

MEASUREMENT OF SUSPENDED PARTICLES IN WATER FILTRATION

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ABSTRACT

It is very important to constantly control the dynamic work of rapid filters during runs. Usually, turbidity is used for filtration process monitoring, but recently, particle size distribution has also been adopted for this purpose. Particle size distribution characterizes treated water quality and filter efficiency more precisely than turbidity. Particle size distribution is also easier than turbidity to interpret and apply in mathematical models. The size effect of suspended particles on turbidity was analyzed in this paper. A comparison of the results of filtrate quality measurements and the efficiency of sand filter operation based on particle counter measurements and turbidity measured online and for periodically taken samples has been carried out.

Keywords: Rapid filtration, Filter efficiency, Water quality monitoring, Particle size distribution, Suspension

1. INTRODUCTION AND LITERATURE REVIEW

In the past, the clarity of drinking water had chiefly aesthetic significance [1], later the adverse role of undissolved particles was shown, as they offered favourable conditions for surviving and growth of pathogenic organisms. It was also noticed that at such a high concentration of suspended matter, the disinfection efficiency is reduced. High amount of undissolved particles causes also errors in the determination of chemical and biological parameters. The concentration of suspended matter in water can be determined by filtering water and weighing the suspended matter left on the filter paper. In practice, however, the method is very laborious and inaccurate. Hence, to assess the quantity of particles undissolved in water, optical methods are used usually today. It is possible to perform the turbidity on-line measurement automatically with $\pm 2\%$ accuracy and $\pm 1\%$ repeatability. In most countries worldwide, the turbidity is determined nephelometrically, thus, by measuring scattered light intensity at 90° [2], or based on the measurement of transmitted light, thus at an angle of zero degrees. Recently, an ever increasing number of water treatment plants have been installing particle counters and particle size analysers that allow controlling not only the number of dispersed particles but also their size. Attempts have been made to use the turbidity and particle counters to monitor the presence of pathogenic organisms of the size equal to the suspended particles [3,4]. Though they do not allow direct detection of the presence of pathogenic organisms, they may be used to estimate the probability of

their appearance in purified water at appropriately operated technological processes [5,6]. They are also applied in optimising the flocculation and filtration processes as a parameter that makes it possible to continuously assess the efficiency of their performance [7]. They allow adjusting the coagulant dose, diagnosing the filter condition, detecting the moment of filtrate quality deterioration [8]. Suspension concentration and particle size distribution are essential parameters for all mathematical models of depth filtration. More of the particle removal mechanisms during depth filtration strongly depend on their sizes [9].

However, relatively cheap turbidimeters are still often used as the only means of estimating suspended matter quantity and filter efficiency. Most of the mandatory regulations still only limit turbidity as a measure of suspended solid quantity in drinking water. Thus the investigation of the correlations between the removal of suspension concentration, the number of different suspended particle sizes and the turbidity during filtration seems to be beneficial today.

Nephelometric turbidity, expressed in NTU (Nephelometric Turbidity Units), is a measure of the intensity of light scattered on suspended particles at 90 degrees to the incident light beam. Light scattering by particles is described by Maxwell's equations solved by Gustav Mie [10,11], which is known as the Mie theory. For the wavelength of 860 nm, employed in the nephelometric turbidity measurements in accordance with ISO 7027 [2], the dependence of the relative intensity of the light beam scattered at an angle of 90 degrees calculated for the volume unit on the particle size is presented in Figure 1. Figure 1 is based on numerical calculations for solid particles characterised by real part of refractive index equal 1.51 and imaginary part equal 0.05. The effect of the finest particles of the size below 2 μm on the nephelometric turbidity measurement is dominating at the same volumetric concentration, whereas the effect of particles above 6 μm is very small. According to the experiments [12] and relationship presented in Figure 1 the same volume of finer particles affected definitely more the turbidity measurement than that of larger particles.

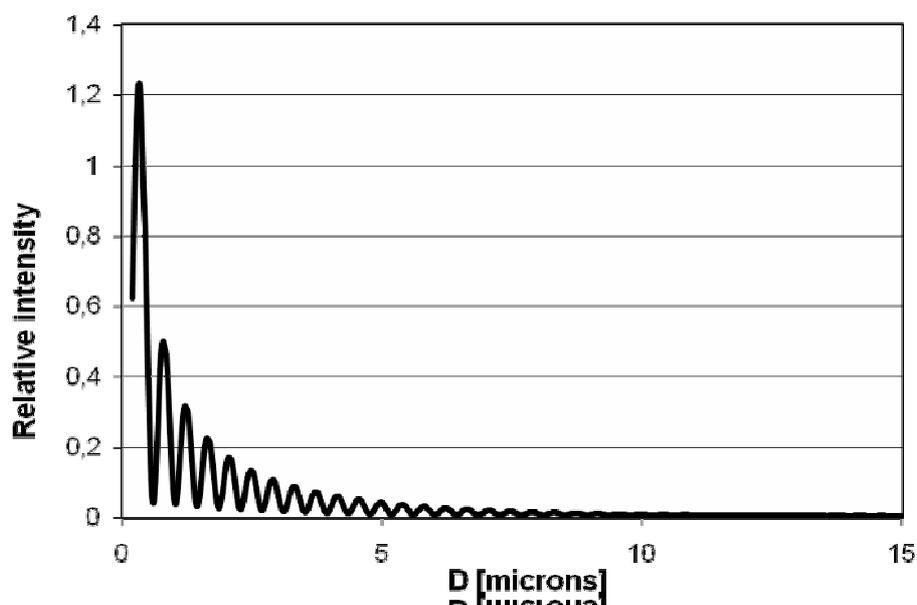


Figure 1. Relative intensity (ratio of 90 degree scattered light intensity to particles volume) versus diameter of particles

2. METHOD AND MATERIALS

Experimental studies of rapid filtration were carried out on a laboratory set-up at the Cracow University of Technology. This set-up (Fig. 2) is equipped with a feeding element comprising a stainless steel tank of 1 m³ volume for the preparation of raw suspension of appropriate concentration with forced hydraulic mixing assuring that the particles are dispersed. Next, the suspension so prepared flew into an overflow tank that allowed maintaining the water level constant, which guaranteed keeping the suspension flow to the filtration column constant. The suspension was additionally coagulated with hydrated aluminium sulphate, and next flocculated in the flocculator. The flocculation time of the suspension in the flocculator was 22 minutes, and the rotational speed of the mixer 13 rpm. The feeding of the selected dose of the coagulant was performed by means of a peristaltic pump. The filtration process occurred in a Plexiglas column of 96 mm inner diameter packed with non-homogeneous sand of 80 cm bed height. The grain size distribution of the sand bed in the filter is presented in Table 1. The samples were taken at the inflow and outflow of the filter.

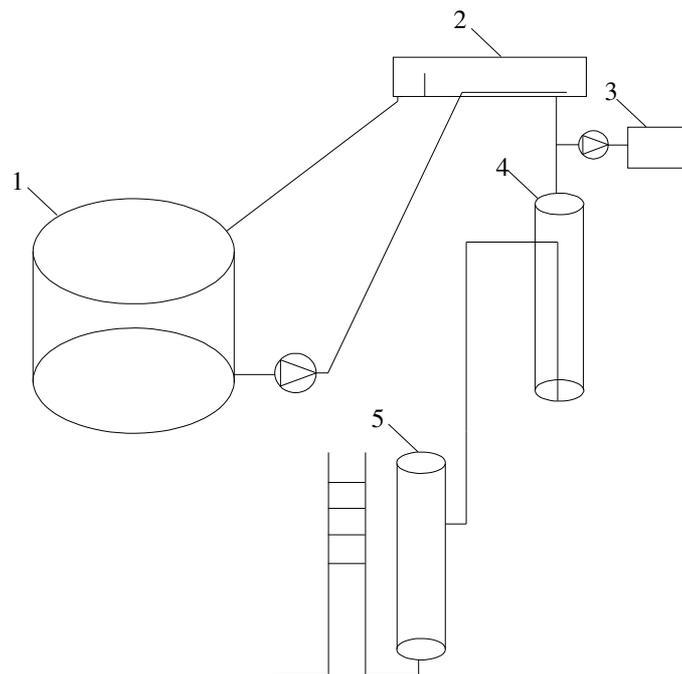


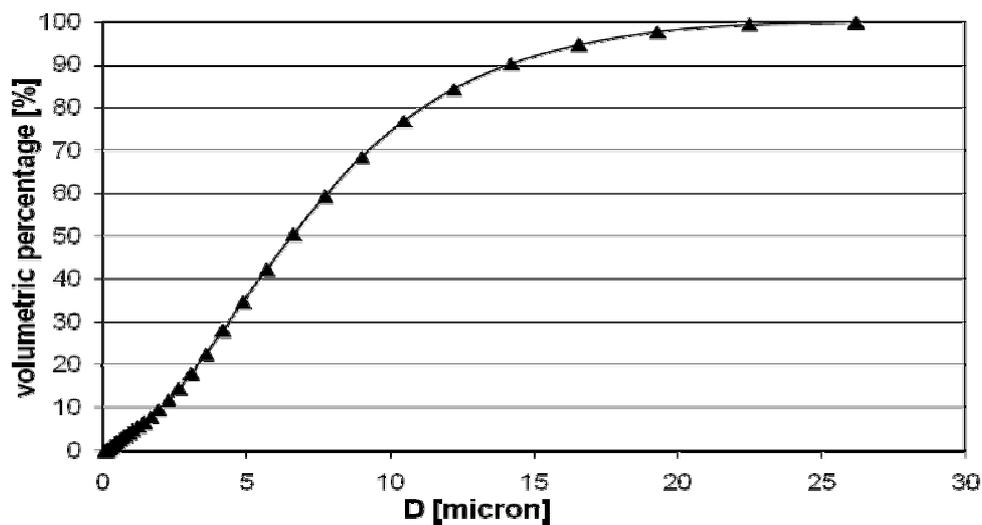
Figure 2. Laboratory set-up
(1 – suspension preparation tank, 2 – overflow tank,
3 – coagulant, 4 – flocculator, 5 – filtration column)

Table 1 Filtration media grain size

Grain size	Weight percentage
0.4 mm – 0.5 mm	10 %
0.5 mm – 0.63 mm	19 %
0.63 mm – 0.8 mm	31 %
0.8 mm – 1.0 mm	36 %
1.0 mm – 1.25 mm	4 %

The suspension measurements were carried out at the inflow and outflow of the filter. Continuous and periodical turbidity measurements were performed by means of two nephelometers: WTW Turb 555 IR with a possibility to be operated online and with Ratio system and WTW Turb 550. Whereas the size and numbers of suspended particles were measured by means of a Particle Measuring Systems LiQuilaz E-20P volumetric flow spectrometer. The number of particles in 1 millilitre of water should not exceed 10 000. These conditions were maintained upon the studies.

Raw suspension of 6.3 mg/l concentration was prepared by adding fine into tap water aluminosilicate powder SIPERNAT 820 A manufactured by Degussa. The chemical and grain size composition of the powder is presented in Table 1 and Figure 3. The suspension so prepared was coagulated with hydrated aluminium sulphate and subjected to flocculation. The coagulated suspension flew into the filtration column. During filtration, the average filtration rate was kept at about 6.6 m/h. Mean temperature was about 15.9°C during the studies. The filter work cycle was about 8 h. Samples were taken at the inflow and outflow of the filtration column.

**Figure 3. Particle size distribution of raw suspension SIPERNAT 820 A**

3. RESULTS AND DISCUSSION

During filtration the turbidity was measured online and in one-hour periods at the outlet of the filtration column. The measurement results are presented in Figure 4. During the first half-hour, directly after the filtration column starting, an insignificant deterioration in the filtrate quality was noticed. Right after the start of the filtration cycle the column was filled with clean wash water, hence exceptionally good quality of the filtrate right after starting the filtration and gradual deterioration in the filtrate quality during the first half-hour. In the next hour, a gradual improvement in the filtrate quality was observed, which could be rationalised by an improvement in the filtration conditions in the bed that develop together with its colmatation. After two hours, the turbidity stayed at a constant level until the end of the filtration cycle. During this time, the total loss in bed increased from 34.4 to 77.3 cm. During the experiments, no phase was observed that might often be distinguished at the end of the cycle and characterised by deterioration in the filtrate quality. Figure 4 presents also turbidity measurement results from the manual sampling of water at the outflow every hour. The results of stationary measurements of turbidity were generally consistent with the results obtained online. They did not contain, however, momentary, though sometimes significant, changes in the quality of filtrate noticed in online measurements. Particularly distinct deterioration in the filtrate quality was observed after half an hour and after 4 hours.

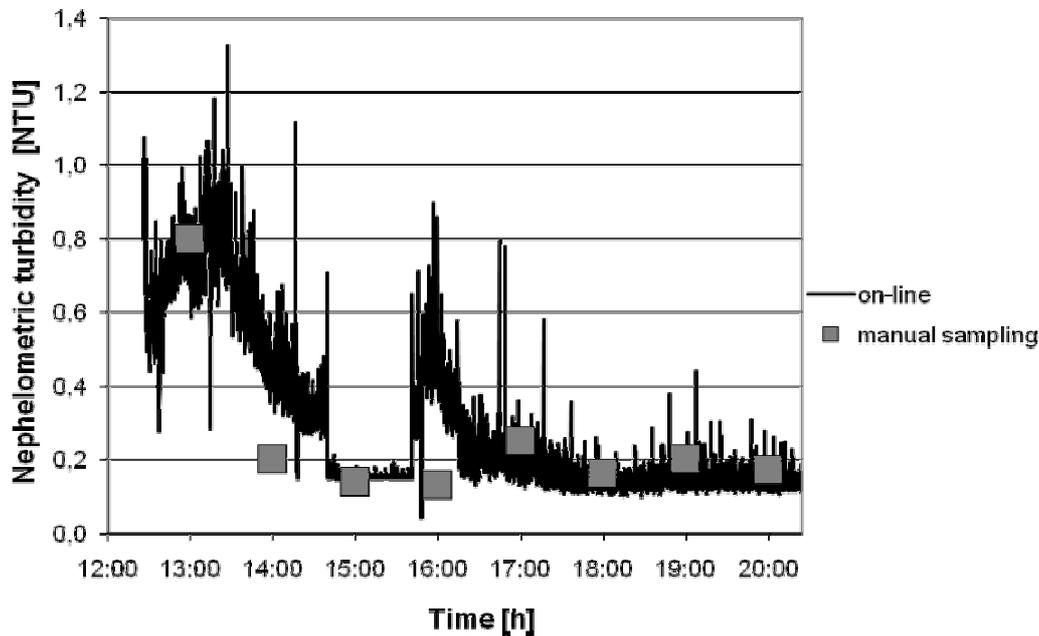


Figure 4. Filtrate turbidity versus time during experiments

Online measurement was performed with a Ratio system turbidimeter correcting the errors resulting from multiple reflections of the light beam, opacity of suspended particles and air bubbles collecting in the sample. The measurement on the stationary turbidimeter was done without Ratio system. Despite the prior coagulation and flocculation of the suspension flowing into the filter, no significant differences were observed between the measurements with and without the Ratio system.

Figure 5 presents the results of measurements performed by means of a counter of particles suspended in water and a comparison of these results with those of turbidity. According to the plot presented in Figure 5, nephelometric turbidity was removed in a similar degree as the finest suspended particles. It was in accordance with correlation in figure 1 presenting dominating effect of finer particles on turbidity measurement. The removability of coarser particles varied slightly differently upon the entire filtration cycle. At the end of the cycle, the removability of coarser particles was significantly worse than the removability of finer particles and the removability of turbidity. The fall in the efficiency of the removal of coarser particles can be easily rationalised. An increase in the deposit content of the bed is accompanied by a fall in the bed porosity. On the other hand, a decreasing porosity of the bed is accompanied by an increase in the flow rate between the grains and an increase in the shear stress. Exceeding the shear stress limit inside the bed causes a sudden fall in the removal of particles. The removal time limit for coarser particles occurs considerably earlier than the removal time limit for finer particles, hence the removal efficiency of particles larger than 25 μm begins decreasing as early as after 4 hours, the removal efficiency of particles of the range 15 – 25 μm deteriorates only after 6 hours. The decrease in the removal efficiency of finer particles is slight and appears only in the last hour. Counting the particles makes it possible to notice a decrease in the removal efficiency of coarser particles at an earlier time, which is impossible by means of turbidity measurements.

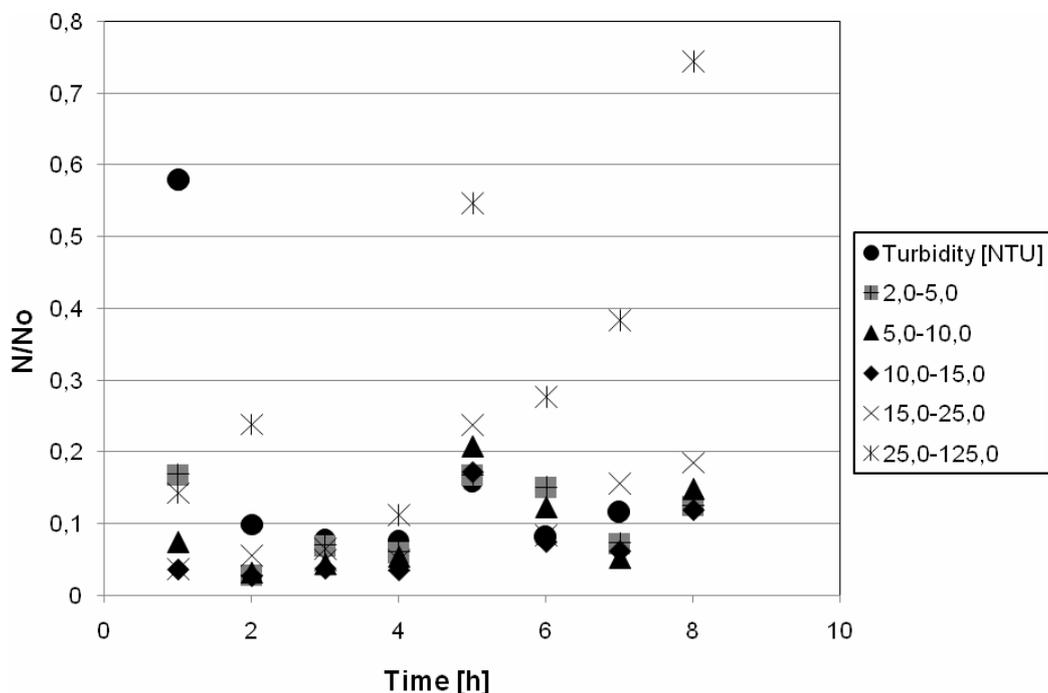


Figure 5. Fractional remaining against time during experiments

4. CONCLUSION

Experimental studies and numerical calculations based on the light scattering theory of Gustav Mie indicate a very strong effect of the distribution of suspended particle size on the turbidity measurement. Continuous measurement of filtrate turbidity, though yielding similar values to the turbidity measurements on samples taken manually at the outlet every hour, detects turbidity fluctuations inevitably occurring during the filtration cycle. Under technical conditions, they are often caused by sudden changes in the flow rate produced by switching off for washing or re-switching other filters in the station. Undoubtedly, the online measurement of turbidity yields definitely a better possibility to control the filter performance than periodic measurement. For the studied suspension samples after flocculation, and omitting it, Ratio system used for the reduction of measurement errors, did not show big deviations relative to turbidimeter not equipped with such a system.

The particle counter yielded definitely more information; the removal efficiency of separate fractions of particles was significantly different. The removal efficiency of coarser particles began to decrease quite early, finer particles, similarly to turbidity, even at the end of the filtration cycle, were removed in a high degree. This confirmed the fact that the turbidity is removed in a similar degree as the finest particles. The removal of coarser particles, which may often make a significant fraction of the volume of all particles, may proceed quite differently. The particle counter makes possible to detect a moment, at which the removal efficiency of coarser particles starts falling, despite the removability of turbidity staying at the unchanged level. Knowing the removal efficiency of individual size fractions of particles, and not only the turbidity, it might be attempted to calculate the probability of the removal of pathogenic organisms of similar size. Most of methods that allow determining the amount of pathogenic microorganisms, which remain in water, require laboratory conditions and are difficult to employ under online technical conditions. Instantaneous measurement of the particle size may yield useful information on the removability of particles of the size close to the size of monitored microorganisms. Difficult interpretation of turbidity, sometimes surrogating suspension concentration and particle size distribution, causes to create significant errors in mathematical models of depth filtration.

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