PARTICLE COUNTING FOR EARLY DETECTION OF CONTAMINANTS IN DRINKING WATER

F. Gosselin[1], P. Pollmann[2], E. Colon[2], and J.-C. Block[1]

[1] Université de Lorraine and CNRS, LCPME, UMR 7564, 405, rue de Vandœuvre, 54601 Villers-lès-Nancy, France
[2] PAMAS GmbH – Dieselstrasse 10, 71277 Rutesheim, Germany

1 INTRODUCTION

As pointed out for many years there is a flux of particles in drinking water distribution systems which may originate from the treatment plant itself or may be generated in the distribution system (biofilm sloughing, sediment resuspension, flocculation, …). Most of these particles are below 50 μm with an average size of 5 μm [1,2]. These particles, which are easy to be mobilized by a water flow above normal, are generally made of iron (60%) and organic matter (20%) [3].

The unexpected variations of the particle counts could be used as a signal of some unfriendly discontinuities on the water treatment lines or accidental/intentional contamination on the distribution system. Indeed the intrusion of any contaminant (bacterial suspension or very soluble chemicals) could both mobilize loose pipe sediments (just by changing the pH, resistivity, or chlorine) or introduce particles as it is very difficult to produce large quantities of particle-free solutions.

The particle counter (WaterViewer) was analysing the drinking water of a pilot plant connected to the drinking water distribution system of the city of Nancy (surface water treated by a traditional process combined with microfiltration followed by remineralisation with lime water and post chlorination). Particle counting measurement results were recorded every minute during several weeks and showed specific results in the 1 - 15 μm particle size frame.

Different situations were tested on the network of the city of Nancy:
- analysis of the particle flux in the drinking water of the city on a routine way
- analysis of the particles in the water of the city after a major raining event (Figure 1) and the lightning of the water treatment plant with determined the stop of water production for several hours
- Additionally, we assessed the impact on particle number of an experimental injection on a pilot plant (continuously fed loop system) of bacteria suspension.
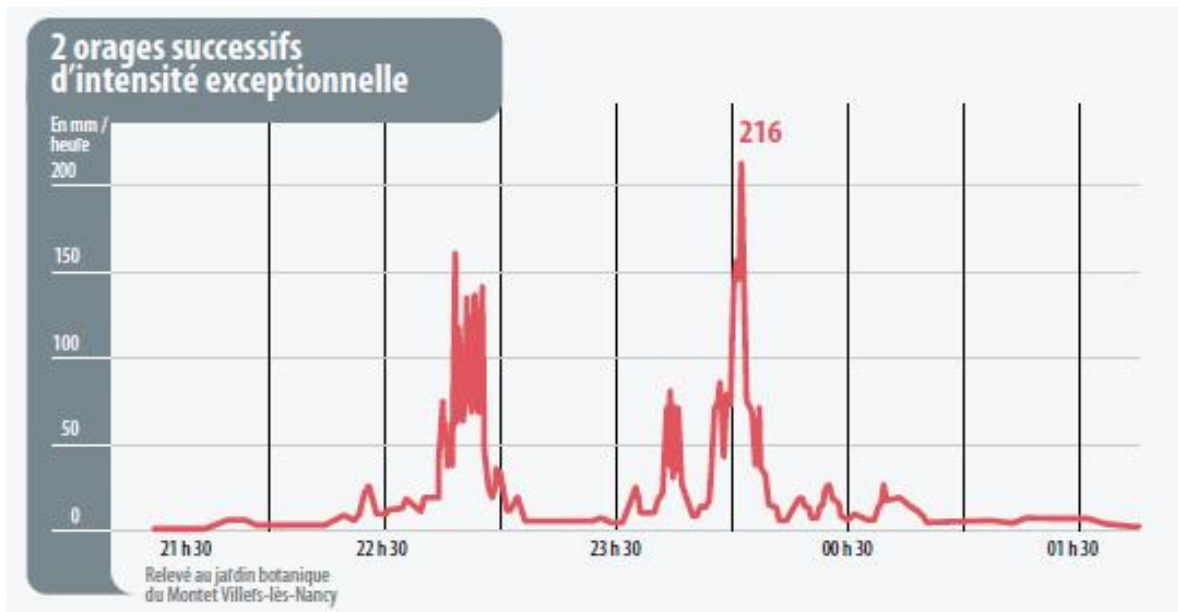
Figure 1 *Rain intensity (in mm of water) due to two major storms on the city of Nancy in the night of May 22, 2012 (in « Grand Nancy -Special Inondations – Nancy ; CUGN, 2012 »).*

2 MATERIAL AND METHODS

2.1   WaterViewer (PAMAS)

The particles are counted by the light blockage principle, based on the use of a "volumetric measurement cell design" (cell is 100% illuminated by laser light). They will block the light and project their shadow on a photo detector.

The particle size is determined by measuring the amount of blocked light (Figure 2).

For each of the eight measured size channels, the particle counts are expressed as a trending of particle concentration (counts/mL) over time.
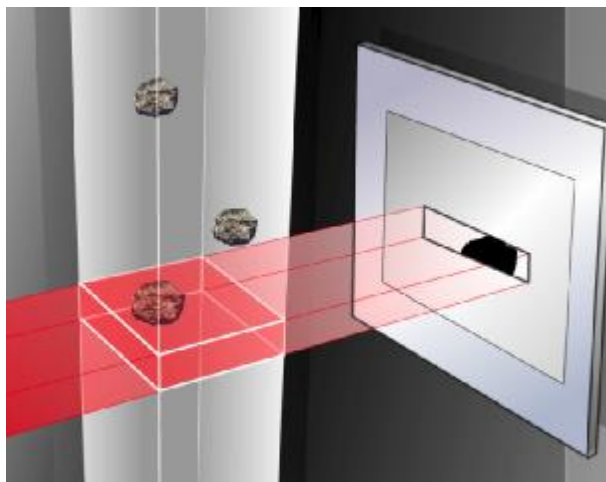
Figure 2 *WaterViewer (PAMAS) on-line particle counter using the principle of light blockage based on the « volumetric cell design »*

2.2 Loop system

The industrial pilot plant used was made of a loop with pipes of 20-year-old cement lined cast iron (31 meters in length, 100 mm in diameter, volume of 243.4 liters,). The water flow velocity is approximately 1.6 m s^{-1}, and the theoretical hydraulic residence time of 22 hours. It worked as a perfectly mixed reactor. The loop was continuously fed with treated drinking water from the surface water treatment plant of the city of Nancy, France. The water is pumped from the Moselle River, treated by coagulation with aluminium chloride, followed by settling, rapid sand filtration, ozonation and GAC filtration. Lime and chlorine are added to the treated water.

Figure 3 *Drinking water pilot plant made of several loop serially disposed*

2.3 Total cell counts

Cell suspensions (water samples) were stained with SYBR Green II RNA gel stain (Sybr II) (Molecular Probes; S-7586, Invitrogen, Cergy Pontoise, France) at a concentration of 2 µL/mL for 30 min in the dark at 20°C (+/- 1). The cell suspensions were filtered through 0.2 µm black isopore membranes (Millipore, Molsheim, France), which were directly observed with an Olympus BX51 epifluorescence microscope fitted with a ×100 oil immersion objective. A mercury lamp with a specific filter supplied an excitation wavelength of 480 nm and a green emission filter permitted to select the 520 nm wavelength (maximal emission of Sybr II). Images were taken with an Olympus E-510 CCD camera. The results were expressed as number of cells/mL (or cells/cm² in the case of biofilms).

2.4 Biofilm growth rate assessment

By using the formalism of Van der Wende and Characklis and Manuel *et al.*,[4,5] it is possible to express the growth rate µ of the biofilm as follows:

$$\frac{F}{V}(X_1 - X_0) = \mu X_b \frac{A}{V}$$

(1)

where X_1 (cells/mL) represents the planktonic cell concentrations in "water out", X_0 the planktonic cell concentrations in "water in" (cells/mL), X_b the biofilm cell density

(cells/cm^2), A the total inner surface area (cm^2), V the liquid volume (mL) and F/V the dilution rate (T^{-1}) of the Propella™ reactor.

2.5 Culturable cell counts

Bacteria suspensions (from biofilms or water samples) were spread on R$_2$A agar (Oxoïd, Dardilly, France) with 100 µL per Petri dish. Colonies were counted after a 14-day incubation time at 20°C (+/- 1) and results were expressed as number of colony forming units (CFU/mL).

3 RESULTS

3.1 Characterization of the loop system

As described previously, the industrial pilot plant used is fed with treated drinking water from the surface water treatment plant of the city of Nancy, France. Table 1 gathers some characteristics of water coming in (Water In) or coming out (Water Out) of the loop system.

Table 1   *Some characteristics of water In and Out the pilot plant (loop system)*

Parameters	Water In	Water Out
T (°C)	19	20
pH	7.99	7.97
Total cells (cells/mL)	1.6×10^4	8.5×10^4
Cultivable bacteria (CFU/mL)	5×10^2	6.9×10^3
Fe (mg/L)	0.04	0
Cl$_2$ (mg/L)	0.02	0

The biofilm accumulated on PVC coupons was equal to 1.5×10^7 cells/cm², and its apparent growth rate µ was equal to 0.01 j^{-1}.

3.2 Variations of the number of particles in the drinking water system following water treatment discontinuity

The loop system was equipped with the WaterViewer particle counter to measure the number of particles in the drinking water system. On a routine way, we measured an average of 310 counts/mL of 1 to 15 µm in the drinking water of the city of Nancy (Figure 4). The shape of the curves is the result of the positioning of the WaterViewer not on one distribution pipe of the city, but on the experimental loop system continuously fed with the drinking water from the network. Moreover, we measured some low but unexpected discontinuities that were registered several times as the result of waterborne particles possibly associated to the lime treatment.
In May 2012, a major water storm and lightning of the water treatment plant was stopping water production for several hours. Such an unexpected event has requested the intensive use of security reservoirs coupled to high chlorination. These drastic changes in water production and distribution increased by almost a factor of three the number of particles with an average value of 801 counts/mL for several days, and a major pic the 23rd of May with 2,300 particles per mL.
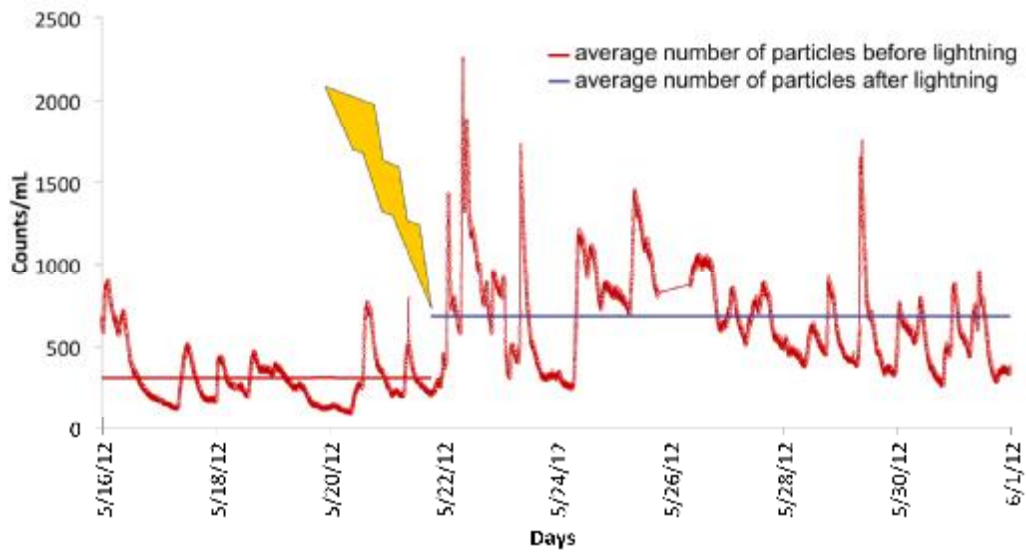
Figure 4   *Particles (> 1 µm) in the loop system fed with drinking water (the yellow sign represents the lightning event which disturbed the water production for several hours).*

3.3   Variations of the number of particles in the drinking water system following experimental contamination

We measured the variations of the number of particles in the drinking water system after the injection in the loop system of 2 litres bacteria suspension in nutritive medium (half of these bacteria cells were lower than 1 µm) with a theoretical concentration into the loop at 10^7 bacteria/mL. Particles (1 to 15 µm class) were detected at a concentration of 20,000 counts/mL (Figure 5). A pic of particle was measured in the hour following the injection of the bacteria suspension. The particle number declined rapidly in few hours according to two regimes: high kinetic related to sorption/sedimentation, and low kinetic related to the dilution rate. As most of the bacteria cells were too small to be counted by the particle counter, one has to consider that some deposit particles were washed out by the contaminant injection and counted here.
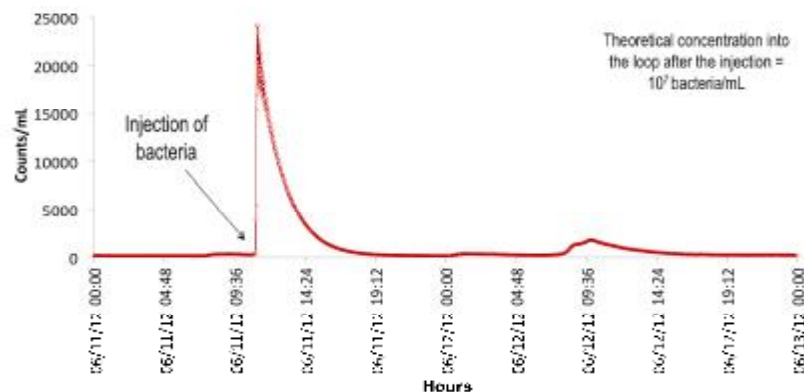
Figure 5   *Particles (> 1 µm) in the loop system experimentally contaminated with a bacterial suspension*

4 CONCLUSIONS

Accidentally stopped water production and intensive use of drinking water reservoirs led to particle mobilisation and transport, which was detected by the particle counter.

Even if the used sensor was not ment to count bacteria particles which are in the range of $0.5 - 1$ μm, malevolent bacteria suspension injection was detected due to mobilization of pipe sediments.

These experimental and field measurements have confirmed the interest to use particle counting. Particle counting can be used (i) for controlling the drinking water production or hydraulic discontinuities, and (ii) as a surrogate for early detection of accidents and contaminant introduction in the drinking water systems.

References

1   J.B. Boxall, P.J. Skipworth, and A.J. Saul, *Proceedings of the computing and control in the water industry conference, water software systems: theory and applications, De Monfort University, UK*, 2001.
2   J.H.G. Vreeburg, and J.B. Boxall, *Water Res*earch 2007, **41**, 519.
3   V. Gauthier, B. Gérard, J.-M. Portal, J.-C. Block, and D. Gatel, *Water Research* 1999, **33,** 1014.
4   C.M. Manuel, O.C. Nunes, and L.F. Melo, *Water Research*, 2007, **41**, 551.
5   E. Van der Wende, W.G. Characklis, and D.B. Smith, *Water Research*, 1989, **23**, 1313.