Monitoring of the processes in water treatment plant

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Congress Sub-themes

1. Development of water resources and infrastructure - Data, monitoring and information technology
2. Water availability, use and management - Water quality management: surface and ground water

Abstract

Traditionally, water treatment plant includes general processes like: coagulation, flocculation, sedimentation, filtration and disinfections. Optimal choice of working parameters for each of them is the most important designing principal. Unfortunately, all of the processes are very dynamic and strongly dependent on changing quality of raw water. In consequence, optimal working parameters guaranteeing relatively low cost and enough removal efficiency are also changing during the time. Complex mathematical descriptions indicate dependence of the processes on many parameters. Particle size distribution is one of the most important for all of them. Significant development of the particle size distribution (PSD) measuring methods was observed during last years. Simple and quick "on-line" PSD measurement is possible today. Particle size distribution enables more detailed water treatment processes analysis than still commonly used turbidity. The research was carried out in water treatment plant on Dłubnia river, which is one of the several supplying Krakow. Flocculation, sedimentation and filtration were analyzed based on particle size distribution curves between processes. Refractive indexes were adequately selected. After flocculation, quantity of particles between 1 and 30 microns increased proportionally stronger than rest of the fractions. After sedimentation particles bigger than 10 microns proportionally decreased, and particles smaller than one micron and bigger than 100 microns proportionally increased. During filtration process volume of particles bigger than one micron were removed proportionally better than rest of the particles from suspension. Total volumetric suspension concentration slightly increased after flocculation and visibly decreased after sedimentation and the same significant decreased after filtration. Theoretical interpretation and conclusion of the results of particle size removal efficiency measurements for each of the water treatment processes were proposed.

Introduction

Traditionally, water treatment plant includes several basic processes: coagulation, flocculation, sedimentation, filtration and disinfections. Optimal choice of working parameters for each of them is the most important of designing goals. Unfortunately, all of the processes are very dynamic and strongly dependent on actual conditions and changing quality of raw water. In consequence, optimal working parameters guaranteeing relatively low cost and enough removal efficiency are also changing during the time. Complex mathematical descriptions indicate dependence of the processes on many parameters characterizing inflowing raw water like: temperature, pH, conductance, alkalinity and also characterizing suspended particles like surface potential indirectly measured by zeta potential, shape and roughness of particle surface, porosity and density of particles or flocs. Probably, size of suspended particles is one of the most important parameters for removal efficiency of basic water treatment processes. Methods of the particle size distribution (PSD) measurement have been significantly developed for last years. Laser diffraction method seems to be very suitable for water technology. Laser diffraction method is relatively fast and possible to use on-line. More of them use Mie theory as the most precise, today. Unfortunately, Mie theory perfectly describes only light scattering through transparent even spherical particles. Suspended particles in natural water are often colored, uneven, non spherical and characterized by various refractive indexes. Complex refractive index, a little bit reduces error created by natural conditions. Imaginary part of refractive index describes absorption loss through non transparent particles. Light scattering through suspended particles bigger than several microns are much easier to describe, because results are almost independent on particle refractive indexes (Rod, 2003). Then, it is possible to use successfully even old, simple Fraunhofer theory. Theoretical results for this kind of particles are more reliable than for smaller particles. Basic rule for light scattering theory suggests that intensity of light scattered at low angle increases together with particle size (Sadar, 1998).

Mie theory is the only describing quite precisely light scattering for wide particle size range (Elimelech,1999). The basic rule of Mie theory suggests that shorter light wave are scattered more intensively through the finer particles than bigger. Inversely, longer light wave scatters more intensively through the bigger particles.

Higher refractive index of particle compares to refractive index of water means higher scattering angle. Generally, organic particles have lower refractive indexes than mineral (Gregory, 1998).

Some observations (McMillan, Considine, 1999) suggest that more different shape of particle than spherical, lower intensity of transmitted light or scattered at smaller angle compares to intensity of light scattered at higher angle.

Natural colored particles absorb the light and only part of the light is re-emitted by particle. In consequence, transmitted and also scattered light intensity are reduced. Lower scattered light intensity at 90 degrees angle, lower nephelometric turbidity. Lower transmitted light intensity, higher turbidity based on absorbance parameter.

Particle size distribution is more useful than turbidity for decision making in water treatment plant. Operators receive more information about processes that help them remove particles the same size as the most dangerous pathogens. Particle size distribution characterizes quality of treated water more precisely than turbidity. In consequence, probability of epidemiological dangerous of tap water decreases. The research results (Le Chevallier, Norton 1992) show quite high correlation between Giardia and Cryptosporidium oocyst and particles smaller than five microns and also (Kobler, Boller,1996) between CFU and smaller particles than eight microns.

Turbidity strongly depends not only on suspension concentration, but also on particle size. Function describing dependence of turbidity on particle size is very complex. It cause to difficult interpretation of turbidity parameter. Figures 1 and 2 present dependences of nephelometric turbidity and absorbance versus particle size based on numerical calculations of Mie theory for transparent spherical particles characterized by refractive index 1.51 and length of light wave 860 nm. Calculation were carried out based on numerical program (http://www.philiplaven.com/index1.html) and simplified solution for equations of Mie theory (Elimelech, 1995)

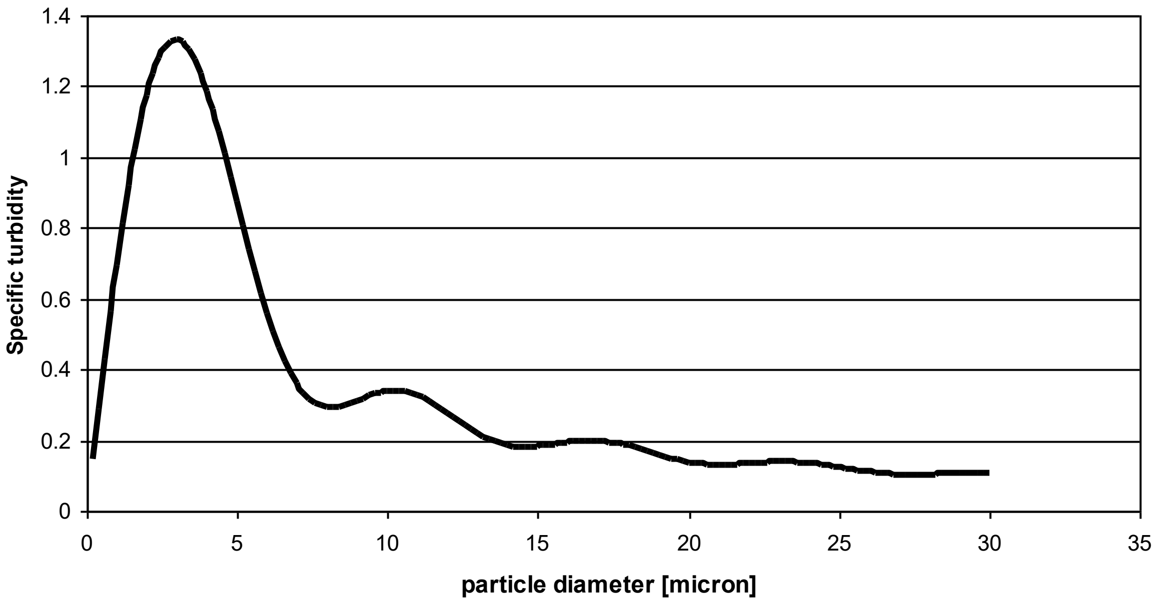

Figure 1 Specific turbidity (absorbance) defined as turbidity (absorbance) divided by volume of spherical particles versus particle diameter

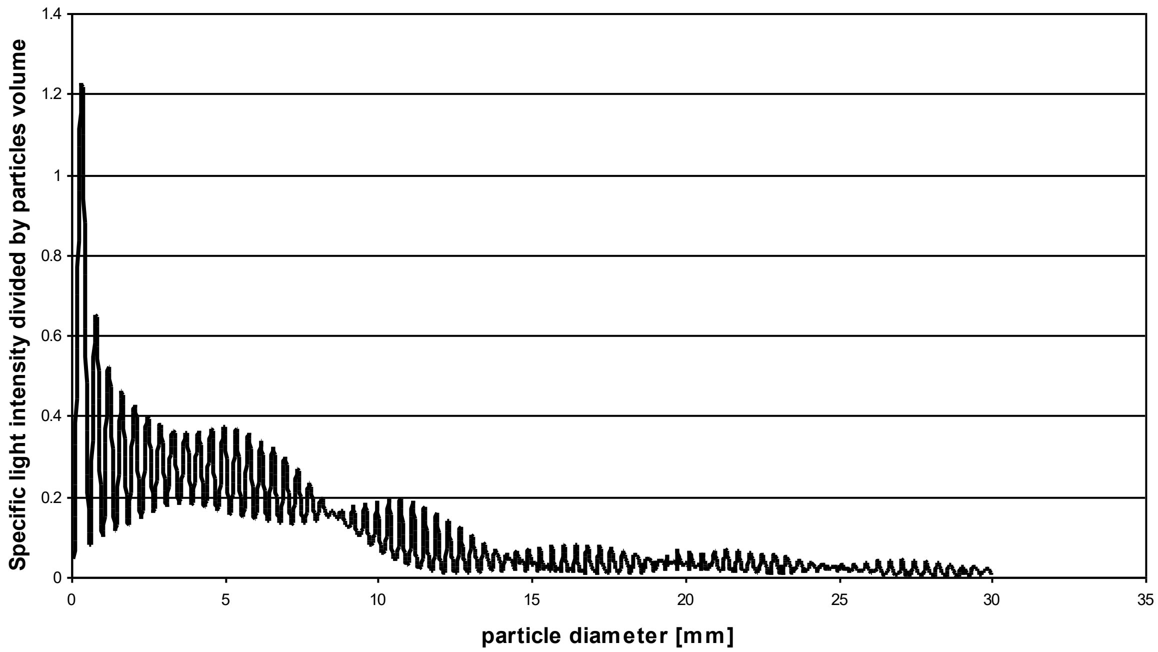

Figure 2 Specific light intensity scattered at angle 90 degrees (nephelometric measurement) divided by particle volume versus particle diameter

Water treatment plant

The experiments were carried out in one of the water treatment plants supplying Krakow (Poland) from Dlubnia river. The water is treated with traditional processes like coagulation, flocculation, sedimentation, filtration and disinfections and occasionally activated carbon dosing. First, the raw water is coagulated continuously with aluminum sulphate. Next, the water flows through the horizontal sedimentation tanks and arrive to ten rapid filters. The filters are filled with one-meter high sand media with following mass stratification: fraction 0-0.4 mm – 2.2%, 0.4-0.5 mm – 2.4%, 0.5-0.63 mm – 3.5%, 0.63-0.8 – 5.9%, 0.8-1.0 – 13.6%, 1.0-1.25 – 49.4%, 1.3-1.6mm – 24%. The conductance of the treated water kept close to 0.550 mS/cm, pH = 8.2 and temperature 7 C. The low concentrated samples after filtration were settled and decanted before measure to obtain enough high concentration. The suspension concentrations of samples from raw water and after flocculation were optimal for particle size distribution measurement.

The nephelometric turbidity was measured by turbid meter Turb 500 IR manufactured by WTW company. The volumetric particle size distribution and volumetric suspension concentration were predicted by Malvern Instrument apparatus. The Mie theory was applied for calculation.

Experiments and conclusions

Turbidity and particle size distribution were measured between unit water treatment processes during experiments. Shape, porosity, roughness, chemical composition and color of suspended particles were changed during the processes. Unfortunately, more laser diffraction theory are perfect only for transparent even spherical particles. Complex refractive index improves Mie theory for natural suspension. Refractive indexes for particles suspended in water during experiments were chosen: 1.45+0.03i for raw water, 1,3899+0,2i for flocculated water, 1,41+0,1i after sedimentation, 1,41+0,1i for filtered water.

Unit process	Raw water, before coagulation	After slow mixing	After sedimentation	After rapid filtration
Turbidity[NTU]	42.4	47.6	1.46	0.35
Volumetric suspension concentration predicted by laser instrument [vol/vol]	0.000262	0.000394	0.000009	0.000002

Table 1 Nephelometric turbidity and suspension concentration between each of the unit processes

Table 1 includes turbidities and volumetric suspension concentrations between unit processes. The figures 3 and 4 present particle-size distributions for samples taken between processes as a cumulative percentage frequency and also as a probability density function. As we supposed, no reduction and even increase of both parameters were observed after flocculation. Higher hydration of flocs after flocculation caused to increase of total suspended particles volume. Both analyzed parameters, turbidity and suspension concentration were based on particle volume measurement. However, lack of control possibility of refractive index and less impact of bigger particles than the same volume but different number of smaller particles

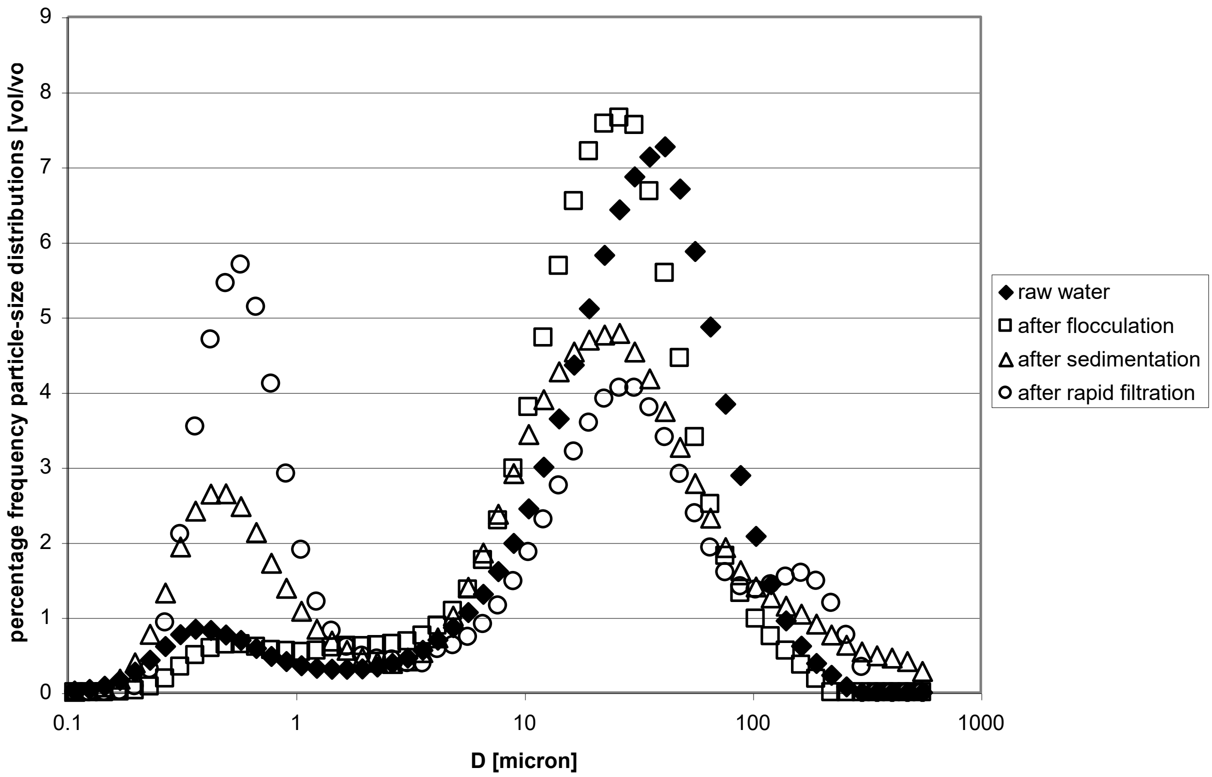

Figure 3. Percentage frequency particle-size distributions between unit treatment processes in Dlubnia water plant

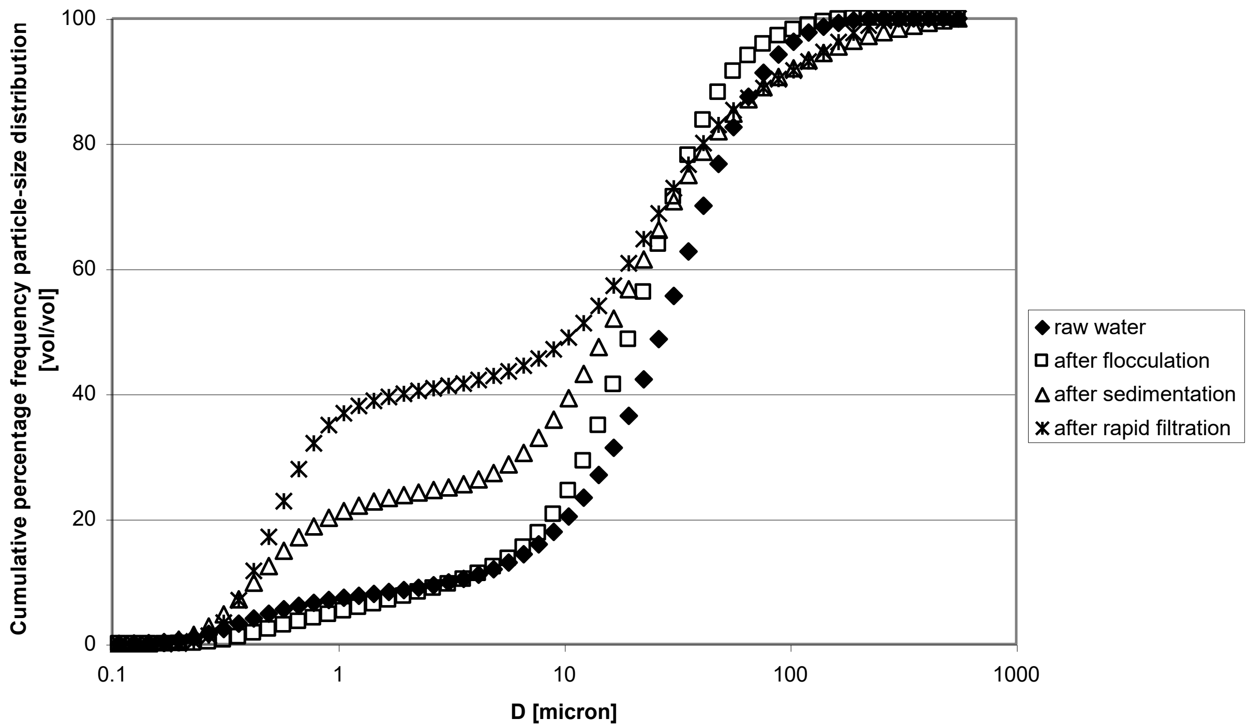

Figure 4. Cumulative percentage frequency particle-size distributions between unit treatment processes in Dlubnia water plant

on turbidity cause to lower increase of turbidity than suspension concentration after flocculation. The next reason of different increase of both parameters, suspension

concentration and turbidity after flocculation is due to reduction of light scattering and nephelometric turbidity by colored particles. Some decrease of fine particles, smaller than 1 micron was observed after coagulation and flocculation in figures 3 and 4. At the same time, volume of particles between 1 and 30 microns decreased.
The most important reductions of turbidity and particle size distribution were noticed after sedimentation. Flocculated particles were effectively reduced in sedimentation tank. Suspension concentration decreased (almost 45 times) much stronger than turbidity (about 30 times). It could be explained by proportionally lower volumetric decrease of fine particles in total suspended solid volume than bigger particles after sedimentation. It resulted in lower reduction of nephelometric turbidity than suspension concentration. Volume of particles smaller than one micron relatively increased and particles bigger than 10 microns relatively decreased in proportion to the reduction of total suspended solid volume after sedimentation. Some volume of particles bigger than 100 microns were even poorly removed than rest of particles. Probably, some big, strongly hydrated flocs characterized by small density settled too slowly to stop in sedimentation tank. Such big particles like these should not inflow to the filters, because they block upper pores of sand media. However, it could be very small number of the big particles, that was noticed as quite important percentage of volume of total suspended solids. Filtration reduces nephelommetric turbidity from 1.46 to 0.35, guaranteeing lower value than standards. Suspension concentration was also reduced about four times. As we supposed, bigger particles were removed much better than smaller. Significantly poorer reduction of particles around one micron was observed. It was proved (Yao, Habibian, O'Melia, 1971) that removal efficiency of this size particles is the lowest. Surprisingly, quite high number of particles bigger than 100 microns were still not removed. Maybe, some of the aggregates were detached from deposit and got to the filtrate.
Results presented in table 1 show higher removal efficiency of sedimentation and filtration processes predicted base on volumetric suspension concentration parameter than predicted base on nephelometric turbidity. It was analyzed for filtration (Zielina, Hejduk, 2007). Bigger particles are better removed during filtration and sedimentation. Particle size distributions before these processes are characterized by proportionally higher volume of bigger particles to smaller particles than after these processes. In consequence, removal efficiency seems to be lower based on nephelometric turbidity than volumetric suspension concentration. Light scatters through bigger particles proportionally more intensively at lower angle than at bigger and this proportion increases together with particle size. That is why, nephelometric turbidity measured at 90 degrees reduces lower than volumetric suspension concentration.
Particle size distribution measuring instruments are very suitable for making decisions on operation of unit water treatment processes. Much more information about efficiency of unit process can be received from particle size distribution parameter than only from turbidity. On-line particle size information let operators better control quality of produced water, choosing the most optimal working parameters and protecting against epidemiological dangerous .

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