Technologies for Measuring Turbidity in Drinking Water Production

By Mike Sadar

Turbidity has long played a critical role in drinking water production with the most common application being as a regulatory compliance parameter in filter effluent applications. More recently water treatment plants have discovered the benefits of measuring turbidity in other applications such as source water and backwash monitoring.

However, traditional nephelometric turbidity measurement technology is not optimized for accurately measuring the higher levels of turbidity nor for measuring turbidity in the presence of color, bubbles, and light absorption often found in these applications. Newer measurement technologies have been developed in an effort to extend measurement ranges and to compensate for interferences.

The purpose of this article is to present an overview of the different turbidity measurement technologies in use today and how each measures turbidity in samples. Understanding the relationship between measurement technologies and inherent sample characteristics should help select the best turbidity measurement technology for the full range of drinking water applications.

Turbidity Measurement Technologies

Turbidity is defined as an expression of the optical properties of a sample that causes light rays to be scattered and absorbed rather than be transmitted in straight lines through the sample. Turbidity is caused by the presence of suspended and dissolved matter such as clay, silt, finely divided organic matter, plankton, other microscopic organisms, organic acids, and dyes. It's important to note that turbidity is not a measure of the quantity of suspended solids in a sample, but instead, an aggregate measure of the combined scattering effect of the water sample's suspended material on an incident light source.

Traditional drinking water filter effluent applications involve measurement of very low levels of turbidity, typically below one nephelometric turbidity unit (NTU). These methods are addressed well by traditional turbidity measurement technology. This technology directs an incident beam from typically an incandescent source into a sample. A detector positioned at 90-degrees relative to this incident light beam detects the light scattered by the particles in the sample and converts it to a turbidity value. This basic turbidimeter design is a good fit for this regulatory application because samples are typically free from interferences such as color and particulate absorbance

Figure 1: Common Turbidimeter Design. The design contains the three critical components: incident light source, detector and sample cell. The most common turbidimeters use a 90-degree detection angle and are also referred to as nephelometers.

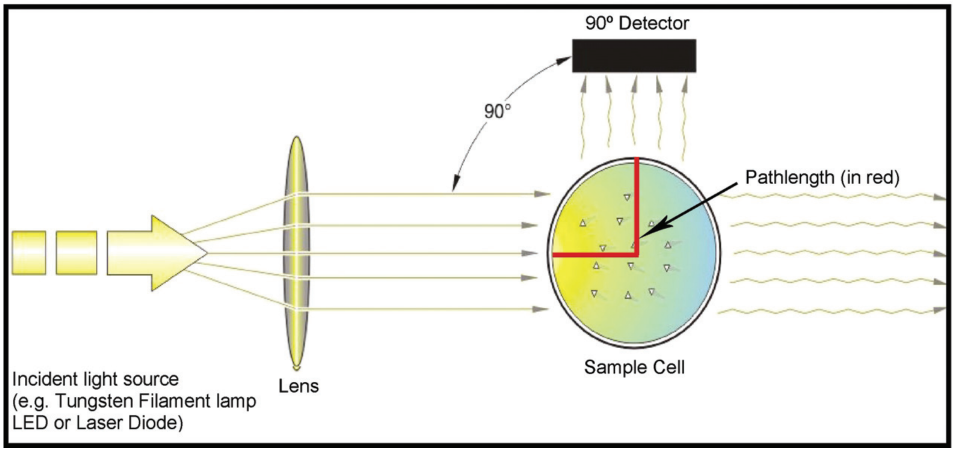
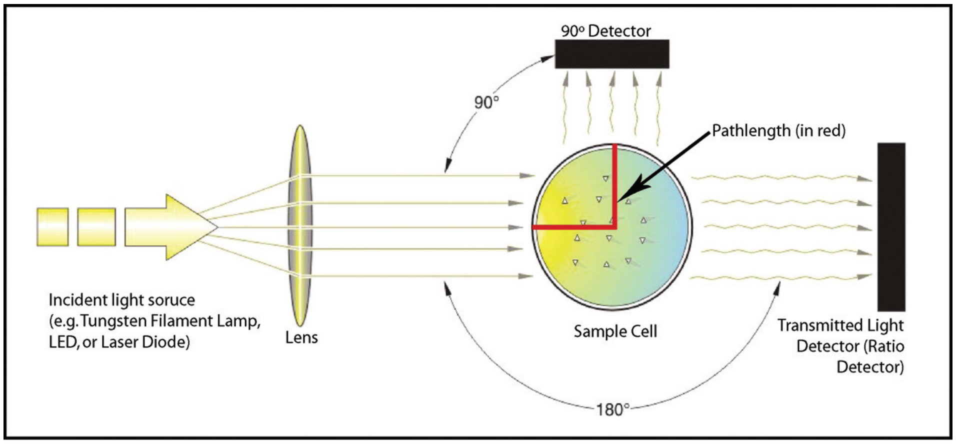


Figure 1: Ratio Turbidimeters include a 90-degree detector plus another detector that in combination determine the turbidity. The additional detector can help to compensate for interferences due to color and particulate absorbance.



Today, numerous turbidity measurement technologies exist, with some designed specifically for regulatory use and others to meet the monitoring requirements associated with process control applications. These technologies use additional light source types, detectors, and detection angles to enable different measurement techniques. For example, detectors are sometimes positioned to capture light that is reflected directly backward by samples with very high levels of turbidity. It is important to understand that samples with different characteristics such as particle absorption, reflectivity, size and size distribution will interact differently with the wavelengths of different light sources. Thus, different turbidity measurement technologies often deliver different results on the same sample.

Turbidity monitoring technologies can be categorized by three design criteria:

- The type of incident light source used
- The detection angle for the scattered light
- The number of scattered light detectors used.

Three types of light sources are commonly used in turbidimeters: incandescent, light emitting diode (LED), and laser diodes. Incandescent light sources emit a broad spectrum of light that includes shorter wavelengths that are better suited to detection of smaller particles. Common infrared LEDs (IR) used in turbidity measurements emit 830-890 nanometer (nm) light that is typically not absorbed by visible color in the sample, eliminating a common source of error. Laser-based light sources are very sensitive to small changes in turbidity and are often used to monitor the performance of filters producing ultrapure water such as is commonly used in many industrial processes.

The detection angle is formed between the centerline of the incident light beam and the centerline of the detector's receiving angle. A 90-degree detection angle is often referred to as the nephelometric detection angle and is the most common detection angle because of its sensitivity to a broad range of particle sizes. The attenuated detection angle is 180-degrees relative to the incident light beam so it measures the attenuation of the incident light beam due to both light scatter and absorption. The backscatter detection angle uses a detector that is geometrically centered at an angle of between 0- and 45-degrees relative to the directional centerline of the incident light beam. This angle is sensitive to light that is reflected in the direction of the incident light source, which is characteristic of extremely high turbidity samples.

Multiple detection angles is a ratio approach that uses a combination of detectors that together determine a turbidity value. For example a technology that has one primary detector, which is typically oriented at a 90-degree angle relative to the incident light beam, and other detectors at various angles, including attenuated, backscatter, and forward scatter angles, is used to measure turbidity from very low to very high levels.

Dual light source, dual detector measurement technologies use a combination of light sources that are geometrically oriented at 90-degree angles to each other. The detectors are also oriented at 90-degrees to each other and at 90- and 180-degrees to each of the light sources. These different combinations of optical elements provide a turbidity measurement that is compensated for color, absorption, fouling of the optics, and any optical changes that can occur.

Filter effluent applications

The Safe Water Drinking Act requires low level turbidity measurement in water produced for consumption, generally below 0.3 NTU. Traditional turbidimeter designs are a good fit for this regulatory application because the samples are typically free from interferences such as color and particulate absorbance. The standard technology used for this application is an online nephelometric non-ratio instrument with an incandescent light source. Incandescent light directed from the sensor head assembly into the turbidimeter body is scattered by suspended particles in the sample. The sensor's submerged photocell detects light scattered at 90-degrees from the incident beam. Turbidimeters of this type comply with EPA standard 180.1 for low-level turbidity monitoring, making them suitable for regulatory reporting.

Another option for measuring filter effluent is a laser nephelometer that uses advanced laser optics and signal processing to detect low concentrations of submicron-sized particles that are often a precursor to larger particles. This type of instrument can detect particles smaller than 0.1 mm and changes in turbidity as small as 0.3 mNTU or 0.0003 NTU. This level of sensitivity makes it possible for operators to detect precursors to filter breakthrough, delineate filter ripening and maximize effective filter run time. Laser nephelometers can also be used to measure feed water to prevent fouling in reverse osmosis facilities, to confirm membrane integrity, and can be used to measure permeate water for regulatory compliance.

Source and Raw Water Monitoring

The amount of particulate matter in raw water can have a big impact on pre-disinfection, coagulation and filtration processes. The required coagulant or pre-disinfection dose is often affected by the amount of particulate matter. Turbidity measurement of source water helps maintain visibility to spikes in turbidity typically caused by weather events that can overwhelm established treatment issues. Turbidity can also serve as a surrogate parameter for contaminants with a spike in turbidity being a possible indication of a new pollution source. If the intake is not close to the treatment facility, placing an instrument at the intake can alert you about changes in water conditions and give time to react to those changes as water travels through the intake lines to the treatment facility.

The turbidity levels in raw water typically vary widely depending on factors such as seasonal flow levels and weather so an instrument with a wide measurement range is needed. Instruments used in raw and source water monitoring applications also require the ability to handle high flow rates. Surface scatter turbidimeters usually provide excellent performance in this type of application. These instruments determine turbidity through light scatter from below the surface of a sample. A high intensity light source is directed at the surface of the liquid at an acute angle. Light is scattered by particles in the sample and is detected by a photocell positioned directly over the point where the light enters the liquid. The light is scattered at or near the surface so very little is absorbed by the liquid. The amount of light scattered changes in direct proportion to the turbidity.

Turbidimeters using an insertion probe with an IR based LED for in-pipe measurements offer another excellent choice for source water and raw water monitoring. This measurement technique compensates for color and surface reflection. The LED source transmits IR light at 45-degrees to the sensor face. Nephelometric photoreceptors detect light at 90-degrees to the incident light beam. The ratio technique with a backscatter detector allows for interference compensation and the backscatter angle makes it possible to measure very high turbidity levels. Another advantage of in-pipe measurement is that it is directly placed in the sample rather than having to be diverted from the pipe, resulting in faster measurement response times.

Clarification Process Monitoring

Clarification processes including flocculation and sedimentation are often used to separate particles. Turbidity measurements can help understand the effectiveness of the clarification process by monitoring the effluent of the sedimentation basin. This application typically requires an instrument with a low to medium turbidity measurement range from 0.5 to 5 NTU. Standard nephelometric ratio or non-ratio turbidimeters or immersion probe turbidimeters with IR light which were described earlier are both well suited for this application.

Backwash Monitoring

Backwash typically consumes up to 10 percent of a filter's production. Water used for washing occupies production capacity and consumes energy. Or, if the water used for washing is not recycled, the need for raw water resources is increased. Over washing a filter will also remove the smaller anthracite particles and prevent effective ripening. This can result is shorter filter run times. Water operators typically monitor backwashing either visually or on the basis of a pre-set time. Every wash will be different if the backwash is controlled visually because every operator has a different idea of what constitutes the conditions for a proper wash. A turbidimeter can be used to objectively determine when backwashing is complete without excessive washing. Using a turbidimeter to monitor backwash provides a consistent and thorough wash while also in most cases saving thousands of gallons of water per backwash cycle.

The requirements of backwash turbidity monitoring include a wide measurement range and a high flow rate. In-channel measurement is important because this makes it possible to receive almost real-time readings immediately above the filter bed and shut off the backwash flow before water is wasted or the filter media is over washed. Insertion probes with IR based light sources provide an excellent technology for backwash measurements. They offer a response time as fast as one second and provide turbidity readings from 0.1 to 4,000 NTU.

Conclusion

Measurement of turbidity plays an important role in the treatment train of a water treatment plant including points such as monitoring of raw water, clarification processes, backwash, and filtering effluent water. Turbidity measurements can also play a major role in profiling ponds, lakes, reservoirs, or small streams, or grab-sampling construction and development site runoff. Besides effectively measuring the relative clarity of the water, turbidity measurement can serve as a valuable surrogate for identifying biological, organic, or inorganic sources of pollution. However, it is now general knowledge that different turbidity measuring technologies can deliver very different results. These differences are related to the type of technology used and how this technology is impacted by the different absorption and attenuation characteristics that are exhibited by the particles in a given sample.

For measuring low-level turbidity where color is not a concern, conventional EPA approved methods are effective and should be used. On the other hand, EPA approved methods are not applicable to the measurement of high-level turbidity so the newer technologies mentioned in this document, especially ratio technologies, provide a better alternative for optimizing process control.

Water resource professionals can effectively ensure the qualification and quantification of turbidity measurements in all waters by matching the right turbidity measurement technology to their specific application and adhering to best practices and proper measurement techniques. It makes sense to partner with an instrument supplier or engineer that provides a wide range of measurement technologies and objective recommendations on which technology will deliver the best performance in specific applications. **WW**

About the Author: Mike Sadar is a Principal Scientist for Hach Company. He currently performs research and development of particle detection technologies in all types of natural and process waters. He has more than 20 years of experience in the development of technologies that relate to turbidity and particle counting measurements. Sadar serves on several technical committees related to turbidity and particle counting.

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