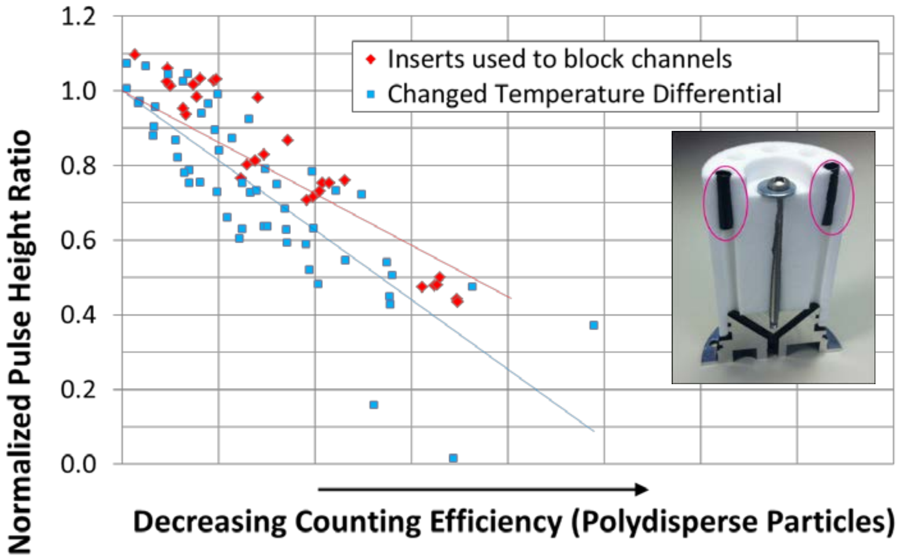
Blocked Channels: Blocking of some of the channels in the saturator wick simulates contamination that can occur under some conditions with engine emissions. As contamination effectively blocks some of the saturator wick area used to produce vapor, the amount of vapor available to condense onto the particles drops and the pulse heights are reduced and the measured concentration (compared to a reference CPC) is also reduced.

Lower Temperature Differential: The temperature differential between the heated saturator and the cooled condenser is what, first provides vapor, and then condenses that vapor onto the particles. Reducing the temperature differential simulates problems with the temperature control system that would result in lower concentrations.





The graph on the left labeled Normal Operation shows a portion of the data for 3 units operated continuously for one week. The average Normalized Ratio was 1.01 ± 0.05 (3σ) for the full sampling period. Under normal conditions the pulse height is very stable and any drop that exceeds 0.05 is an indication of a measurement problem. Tests were done with the CPCs in an environmental chamber. The temperature and humidity were cycled. Humidity had no noticeable effect on pulse ratio. Temperature had a small (<5%) effect. Tests were then done where portions of the saturator wick surface were blocked limiting the vapor output.



Summary of test results

With a stable aerosol source the pulse ratio is very stable. Even under fairly dramatic changes in environmental conditions the pulse ratio doesn't change substantially. Both methods of degrading performance lowered the counting efficiency and decreased the pulse height ratio according to a consistent correlation.

Conclusions

A Pulse Height monitoring method has been developed to provide an indication of the health of CPCs used for measurement of particle number engine emission standards in Europe. Under most conditions the height of pulses should be very similar over a wide range of concentrations and initial particle sizes. When the system health degrades due to, for example, wick contamination, the pulse height monitoring system alerts the user to the problem.

References

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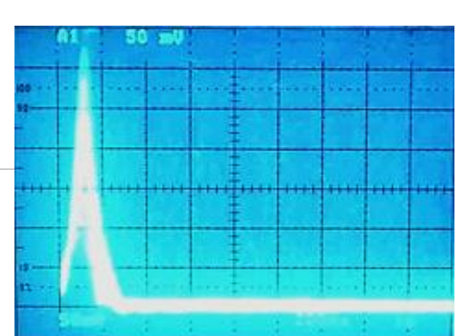

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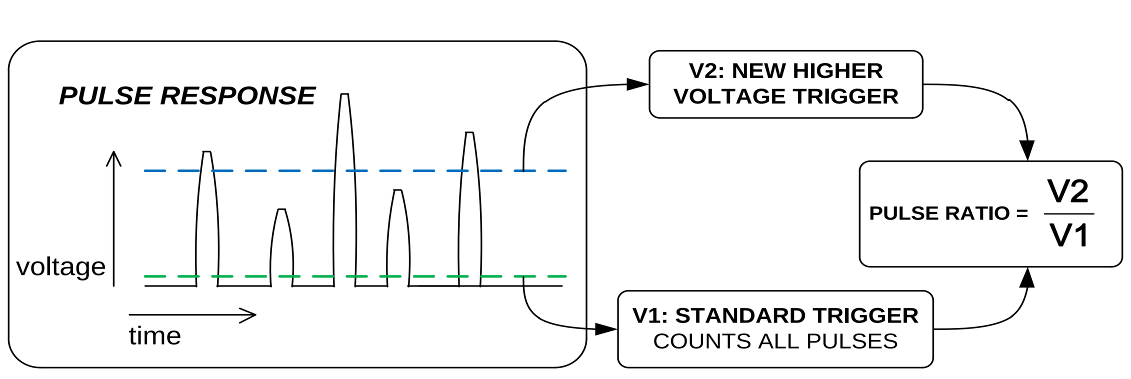

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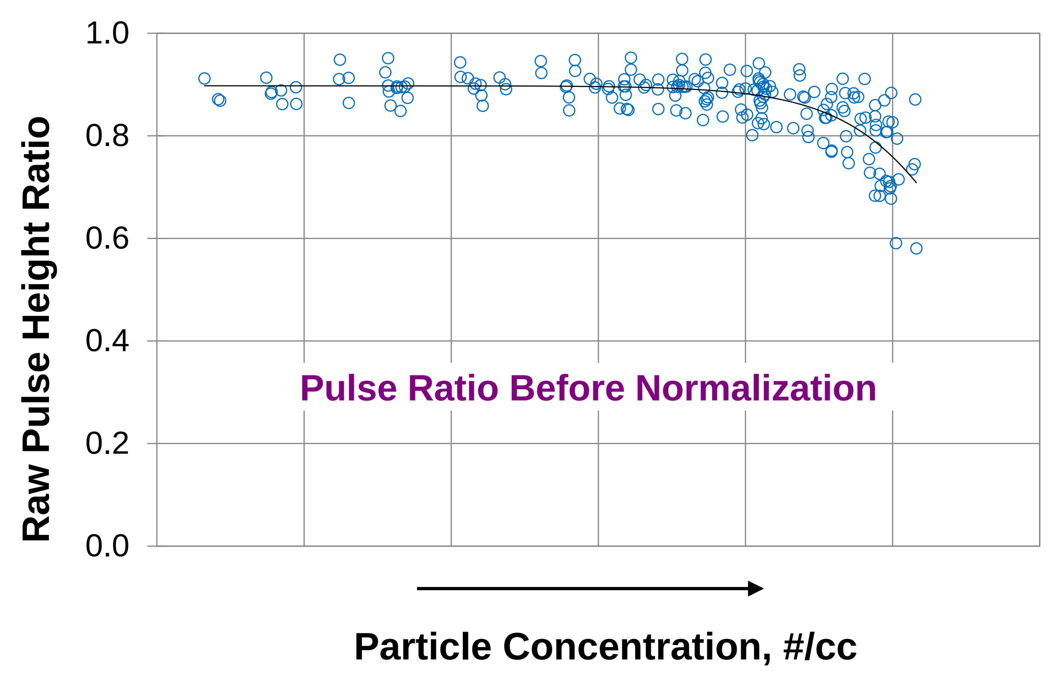

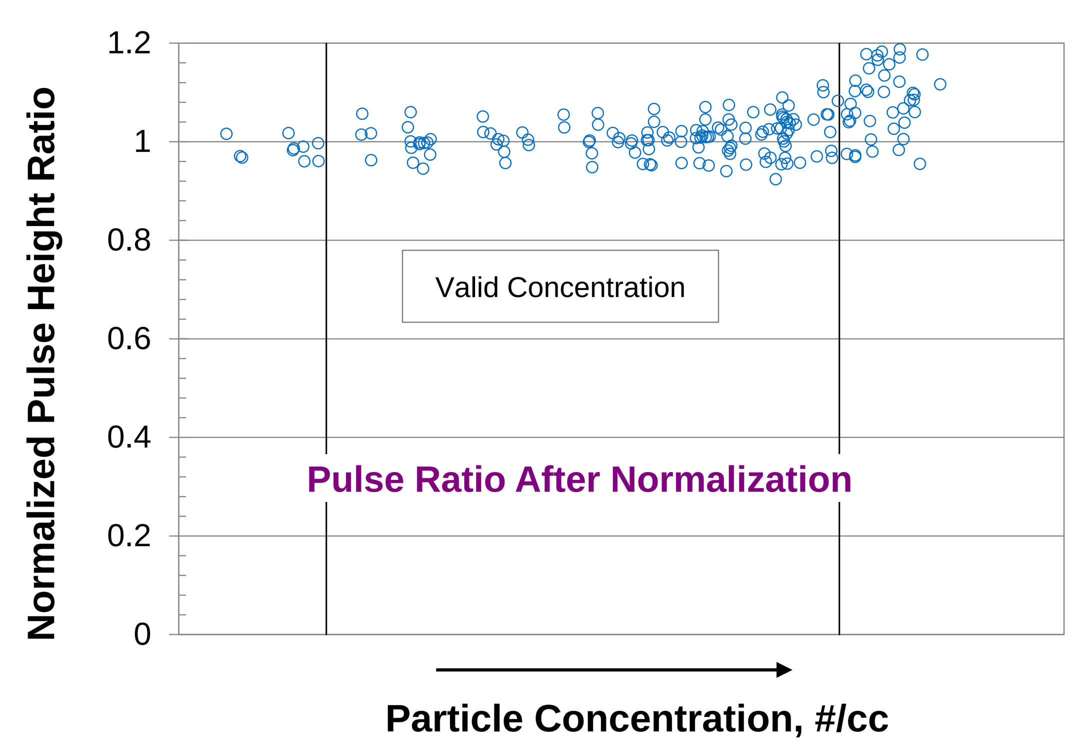

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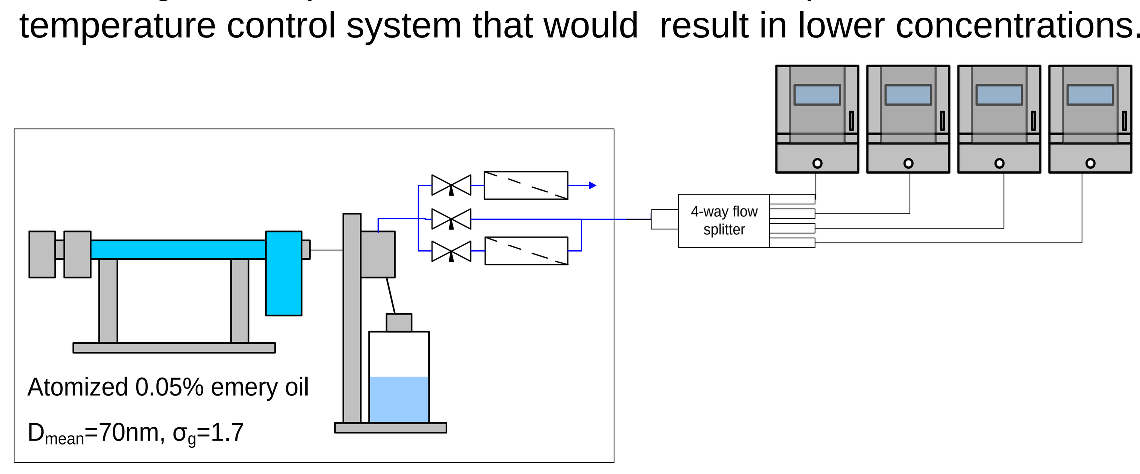

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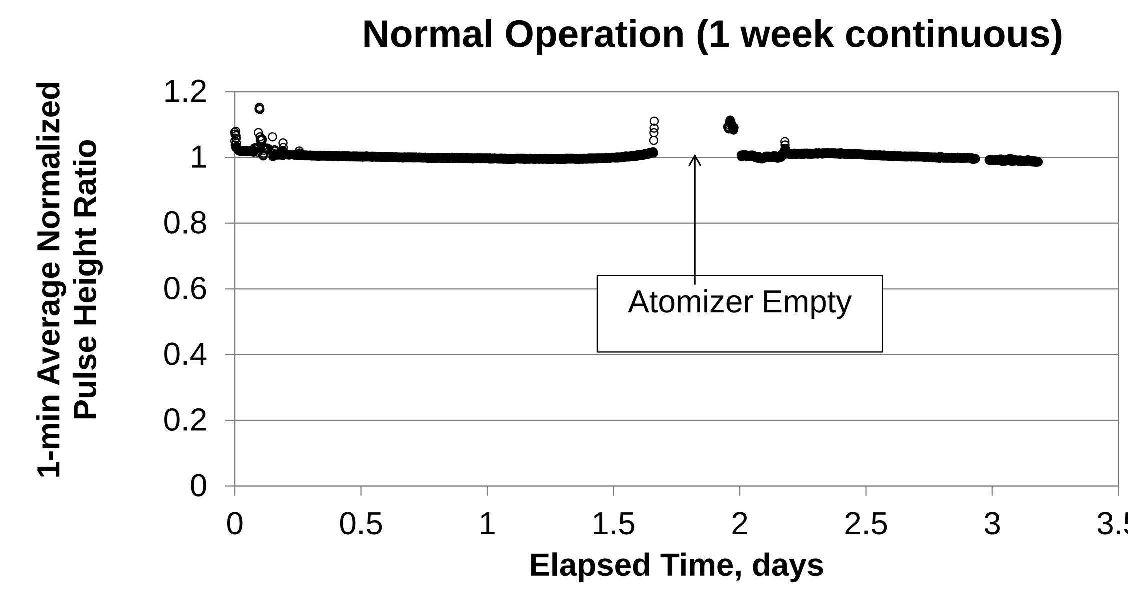

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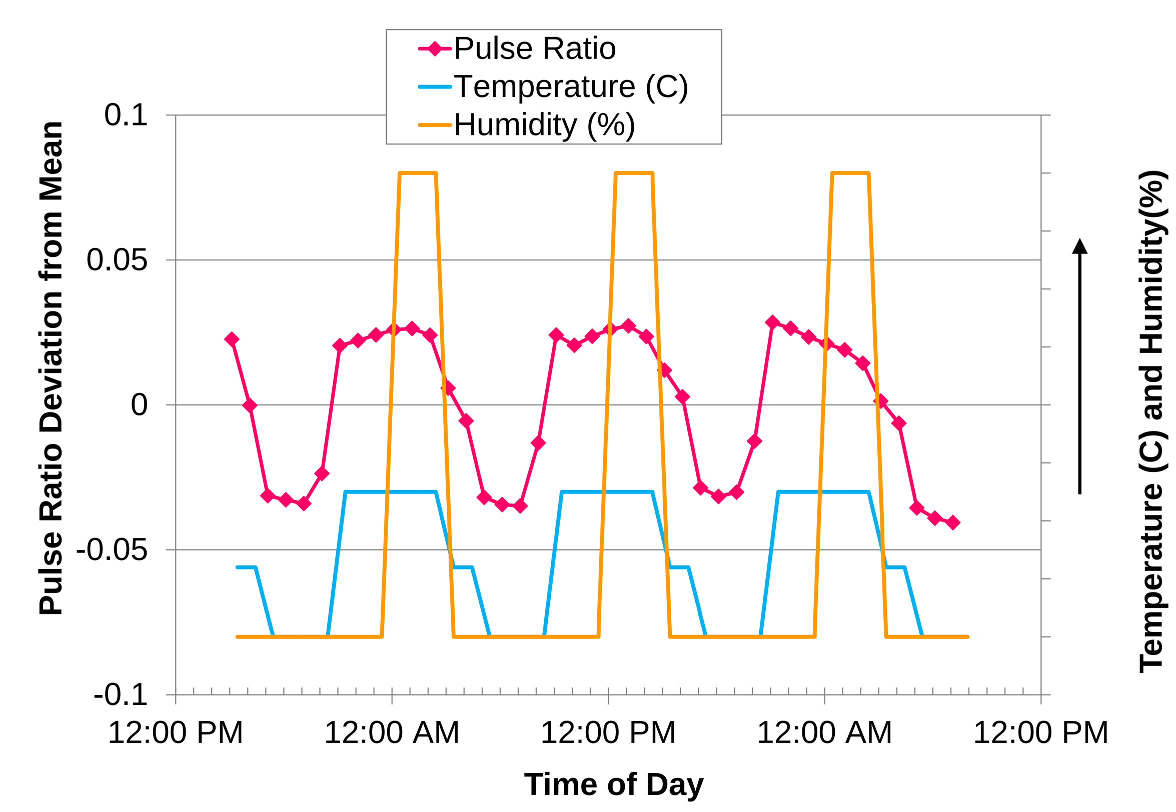

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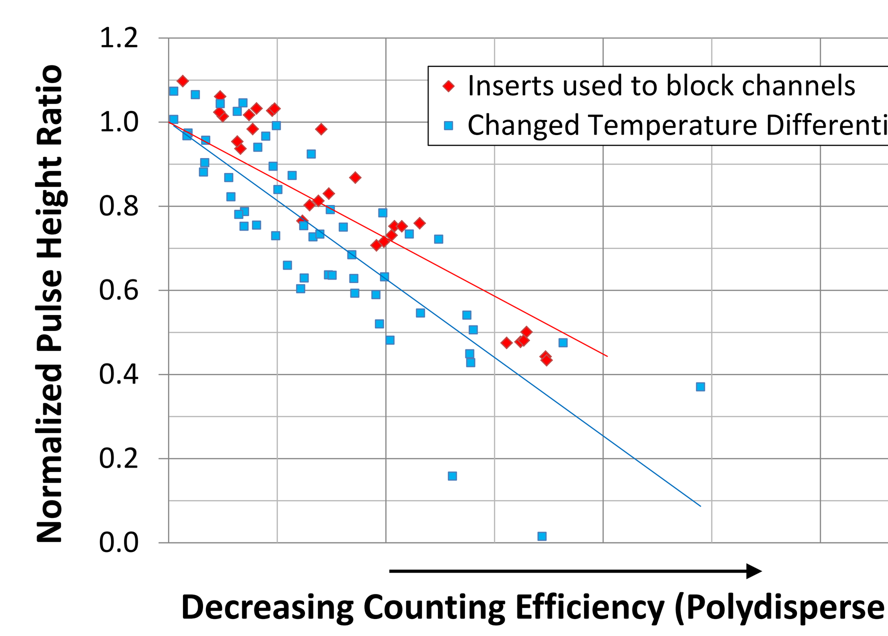

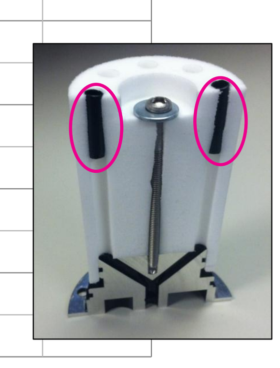

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