Turbidity

Introduction and definition

Turbidity, a qualitative characteristic which is imparted by solids obstructing the transmittance of light through a water sample, is an important water quality indicator. Turbidity can be interpreted as a measure of the relative clarity of water and often indicates the presence of dispersed, suspended solids; particles not in true solution such as silt, clay, algae and other microorganisms; organic matter and other minute particles. Turbidity is not a direct measure of suspended particles in water, but a measure of the scattering effect such particles have on light.

The extent to which suspended solids can be tolerated varies widely, as do the levels at which they exist. Industrial cooling water, for example, can tolerate relatively high levels of suspended solids without significant problems. In modern high pressure boilers, however, water must be virtually free of impurities. Solids in drinking water can support growth of harmful microorganisms and reduce effectiveness of chlorination, resulting in health hazards. In almost all water supplies, high levels of suspended matter are unacceptable for aesthetic reasons and can interfere with chemical and biological tests.

Theory of light scattering

Very simply, the optical property expressed as turbidity is the interaction between light and suspended particles in water. A directed beam of light remains relatively undisturbed when transmitted through absolutely pure water, but even the molecules in a pure fluid will scatter light to a certain degree. Therefore, no solution will have a zero turbidity. In samples containing suspended solids, the manner in which the sample interferes with light transmittance is related to the size, shape and composition of the particles in the solution and to the wavelength (color) of the incident light.

A minute particle interacts with incident light by absorbing the light energy and then, as if a point light source itself, reradiating the light energy in all directions. This omnidirectional reradiation constitutes the "scattering" of the incident light. The spatial distribution of scattered light depends on the ratio of particle size to wavelength of incident light. Particles much smaller than the wavelength of incident light exhibit a fairly symmetrical scattering distribution with approximately equal amounts of light scattered both forward and backward (see Figure 1).

As particle sizes increase in relation to wavelength, light scattered from different points of the sample particle create interference patterns that are additive in the forward direction. This constructive interference results in forward-scattered light of a higher intensity than light scattered in other directions (see Figure 2 and Figure 3). In addition, smaller particles scatter shorter (blue) wavelengths more intensely while having little effect on longer (red) wavelengths. Conversely, larger particles scatter long wavelengths more readily than they scatter short wavelengths of light.

Particle shape and refractive index also affect scatter distribution and intensity. Spherical particles exhibit a larger forward-to-back scatter ratio than coiled or rod-shaped particles. The refractive index of a particle is a measure of how it redirects light passing through it from another medium such as the suspending fluid. The particle's refractive index must be different than the refractive index of the sample fluid in order for scattering to occur. As the difference between the refractive indices of suspended particle and suspending fluid increases, scattering become more intense.

The color of suspended solids and sample fluid are significant in scattered-light detection. A colored substance absorbs light energy in certain bands of the visible spectrum, changing the character of both transmitted light and scattered light and preventing a certain portion of the scattered light from reaching the detection system.

Light scattering intensifies as particle concentration increases. But as scattered light strikes more and more particles, multiple scattering occurs and absorption of light increases. When particulate concentration exceeds a certain point, detectable levels of both scattered and transmitted light drop rapidly, marking the upper limit of measurable turbidity. Decreasing the path length of light through the sample reduces the number of particles between the light source and the light detector and extends the upper limit of turbidity measurement.

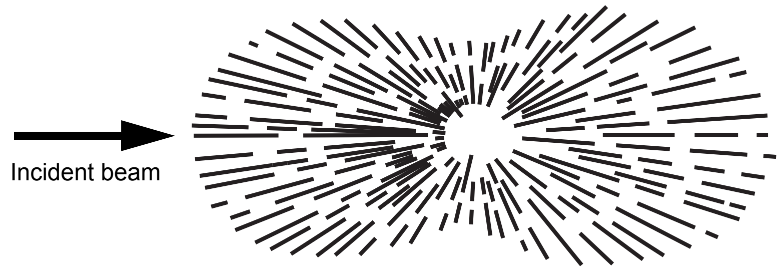

Figure 1 Effects of particle size and light wavelength (small particles)[1]

[1] Size: Smaller Than 1/10 the wavelength of light
Description: Scattering symmetric

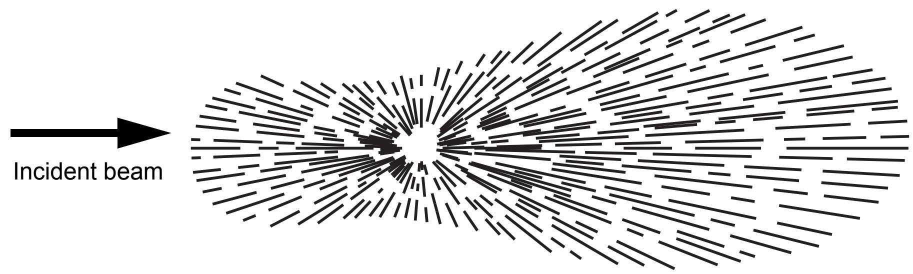

Figure 2 Effects of particle size and light wavelength (large particles)[1]

[1] Size: Approximately 1/4 the wavelength of light
Description: Scattering concentrated in forward direction

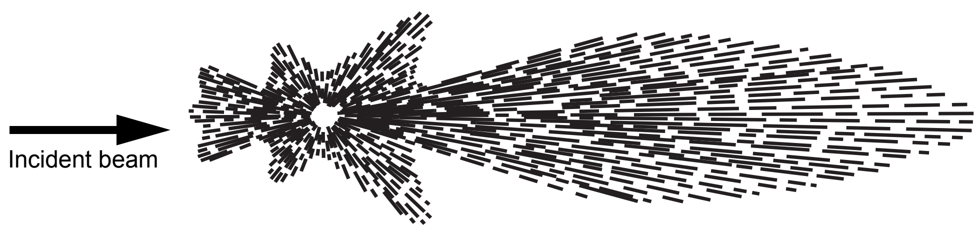

Figure 3 Effects of particle size and light wavelength (larger particles)[1]

[1] Size: Larger Than the wavelength of light
Description: Extreme concentration of scattering in forward direction;
Development of Maxima and Minima of scattering Intensity at wider angles

General instrument description

The instrument optical system typically includes a lamp, lenses and apertures to focus the light, a 90-degree detector to monitor scattered light and optionally, a forward-scatter light detector, a transmitted-light detector and a back-scatter light detector. The optional detectors may be added to minimize the impact of color, stray light and lamp and optical variabilities (see Figure 4).

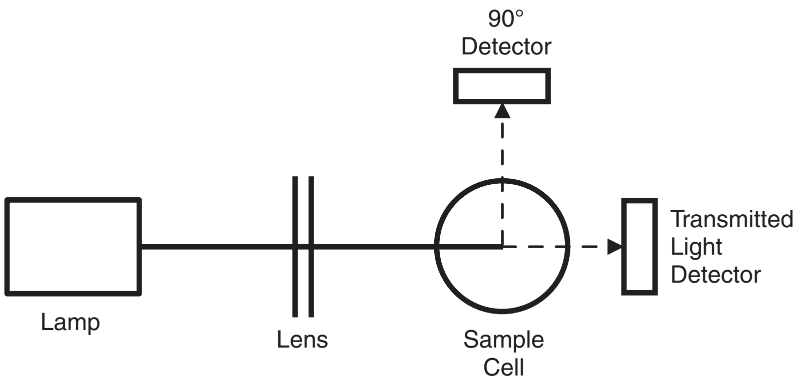

Figure 4 General turbidimeter optical system

Formazin primary standard

The chemically accepted definition of a primary standard is a standard that is prepared by the end user, on the bench, from traceable raw materials.

Formazin meets that criteria when prepared by accurately weighing and dissolving 5.000 g of hydrazine sulfate and 50.0 g of hexamethylenetetramine in one liter of distilled water. The solution develops a white turbidity after standing at 25 °C (77 °F) for 48 hours and can be prepared repeatably with an accuracy of ±1%. This solution is equal to 4000 NTU. All other turbidity standards are traced to formazin.

Due to the statistical reproducibility of the nephelometric scatter of white light by the formazin polymer, instruments with the traditional tungsten filament white light optical designs can be calibrated with a high degree of accuracy and reproducibility. The randomness of particle shapes and sizes within formazin standards yield statistically reproducible scatter on all makes and models of turbidimeters.