WATER TREATMENT PLANT PARTICLE CHARACTERIZATION USING DIGITAL IMAGING TECHNOLOGY

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ABSTRACT

The quantity of suspended particulate matter permitted in finished drinking water is traditionally defined in terms of a regulated turbidity level. Turbidity measurement can readily detect relative changes in the overall particulate loading of water samples but does not provide specific insights on particle populations and complex changes that occur in response to environmental or process inputs. A new particle characterization method using dynamic imaging analysis technology has been developed and evaluated for application in the water sector. The instrument captures in-situ images of suspended particles in a flowing sample stream and analyzes these images in real time to determine particle size and concentration. The technology can measure samples having a wide range of particle sizes (~2 to 400µm equivalent circular diameter) and concentrations (zero to >500,000 particles/ml). The system also provides magnified images of particles for morphological analysis. There are no sample preparation requirements and statistically accurate results are produced in under five minutes.

Representative water samples from North American Water Treatment Plants (WTP's) have been collected and analyzed using the technology. The results are presented and indicate that the measurement method offers many of the advantages of microscopic analysis (particle images, material insensitivity, broad size and concentration ranges) and the attractive features of existing WTP instrumentation (rapid speed of analysis, little or no sample preparation, no operator subjectivity or special skill requirements). The benefit of capturing particle images during a particle characterization program is highlighted.

INTRODUCTION

Water quality scientists understand the importance of various particulate species in harboring pathogens, suppressing chemical and UV disinfection effects, distorting bacteria counts and acting as surrogates in filtration performance monitoring. Turbidity measurement remain a standard particulate measurement tool for water quality but is unable to provide specific information on particle populations (i.e. size, concentrations, shape, etc.). Obscuration particle counting has been partially accepted for filter effluent monitoring, however it also has limitations in measuring higher concentrations and consistently sizing and counting the naturally-occurring heterogeneous particle populations in the water industry. Microscopic analysis (including MPA) is precise and informative but expensive, time consuming and requires considerable technical expertise.

A capability to rapidly and economically perform a comprehensive physical, material and biological analysis of suspended solids from any part of a water system does not currently exist. If available it would be valuable for improving quality and controlling costs in many aspects of water treatment including watershed management, treatment plant operation and maintaining distribution systems.

This paper reviews a new imaging-based particle characterization instrument (Dynamic Particle Analyzer or DPA). The potential value of the device to assist in characterizing and optimizing drinking water treatment plant performance will be demonstrated by analyzing representative samples from WTP's. Additionally, the instrument's ability to detect, measure, and image pathogens is considered.

EXPERIMENTAL SETUP

The principle of operation of the imaging technology is shown in Figure 1. A sample fluid containing suspended particles is drawn through a flow cell capillary (also shown in Figure 1). A light source illuminates the flowing sample and the resultant signal is projected by the optical magnification system onto the photo-detector array. The signal from each pixel is read and processed by the system computer to produce and analyze the final image.

Each particle within the flowing sample interacts with the light emitted from the source creating an area of intensity variation (an image), relative to light passing through the surrounding fluid. This image is projected onto the pixel array. An intensity threshold is used to determine whether or not each pixel lies wholly or partially within a particle image. From the number of pixels within each image and the known magnification, the projected two-dimensional area is calculated and converted to an equivalent circular diameter. The optical system's field-of-view and the physical geometry of the sample flow cell define the sampling volume and permit the particle concentration to be calculated. In order to increase the sampling volume for diameter measurement, the system is operated under conditions where the optical system produces images which are transformed by out-of-focus and diffraction effects. The system processes the signal from each pixel in order to derive information from the particle image and compensation factors are applied to these images as each frame is captured. To the extent that these transformations are consistent and independent of particle properties such as material and structure, this approach allows the system to be operated with a substantial increase in optical sampling volume which also reduces the analysis time. As an illustration, for a typical DPA configuration to measure particles from 2 to 400μm, the sample rate is approximately three minutes per ml. In order to collect images for off-line visual analysis, the instrument is reconfigured to minimize distortion effects.

Figure 2 is a picture of the instrument and Table 1 summarizes the optical configuration.

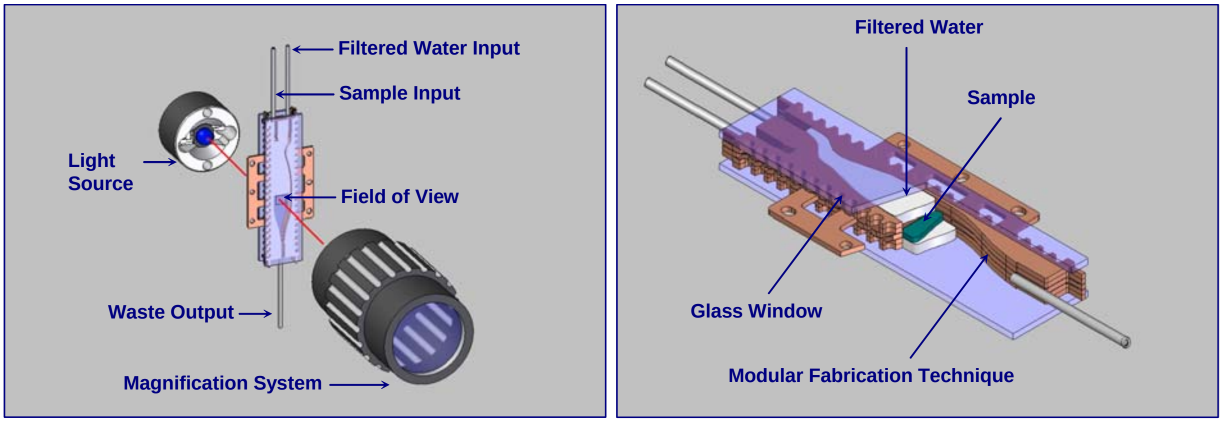

Figure 1: Principal of Operation

Figure 2: DPA System

Parameter	Unit	Low Magnification Operation	High Magnification Operation
Optical Magnification	X	5x	14x
Field of View	µm	1,914 x 1,531	670 x 536
Flow Cell Channel Depth	µm	400	400
Volume/Frame	ml	1.234E-3	1.528E-4
Frames/ml Analyzed	#	811	6,544
Frame Acquisition Rate	fps	4	4
Analysis Rate	Min/ml	3.4	27.3
Practical Analysis Application	**-**	**Size Distributions Image Acquisition**	**Image Acquisition Only**

Table 1: Optical System Configuration

EXPERIMENTAL RESULTS

Sample Analysis

The sampling program was chosen to evaluate the technology's suitability, performance range and convenience for samples representative of the water quality industry.

Samples were obtained from WTP's in North America between December 2003 and March 2004. For each sample three, one ml analyses were conducted. For each analysis the size and concentration of suspended particles was measured and a particle size distribution produced. The measurement size range spanned 2 to 400µm, and results were displayed at resolutions as fine as 0.2µm. A fourth analysis was performed, with the system configured for higher magnification (14x), to capture images from each sample.

WTP Characterization

In order to produce a consistent and accurate particle characterization of the entire WTP train, the measurement technology should operate across a broad range of particle sizes and concentrations. Samples were collected from a Minnesota WTP using conventional filtration from the following points in the WTP: Terminal Chamber, Flocculation Process, Clarification Process, Filter Influent and Filter Effluent. The results are summarized in Figure 3.

Particle concentrations ranged from several hundred to over 300K particles/ml, and particle sizes ranged from <2µm to almost 160µm. As expected, the largest particles and highest concentrations were observed in the flocculation sample, while the lowest concentration was observed in the filtered water. The largest particles detected in Terminal Chamber, Clarification Chamber and Filter Influent, was 94.3, 85.3 and 49.3 respectively.

The analysis provides this WTP with a snapshot of particle populations across the entire treatment train and was compared to turbidity measurements and obscuration particle counters (where applicable). Comparison with particle counter outputs indicated the imaging technique consistently detected a higher number of particles across the entire size range. Particle images were used to confirm the results and further investigation is planned.

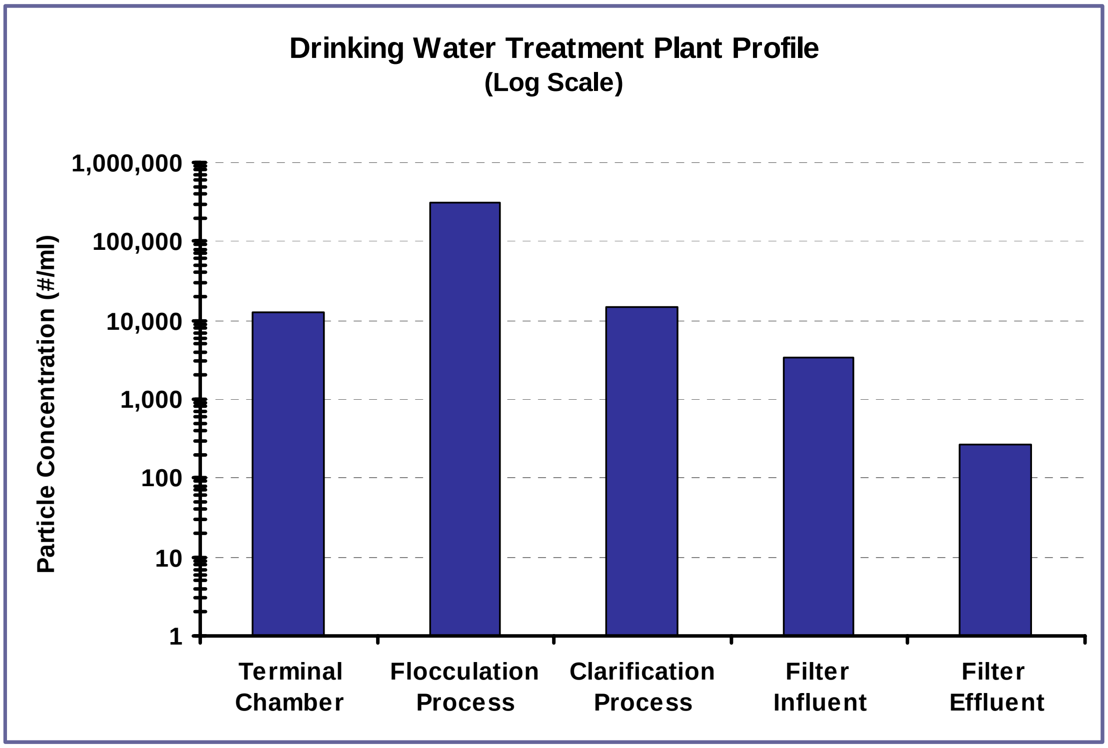

Figure 3: WTP Particle Concentration Profile

Figure 4 shows representative images from the samples and illustrates how automatic image collection can be a beneficial and useful addition to WTP maintenance and characterization programs..

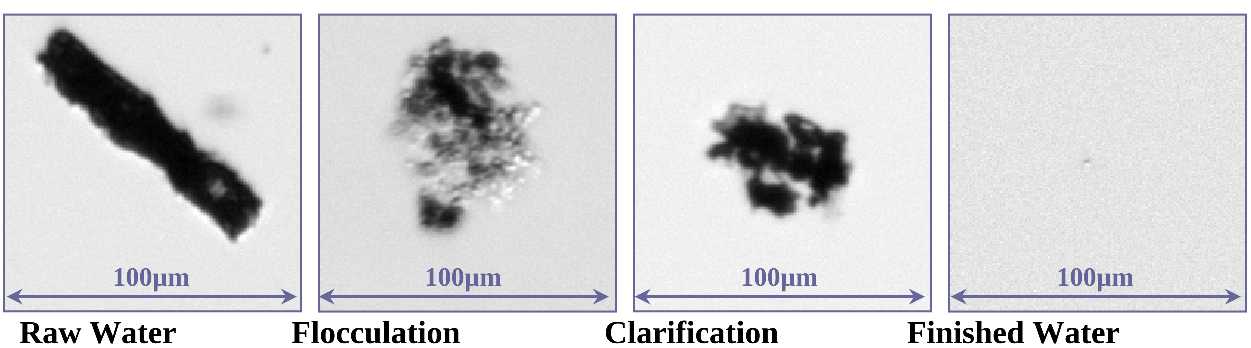

Figure 4: WTP Particle Images

WTP Optimization

Two water samples, each with a different coagulant dose, were provided by a western Canadian university. The resulting size distributions are shown in Figure 5.

The results highlight the dramatic concentration differences between water samples treated with different coagulant doses (3,132 vs. 667,487 particles/ml), as well as the differences in the shape of the size distributions (the largest particle in the heavily dosed water was found to be 278.2µm vs. 108.6µm in the lightly dosed water). An imaging run was performed and used to assess the morphology of particles from the different samples (Figure 6).

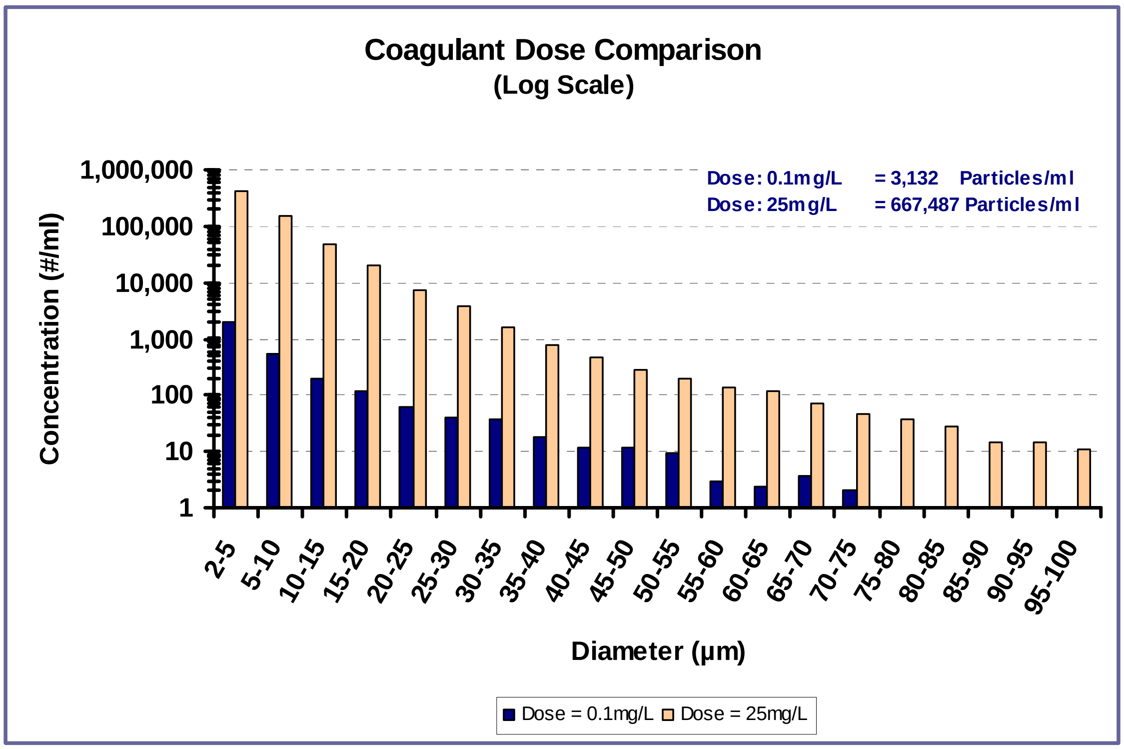

Figure 5: Flocculation Size Distributions

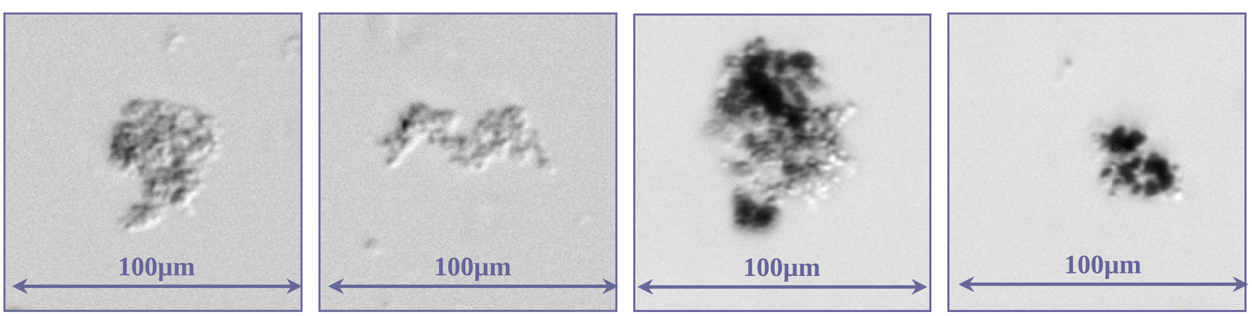

Figure 6: Flocculation Particle Images

Investigate Source Water Variations

Anticipating and understanding the impact of source water variations on WTP processes is one objective of WTP process engineering. Precise particle size distributions, potentially combined with images of the suspended particulate matter, can be used to determine the types (including potential pathogens) and number of particles within raw water, and correlating watershed events to plant operating conditions and performance.

Samples from a western Canadian WTP reservoir were analyzed (see Figure 7). In this instance the aggregate concentration was 163,979 particles/ml and the largest measured particle was 330.8µm. Images were collected and used to catalog the wide variety of suspended particles in the sample (Figure 8).

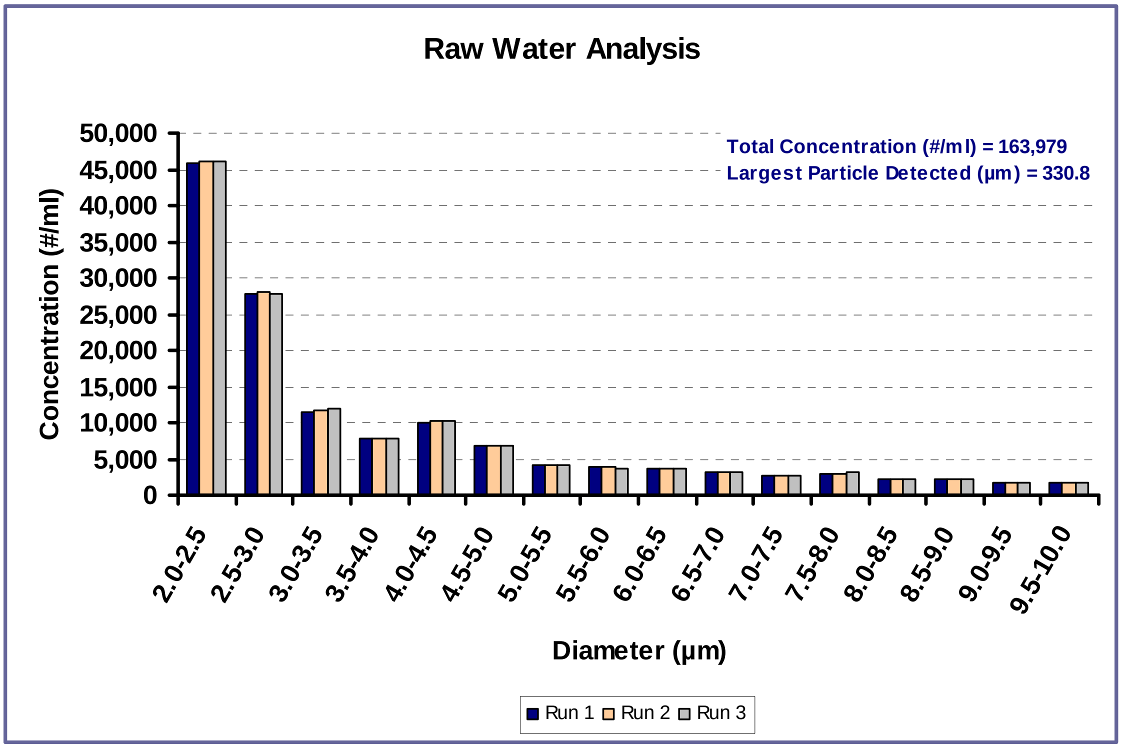

Figure 7: Raw Water Size Distribution

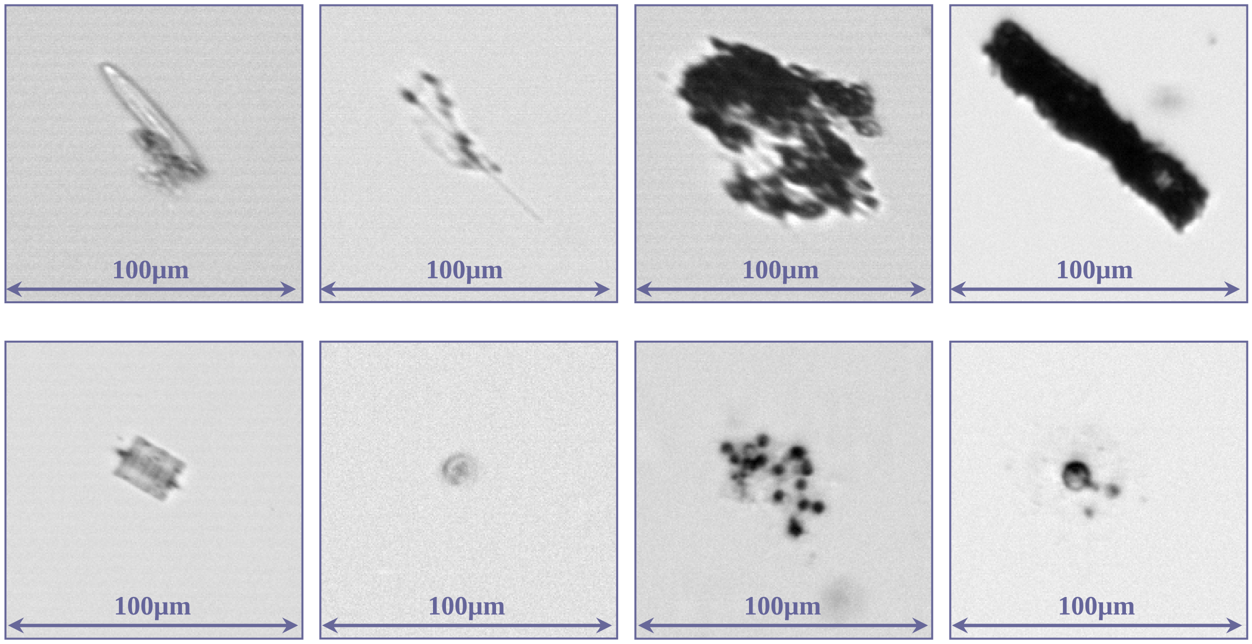

Figure 8: Raw Water Particle Images

Monitor Distribution System Contamination

Diagnosing and rectifying the cause of taste and odor complaints is also the responsibility of municipal water utilities. In many cases particle contamination (via ruptures, hydraulic surges, corrosion, etc.) is the root cause. A regular distribution sampling program can be used to optimize hydrant flushing schedules by correlating particle characterization results (size distributions and images) to incidents of corrosion, surface water intrusion, bio-film formation, etc..

Figure 9 shows the results from a water sample from a distribution system during a hydrant flush. The concentrations were measured at over 75,000 particles per/ml (plant effluent was measured at 30 particles/ml) and the largest particle detected was 175.2µm. Particle images were also logged (Figure 10) to determine particle origin.

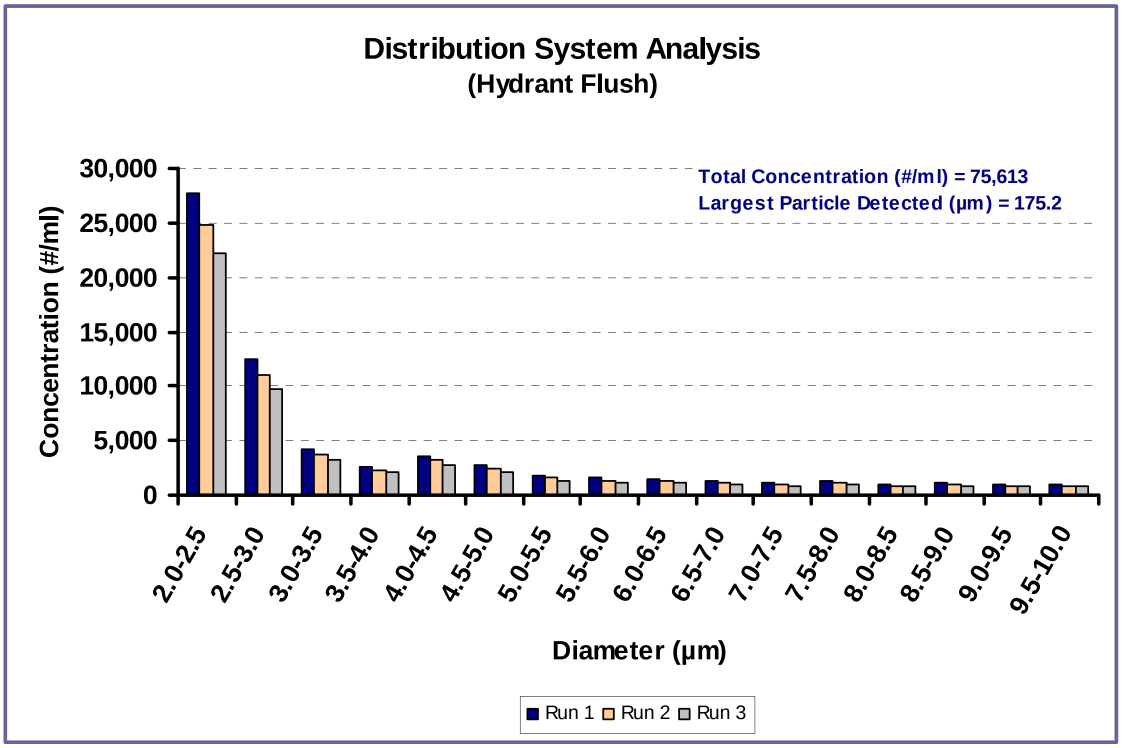

Figure 9: Distribution System Size Distribution

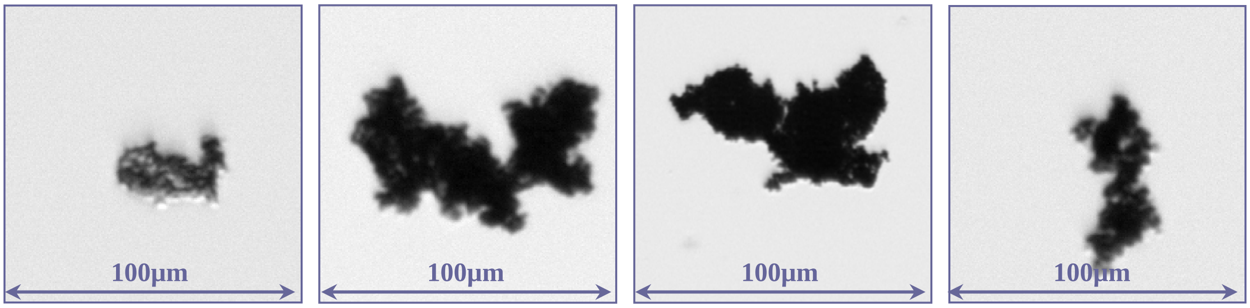

Figure 10: Distribution System Particles

Detect Pathogenic Organisms

Reliably detecting, and producing an accurate size measurement, of highly transparent particles such as micro-organisms is a challenge for traditional optical detection techniques based on light scattering. However, imaging technology is largely insensitive to variations in transparency and the DPA instrument has successfully detected and measured materials such as boro-silicate with a refractive index very close to water. Automatic setting of illumination and gray scale thresholds maintains optimal operating conditions and eliminates operator error and subjectivity.

A sample of deactivated cryptosporidium was analyzed. The size distribution, with a resolution of 0.2µm, is shown in Figure 11. Representative images are shown in Figure 12.

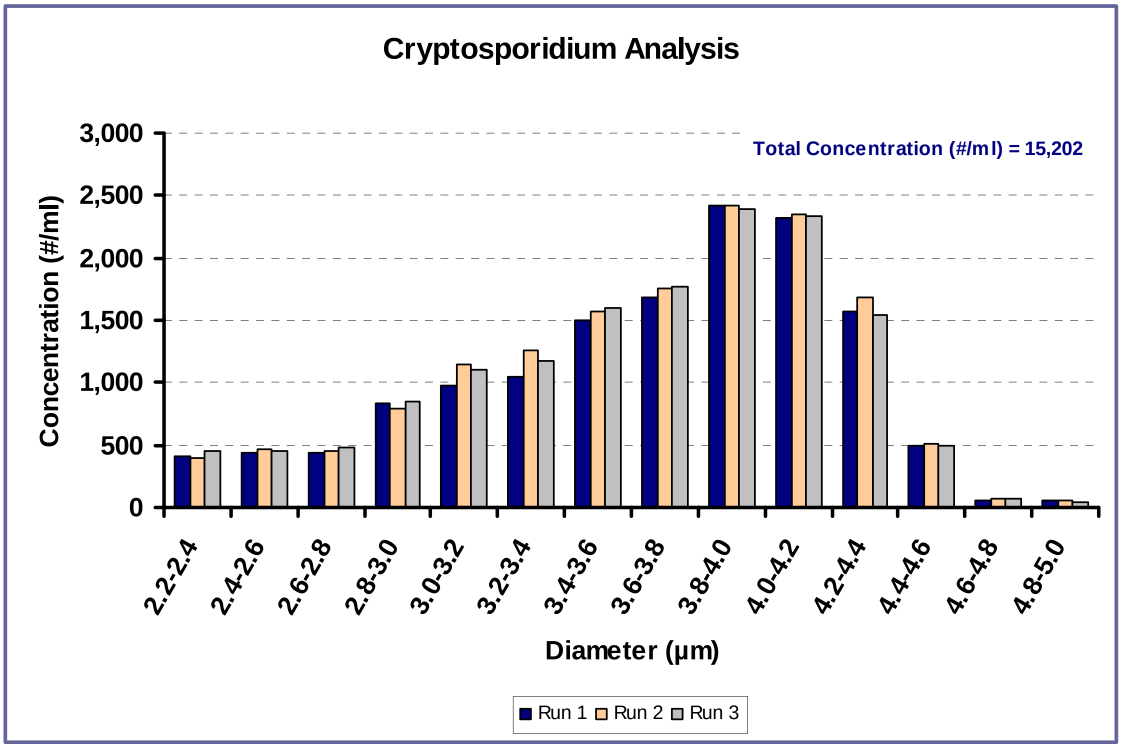

Figure 11: Cryptosporidium Size Distribution

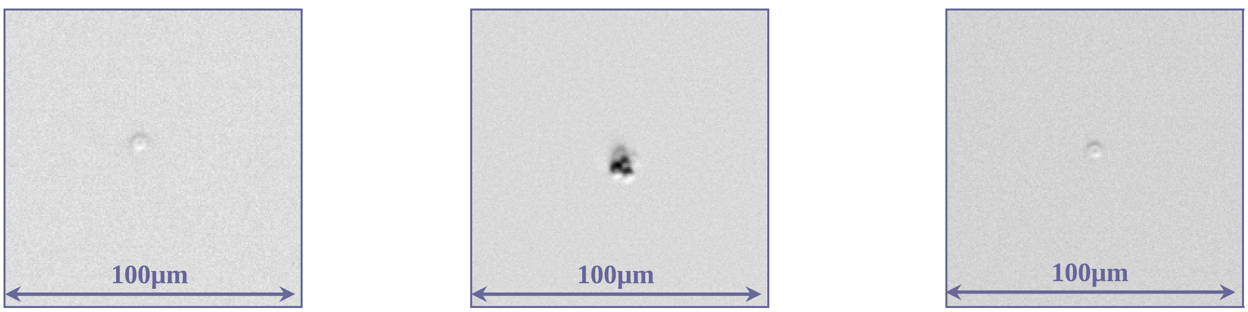

Figure 12: Cryptosporidium Images

CONCLUSIONS

The ability to selectively capture particle images is a significant addition to the information available to the water quality scientist. The technology has successfully analyzed samples from across the particle size and concentration ranges typical of drinking water. The instrument has demonstrated sensitivity that exceeds obscuration particle counters and can detect pathogens such as cryptosporidium. The instrument's speed and ease-of-use make it a practical tool for the industry.

Potential benefits for WTP's include cost savings by having a single multi-purpose instrument for precise particle characterization, using the device for screening samples for further microbiological investigation, improved maintenance and chemical dosing programs (saving time and money) through better understanding of particles populations and improved customer service by rapidly diagnosing taste and odour incidents.