Optec NGN-2 LED Ambient Integrating Nephelometer

Extended Abstract # 77

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INTRODUCTION

The Optec NGN-2 ambient integrating nephelometer is designed to operate in low power, low maintenance, ambient conditions, and to minimally heat the ambient aerosol. Since 1993, NGN-2s have been operated successfully in federal, state, local, and industry sponsored visibility monitoring programs. Ambient aerosol scattering data from these instruments were recently used to derive the new IMPROVE reconstructed extinction equation. Even though the NGN-2 was designed to minimally heat the ambient aerosol as it passed through the optical scattering chamber, the use of an incandescent light source results in a slight heating of approximately 1-2 ^{O}C. At high ambient relative humidities (>80%), an increase in temperature in the chamber as small as 1^{O} C will result in a 8-10% lowering of the relative humidity in the chamber. If highly hydroscopic aerosols are present (Ammonium Sulfate or Nitrate) and ambient relative humidity is high, the aerosol scattering measured by the nephelometer can be nearly 100% less than the actual ambient scattering. In addition the use of an incandescent light requires a mechanical chopping system to modulate the light source and the light source has a short life span resulting in frequent operator site visits to change out the lamp. A high output LED light source has recently been incorporated into the NGN-2. The light source has a life span of thousands of hours, emits essentially no heat, and is electronically modulated which allows the removal of the mechanical chopper.

OPTEC NGN- LED NEPHELOMETER

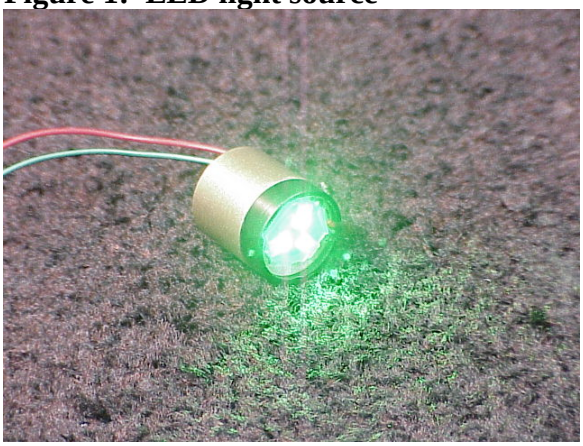
Primary Benefits

- Long lamp life ~ 50,000 hrs
- Electronic modulated –
  no mechanical chopper
- Minimal heating

Differences from NGN-2

- 530 nm light source
- narrow bandwidth ~ 40nm

Figure 1: LED light source



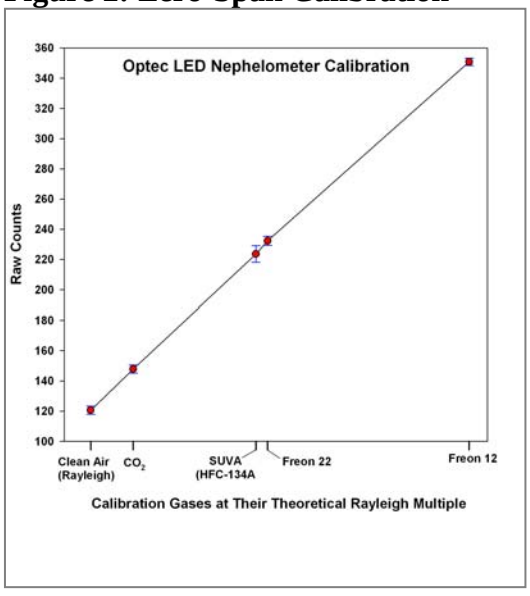
CALIBRATION

Table 1 lists the gases used to perform a complete zero-span calibration of the new LED nephelometer. Figure 2 plots the results.

Table 1

Calibration Gas	Multiple of Rayleigh
Clean Air Zero (Rayleigh	1.0
Carbon Dioxide (CO2)	2.61
SUVA – HFC 134A	7.25
Freon 22	7.69
Freon 12	15.31

Figure 2: Zero-Span Calibration



MODELED NEPHELOMETER RESPONSE

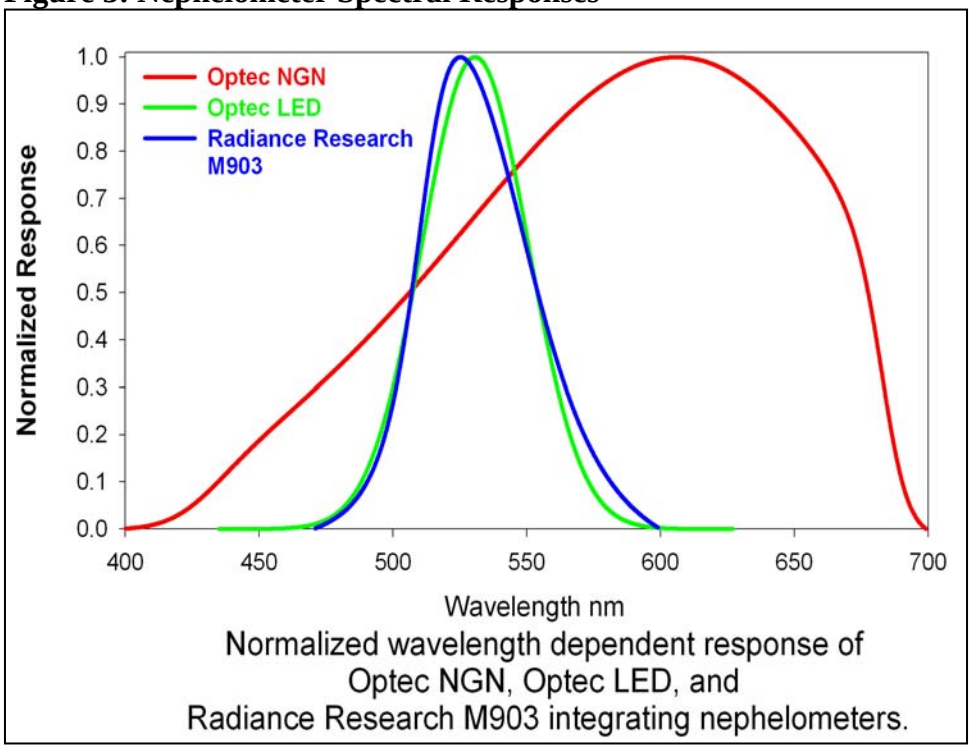
Basic Equation of Nephelometry: The signal output by a nephelometer is proportional to:

$$2\pi\int_{\lambda}\int_{\varphi} B(\varphi,\lambda)\sin(\varphi)\,d\varphi\,R(\lambda)\,d\lambda$$

where: **R(λ)** is the complete spectral response, ***B*(φ,λ)** is the volume scattering function; integration over λ is for all wavelengths the nephelometer is sensitive to; and integration over φ is over the integration angle of the instrument. It is straight forward to use this equation to develop an analytical model to examine nephelometer responses.[1,2]

Spectral Response: The spectral response, R(λ), of a nephelometer is obtained by multiplying the spectral energy distribution of the light source with the spectral sensitivity of the detector, filters and all optical components used in the system. Figure 3 plots the spectral responses of the Optec NGN-2, Optec NGN-LED, and Radiance Research M903 nephelometers.

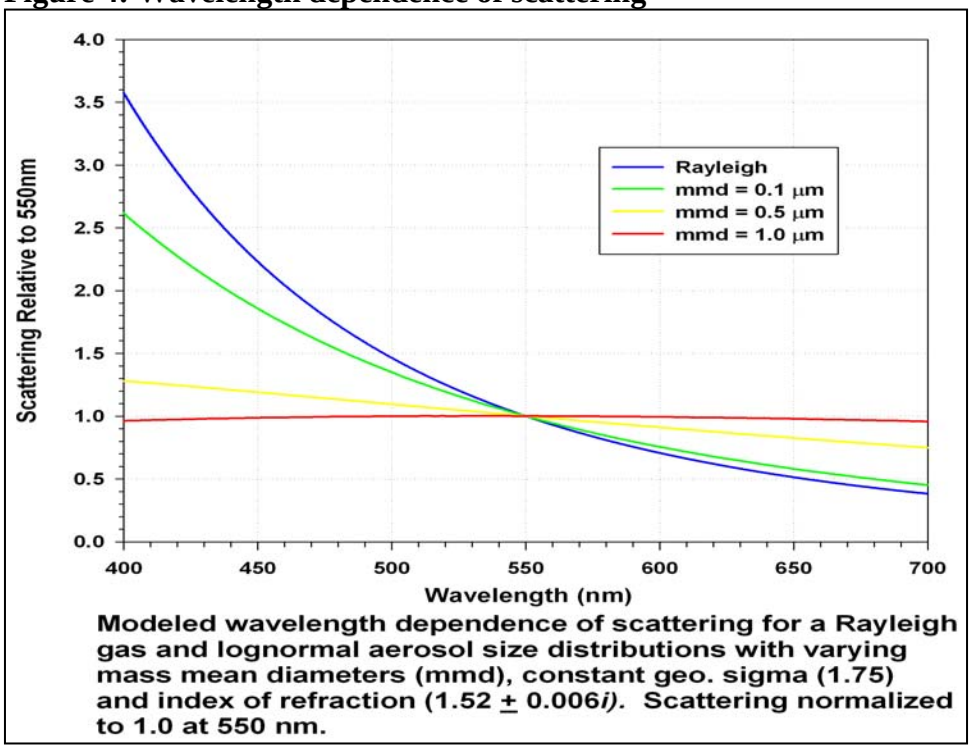
Figure 3: Nephelometer Spectral Responses



Normalized wavelength dependent response of Optec NGN, Optec LED, and Radiance Research M903 integrating nephelometers.

Wavelength Dependence of Scattering: The volume scattering function, both of the calibrating gas and aerosol to be measured, is a function of wavelength and scattering angle. Thus, the measured scattering coefficient depends on the weighted average of the instrument response of both the aerosol and Rayleigh calibration gas. Figure 4 plots the theoretical wavelength dependence of scattering for a gas and various aerosol size distributions.

Figure 4: Wavelength dependence of scattering

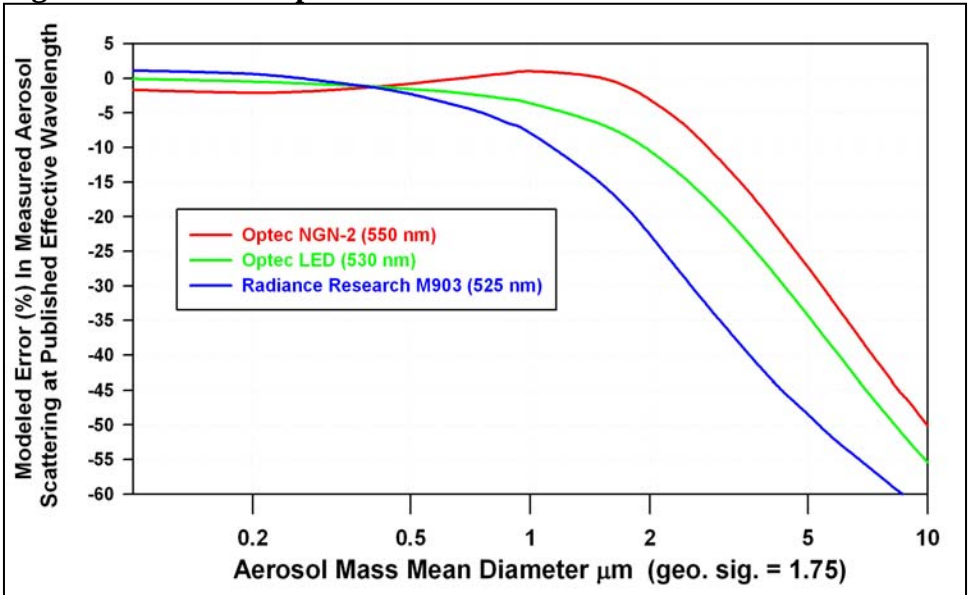


Modeled wavelength dependence of scattering for a Rayleigh gas and lognormal aerosol size distributions with varying mass mean diameters (mmd), constant geo. sigma (1.75) and index of refraction (1.52 ± 0.006*i*). Scattering normalized to 1.0 at 550 nm.

Truncation Angle: A perfect integrating nephelometer will collect all scattered light from 0 - 180^{O} . However, real nephelometers must collect scattered light less than this optimal range due physical limitations of detector size, the need to shield the light trap from direct illumination by the light source, and finite length of the scattering chamber. This effect, known as truncation error, is minimized to some extent by calibrating the instrument with a Rayleigh scattering gas. However, since aerosols have a different scattering phase function compared to gases, the truncation error will increase with aerosol size as more light is scattered in the forward (0^{O}) and backward (180^{O}) directions. The Optec nephelometers integrate from 5-175^{O}, the Radiance Research from 10-165^{O}.

Modeled Error: Figure 5 plots of this modeled error as a function of aerosol mmd for the Optec NGN-2, Optec LED and Radiance Research M903 integrating nephelometers. This analysis includes all spectral and truncation effects as well as the wavelength dependence of scattering

Figure 5: Modeled nephelometer error



Estimated error in measured scattering at published effective wavelength for Optec NGN-2, Optec LED and Radiance Research M903 integrating nephelometers as a function of aerosol mass mean diameter; including spectral response and truncation error.

SUMMARY

The Optec NGN-2 integrating nephelometer was designed to make ambient aerosol scattering measurements under a wide variety of field and experimental conditions. The design requirements of low power, low maintenance, and ambient operation necessitated certain compromises such as a solid state detector and wide band filter. These compromises have been addressed in the Optec NGN-LED nephelometer. Theoretical analysis of instrument responses indicates that the Optec LED will be able to make just as accurate aerosol scattering measurements. The Arizona Department of Environmental Quality retrofitted three NGN-2 nephelometers with the new LED light source in early 2007. These nephelometers have operated for over 8000 hrs without a LED failure. This has resulted in significantly reduced operator costs. AZDEQ plans to retrofit all their remaining OptecNGN-2 nephelometers.

REFERENCES

1. Molenar, J. V. (1997). Analysis of the real world performance of the Optec NGN-2 ambient nephelometer. in: *Visual Air Quality: Aerosols and Global Radiation Balance*, pp. 243-265, Air and Waste Management Association, Pittsburgh, Pa..

2. Rosen, J. M., Pinnick, R. G., and Garvey, D. M. (1997). Nephelometer optical response model for the interpretation of atmospheric aerosol measurements. *Appl.Opt.* 36:2642-2649