APPLICATION NOTE

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Effects of Light Absorption and Scattering in Water Samples on OBS® Measurements

CAMPBELL SCIENTIFIC, INC.®
WHEN MEASUREMENTS MATTER

Effects of Light Absorption and Scattering in Water Samples on OBS® Measurements

Light transmission through a water sample is determined by physical properties such as particle size, shape, suspended solids concentration (SSC), and composition, and chemical properties such as the presence of near-infrared (NIR) absorbing dissolved matter. There is enormous variation in these properties in the environment, resulting in a nearly infinite number of unique optical characteristics for natural and man-influenced water, however, consistent light transmission through a water sample is essential for precise measurements. Suspended sediment concentration and particle size span a 1000-fold range while NIR reflectivity varies by a factor of about 10. The absorption of light by dissolved matter can affect light-scattering measurements by 10% to 50% in run-off from mine tailings. Lack of understanding of these properties can lead to misinterpretation of SSC values determined with an optical sensor. This application note reviews their effects and addresses answers to questions about size, color, and disaggregation effects.

Overview

Knowing some basics about light transmission through water samples will enhance your understanding of how OBS® sensors operate and help you select the best system/instrument for an application. It will also help you recognize technical and operational limitations that can reduce the value of your data and challenge the success of your monitoring program. Light transfer through a water sample is affected in complex ways by water molecules, material dissolved in the water, and scattering by suspended particles. All light-transfer processes depend on wavelength as indicated by the λ symbol in the following discussion.

Absorption Coefficient (a(λ))

Figure 1. Graph of aλ shows that the absorption coefficient of pure, particle-free, water ranges from 0.03 to 0.06 cm^{-1} in the 760 to 1000 nm band.

Light is an ensemble of photons that are absorbed and scattered by water, suspended particles, and dissolved matter as they travel through a sample. The absorption coefficient, a(λ), is a measure of the conversion of radiant energy to heat and chemical energy. It is numerically equal to the fraction of energy absorbed from a light beam per unit of distance traveled in an absorbing medium.

As Figure 1 shows, the absorption coefficient of pure, particle-free, water ranges from 0.03 to 0.06 cm^{-1} in the 760 to 1000 nm band. OBS sensors operate in the near infrared spectral band (780 and 860 nm) to limit their response to direct and reflected sunlight, the NIR content of which is strongly absorbed by water.

Scattering Coefficient (b(λ))

Light scattering changes the direction of photon transport, "dispersing" them as they penetrate a sample, without changing their wavelength. The scattering coefficient, b(λ), is equal to the fraction of energy dispersed from a light beam per unit of distance traveled in a scattering medium, in cm^{-1}. For example, water with b(λ) = 1 cm^{-1} will scatter 63% of the energy out of a light beam over a distance of 1 cm whereas another sample with b(λ) = 0.1 cm^{-1} will scatter the same proportion of energy in 10 cm. Both absorption and scattering reduce the light energy in a beam as it travels through a sample and larger values indicate stronger effects.

NOTE

The scattering coefficient of pure water is less than 0.003 cm^{-1} so light scattering has an immeasurably small influence on an OBS sensor compared to absorption. Pure water is scarce and particles are ubiquitous in the environment and light scattering from a miniscule amount (< 100 gl^{-1}) will cause consistent response from an OBS sensor.

Attenuation Coefficient (c(λ))

The attenuation coefficient, c(λ), is a measure of the light loss from the combined effects of scattering and absorption over a unit length of travel in an attenuating medium. The unit for c(λ) is cm^{-1}. An easy way to remember the relationship among these properties is to recall that a(λ) + b(λ) = c(λ). It is also important to remember that a(λ), b(λ), and c(λ) are inherent optical properties (IOP) that do not depend on how a sample is illuminated. They are the same during the day and night and when a sample is measured with turbidity meter A or sediment meter B.

NOTE

Absorption and scattering processes can be illustrated by using an overhead projection of petri dishes containing inky water and skim milk. The projected images of both dishes will be gray because their contents attenuate light, however, the milky sample does so mainly by scattering whereas the inky one mainly absorbs light.

Light Scattering

We elaborate a bit on light scattering because of its central importance in understanding how OBS' respond in the environment. The angular distribution of light intensity scattered from a beam by a water sample is called the volume scattering function, VSF. The angle between this beam and scattered light rays is the scattering angle. Forward-scattered radiation occupies the hemisphere surrounding the incident beam and oriented away from the source and back scattered radiation fills the opposite hemisphere. Figure 2 shows VSFs computed from Mie theory for air bubbles, mineral grains, and biological material as well as the forward- (0° to 90°) and back-scattering (> 90°) VSF regions.

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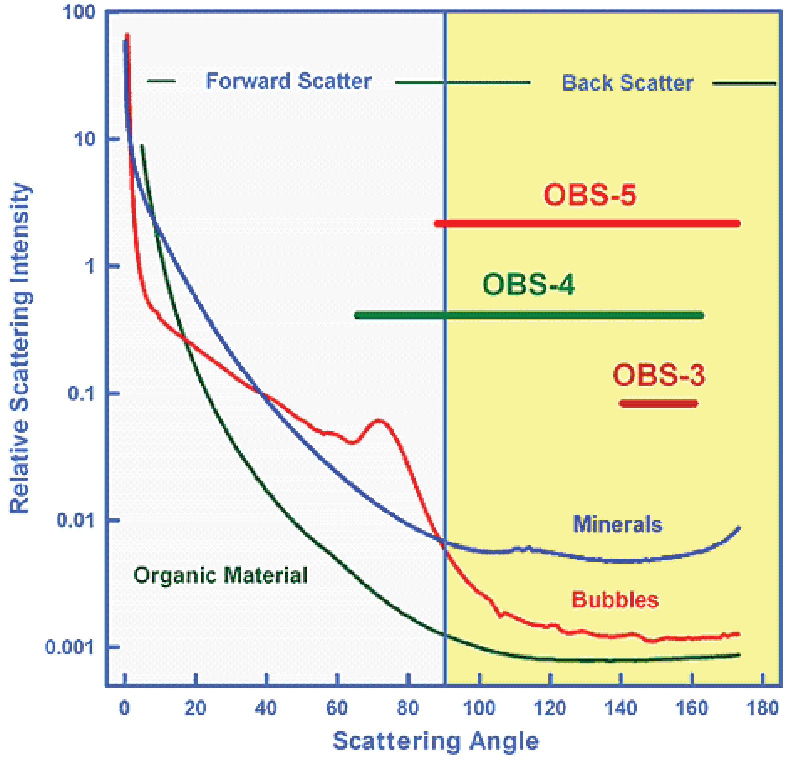

Figure 2. Graph shows VSFs computed from Mie theory for air bubbles, mineral grains, and biological material as well as the forward- (0° to 90°) and back-scattering (> 90°) VSF regions.

The VSF for bubbles is strongly peaked in the forward direction relative to the other materials and biological material back scatters 10 to 50% less light than the other particles. Like the material properties of water samples, the variety of VSFs is huge. Their shape depends, among other things, on particle size and refractive index. The size factor, $x = \pi D \lambda^{-1}$, where D is particle diameter, measures the important relative effects of the operating spectrum and the size of the scattering particles on the response of a meter to a particular sample. For example, the VSF for 100 µm spherical particles when illuminated by red light (650 nm) would be similar to one caused by illuminating 131 µm particles with 850 nm light, other things being equal. Most suspended particles in streams, lakes, and the ocean are larger than the wavelength of a meters' illumination system, and consequently they scatter about half the incident light energy into a 10-degree forward-directed cone and less than 2.5% of it in the backward direction. Because of the many combinations of particle size, shape, and color, similar turbidity readings can be obtained from samples containing physically distinct particles. Effects of sediment properties and sample-handling procedures on the values indicated by our meters are discussed the "*Particle Size Effects*", "*NIR Reflectivity & Particle Color*", and "*Absorption Effects*" application notes.

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References

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