Water Quality Monitoring Using Particle Analysis

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Key Takeaways

Regular monitoring of particle concentration in conjunction with turbidity analysis provides supplementary data that can provide important water quality information.

Particle analysis using flow imaging microscopy (FIM) can help operators better understand various treatment processes and algae growth in source waters.

Specific size ranges can be monitored using FIM for target pathogens such as *Cryptosporidium* and *Giardia.*

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Drinking water treatment is designed to remove particulates, but problems such as filter breakthrough can lead to sudden changes in particle concentrations. The ability to detect and respond to these changes is an essential part of maintaining customer satisfaction. Understanding changes in particle size distribution, concentration, and morphology throughout a treatment process can help operators optimize treatment efficiency and analyze filter performance (Burlingame & Dietrich 2022). As described in this article, using particle analysis in conjunction with turbidity measurements provides a more complete picture of water quality that can help operators improve different treatment processes and better address emergencies.

Turbidity and Particles

Turbidity results have traditionally been used as an indicator of water quality, and in general, continuous turbidity monitoring provides sufficient information for normal operations. Turbidity is a measure of water clarity, and it expresses the optical property that causes light to be scattered and absorbed rather than passing through a sample with no change in direction, according to Standard Method (SM) 2130 (*Standard Methods* 2022).

High turbidity means more light scattering and a higher concentration of particles compared with similar water with lower turbidity. However, there is often no linear correlation between particle counts and turbidity (Bridgeman et al. 2002), essentially because particle size, shape, and refractive index all affect how light passes through a suspension. Dark particles tend to reflect less light than white particles and can cause turbidity readings to be biased low, and similarly, many small particles can reflect more light than equivalent large particles.

Complementing turbidity measurements with technologies that provide particle analysis, in accordance with SM 2560 (*Standard Methods* 2022), can allow operators to better monitor and react more quickly to changes in the process. Particle counting can also help operators detect issues before they appear in turbidity measurements (Nix & Taylor 2018). Particle counts using laser diffraction can be used to measure the variation in the intensity of light that is scattered as a laser beam passes through a sample. But while laser diffraction can provide rapid particle concentration data, it can't measure morphological characteristics pertaining to surface form, shape, and structure—without those, it's challenging to determine a particle's composition and origin.

Flow imaging microscopy (FIM) can address these challenges by combining the morphological information available through traditional microscopy with a high throughput comparable to flow cytometry.

Flow Imaging Microscopy Schematic

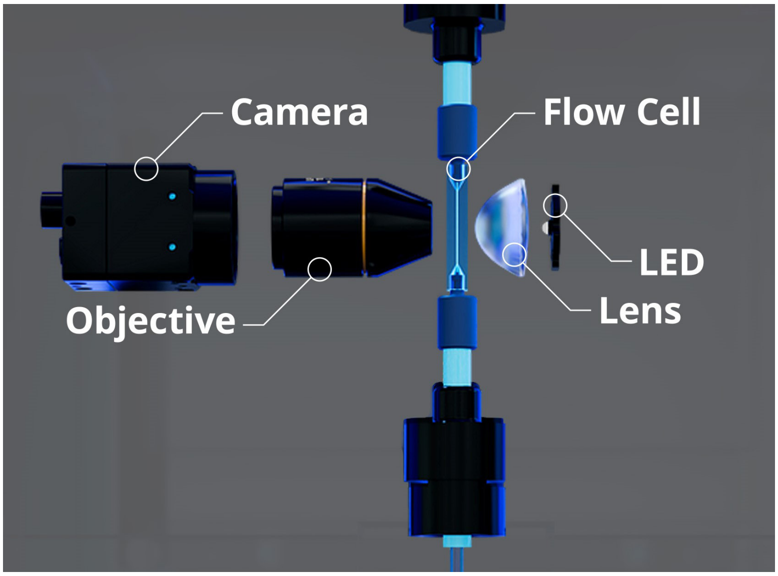

Image: © 2023 Yokogawa Fluid Imaging Technologies

LED—light-emitting diode

Figure 1

Uses and Benefits of FIM

FIM provides rapid particle concentration and size distribution results down to 2 µm, giving analytical results within minutes that are highly representative of the water quality. FIM can be used to help characterize aesthetic issues and reduce complaints (Reilley-Matthews 2007), and many utilities use FIM to monitor algae/cyanobacteria in surface water (Adams et al. 2023). FIM data can also be used along with

Example Particle Count LRVs Through Treatment Processes

Sample Point	3–5 µm Count *no./mL*	*Cryptosporidium* Size Range LRV	7–14 µm Count *no./mL*	*Giardia* Size Range LRV
Source water influent	165,637	2.52	146,286	3.25
EPTDS	500		82	
Clarifier influent	135,868	2.33	133,347	2.19
Clarifier effluent	636		863	
Filter influent	1,090	0.97	1,500	1.62
Filter effluent	118		136	

EPTDS—entry point to the distribution system, LRV—log removal value, no./mL—number/milliliter

Each LRV is calculated using the sample point data found to the left of the respective LRV.

Table 1

compliance data to respond to changes in particle concentrations within the drinking water plant.

The schematic in Figure 1 represents a basic FIM, which functions by aspirating a sample through a flow cell using a syringe pump. A light-emitting diode (commonly known as LED) illuminates the particles in flow, and an objective lens coupled with a camera magnifies and records them. Images and particle measurements generated during the sample run are stored in the software for further analysis, and these measurements can later be used to sort the particles according to size, shape, color, circularity, volume, and more.

Dark particles tend to reflect less light than white particles and can cause turbidity readings to be biased low, and similarly, many small particles can reflect more light than equivalent large particles.

Water Industry Applications

Because FIM can analyze particles over a wide range of sizes (~2 µm to 1,000 µm), it can be used to monitor specific size ranges that correlate to respective pathogens, such as 3–5 µm for *Cryptosporidium* oocysts and 7–14 µm for *Giardia* cysts. In addition, the influent and effluent of clarifiers and filters can be monitored to determine removals of specific size ranges.

As an example, Table 1 shows particle counts for a sample set from the City of Wichita Falls Cypress Water Treatment Facility (WTF), including particle counts in the *Cryptosporidium* oocyst and *Giardia* cyst size ranges and their associated log removal values (LRVs). The formula for log removal is $LRV = \log(PC_I/PC_E)$, where PC_I = influent particle count, and PC_E = effluent particle count.

This type of analysis can help operators determine when coagulants should be optimized if increased particle counts are seen in clarifier effluent, or when filter breakthrough is occurring prematurely and filter run times should be adjusted between backwashes. These results also show that these treatment processes can yield acceptable LRVs for *Cryptosporidium*- and *Giardia*-size particles (>2.00 and >3.00, respectively). For utilities, such analyses can be conducted throughout the year to determine seasonal variations.

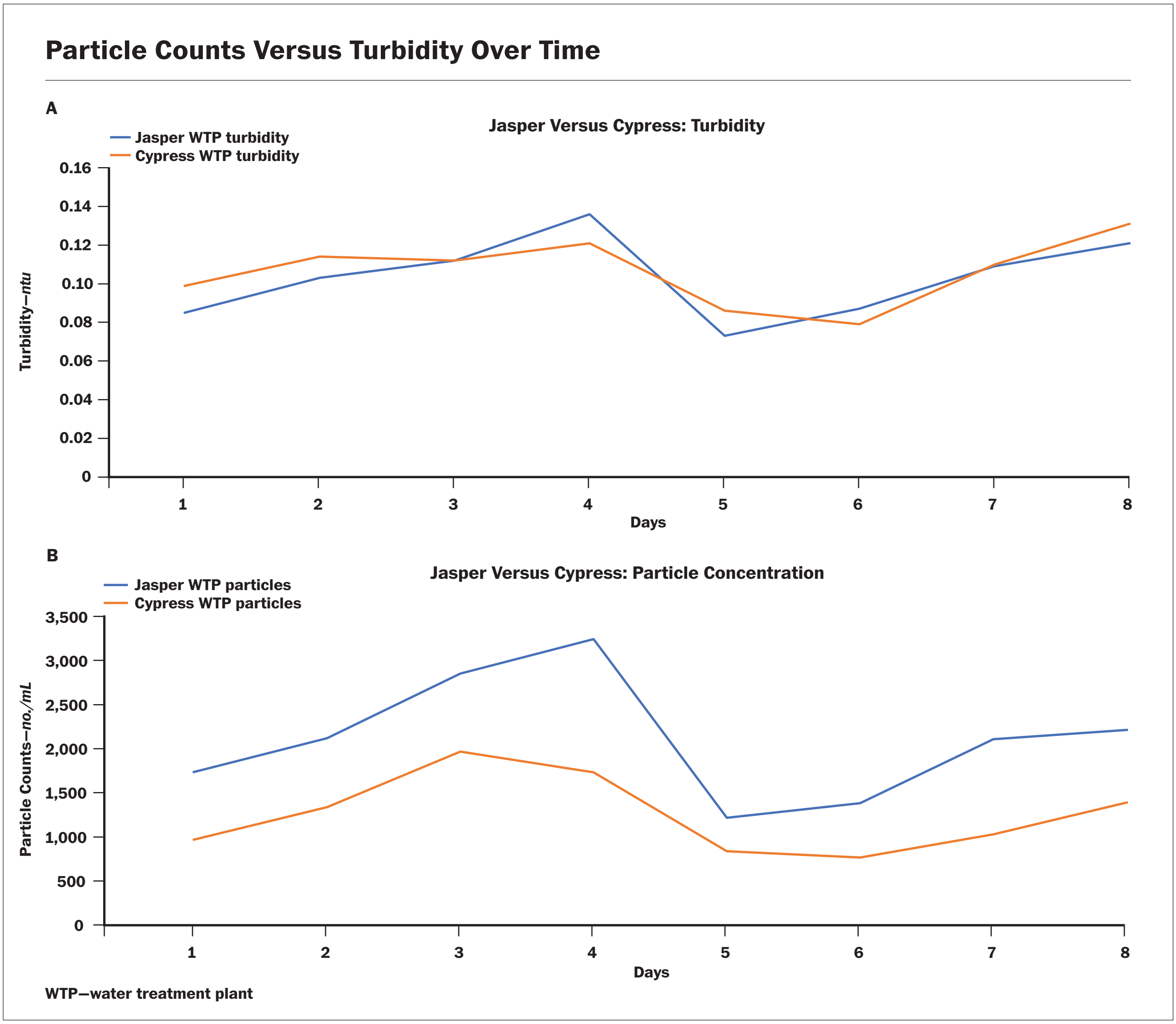

Figure 2

Particle Analysis in Action

The Cypress Environmental Laboratory began analyzing particles in 2007, using a laser counter to conduct size range and particle counts of raw and finished water. The instrument was limited in its ability to correlate measured particles to their respective images, and images were collected only in black and white. A baseline was established in routine monitoring for the next several years, but the instrument eventually stopped working, and flow cells could no longer be purchased.

In 2015, an FIM unit was put into service to perform counts as well as image and enumerate algae and cyanobacteria. While the same size ranges continued to be monitored, the emphasis was to integrate the results into the harmful algal bloom (HAB) monitoring program (Adams et al. 2022, 2021).

After three years of routine monitoring, elevated particle counts were observed at the Jasper WTF, and its finished tap water data were compared with Cypress WTF data. While turbidity stayed close to its usual level (0.100 ntu), total particle counts more than doubled.

Discrete Particle Count and Turbidity as Measured Together in the Distribution System

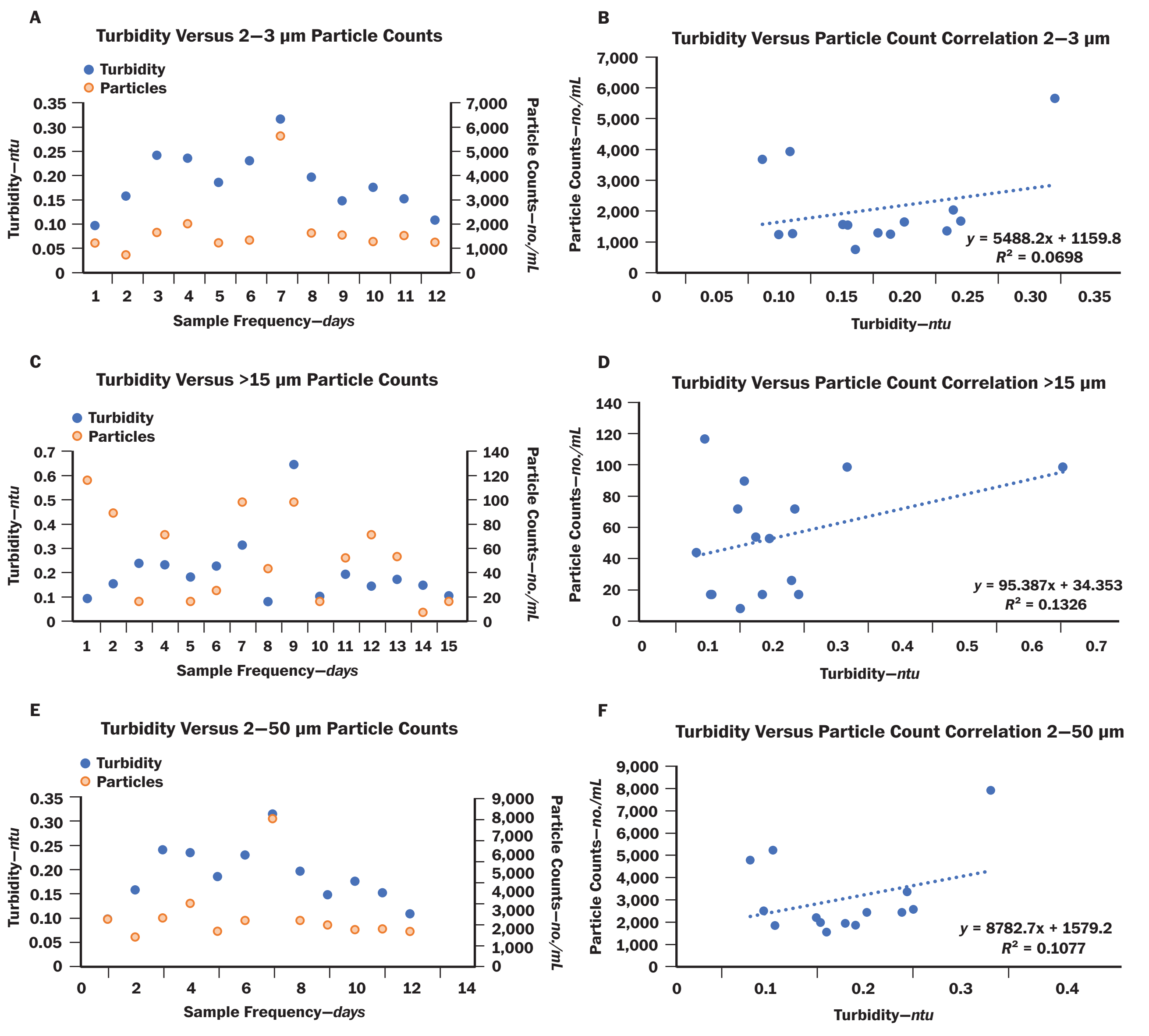

Figure 3

With the turbidity still meeting treatment goals, the increased particle counts were explored more closely. Filter run times at Jasper WTF were about 20 hours less than Cypress WTF, so filter run times were extended to see whether particle counts would drop. Counts decreased within days, falling in line with Cypress WTF values, while turbidity did not significantly change, as shown in Figure 2.

Further tests were conducted in 2022 to study the correlation between particle counts and turbidity. Sampling from the distribution system, readings for both turbidity and particle counts were compared over time and analyzed. Particle counts and turbidity will generally always be lower at the entry point location and increase throughout the distribution system. Likewise, smaller particulates will generally always be found in greater abundance than larger particulates.

FIM captured particle images and statistical measurements for each sample. Value filters (so referred to in the software) were used to separate particles by size, and the results for each size bin were compared with turbidity. Figure 3 shows comparisons of these over a period of 14 days. Particle analysis was made for size 2–3 µm (the smallest size range achievable), >15 µm, and 2–50 µm. After removing one outlier (from day 9), the results of this study show there was no correlation between particle concentration and turbidity data.

> **Particle analysis can support changes in drinking water treatment processes, especially when trying to understand situations with fluctuating turbidity.**

A Wealth of Information on Water Quality

Particle analysis cannot replace turbidity measurements, but it can supplement turbidity data so operators can better understand changes in the raw water and throughout the treatment process. While turbidity analysis measures water clarity and the amount of suspended matter, particulate analysis provides a wealth of information on the type of suspended matter causing increased turbidity.

Particle analysis can support changes in drinking water treatment processes, especially when trying to understand situations with fluctuating turbidity. For more information on particulates in water treatment, see AWWA Manuals M37, *Operational Control of Coagulation and Filtration Processes,* and M68, *Water Quality in Distribution Systems*; the AWWA handbook *Filter Evaluation Procedures for Granular Media*; and other excellent resources in the association's online store (www.awwa.org/store).

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AWWA Resources

- **Recycling Treatment Plant Residuals: Concerns Beyond Pathogens. Duke AW, Roth DK, Gross M, et al. 2020. *Journal AWWA.* 112:6:30. https://doi.org/10.1002/awwa.1516**
- **Use an Integrated Approach to Monitor Algal Blooms. Adams H, Buerkens F, Cottrell A, et al. 2018. *Opflow.* 44:12:20. https://doi.org/10.1002/opfl.1113**
- **Use Best Practices to Optimize Filter Performance. Martin B, Linder K. 2015. *Opflow.* 41:11:8. https://doi.org/10.5991/OPF.2015.41.0070**

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