Environment Protection Engineering

Vol. 27 2001 No. 3–4

ANDRZEJ JODŁOWSKI*

EFFECT OF PRE-OZONATION AND COAGULATION TREATMENT ON PARTICLE-SIZE DISTRIBUTION OF ALGAL AGGLOMERATES

The agglomeration resulting from pre-ozonation and coagulation of two species of green algae was investigated. *Chlorella pyrenoidosa* and *Scenedesmus quadricauda* occurring normally in reservoirs used for drinking water supply were used for the experiments. Pre-ozonation was applied in order to improve subsequent agglomeration caused by the addition of a coagulant. Ferric chloride was utilised in the coagulation step. Measurements of particle size were taken before and after pre-ozonation/coagulation/flocculation process using computerized image analyzer. This method enabled a quantitative recording of varying pre-oxidant dose effect on particle size and particle-size distribution (PSD). The decrease in the number of discrete algal particles and the increase in the number of agglomerates were observed as a result of a small dose of ozone introduced before the ferric chloride application. Shift of the PSD towards larger particles was observed in the case of *Scenedesmus* cells and towards smaller particles in the case of *Chlorella* cells. Ozone overdosage caused the deterioration of agglomeration process as a result of algal cells disruption. The investigation results provided the evidence that pre-ozonation caused the significant change in the algal surface properties entailing the enhancement of the algal particles agglomeration without coagulant dosage changes.

1. INTRODUCTION

Efficient agglomeration of algae during the coagulation step is a key problem in the potable water production process when raw water comes from eutrophic impoundments. Inefficient agglomeration of algal particles during the coagulation/flocculation step of treatment can cause algae penetration through filters and filters clogging which in turn results in the increased volume of backwash water. Algae in water passing through the filter bed are responsible for the increased level of haloforms in the treated water as a consequence of organic matter chlorination and also for biological aftergrowth in distribution systems [1], [2].

* Faculty of Civil Engineering, Architecture and Environmental Engineering, Department of Water Management, Technical University of Łódź, 90-924 Łódź, Poland, e-mail: anjodl@ck-sg.p.lodz.pl

Freshwater algae can be described as biocolloids. They show a point zero charge in the acid range of pH and are negatively charged under most conditions encountered in natural waters. The external surface of algae consists of amphoteric and hydrophillic groups and carries its charge as a result of acid–base interactions of functional ionogenic groups.

Destabilization and agglomeration of algal particles can be accomplished by the use of several organic and inorganic coagulants. The mechanisms responsible for the algal coagulation during hydrolized metal ions (Al(III) or Fe(III)) utilization are adsorption/charge neutralization or sweep-floc coagulation [3], [4]. Generally, the optimum pH range for an effective hydroxide precipitation ranges from 5 to 6 for Al(III) and from 4.5 to 5.5 for Fe(III), although it can be modified by the properties of the impurities being removed. All the trivalent aluminium and ferric ions undergo rapid hydrolytic reactions leading to hydroxopolymers formation within these pH ranges. Charge neutralization usually occurs at low coagulant doses through the adsorption of dissolved metal species or metal hydroxide precipitates and is more favourable at pH values lower than optimum range where free metal ions are prevalent. Sweep-floc coagulation typically occurs at high coagulant doses and within optimum pH range of metal ions hydrolysis. Metal hydroxide promotes the process by increasing the interparticle collision rate and enmeshing suspended particles during sweep-floc coagulation.

Various parameters of the coagulation process are known to affect the size, shape and density of flocs. Floc properties are also changed during flocculation according to hydrodynamic conditions in a flocculation reactor. Particle-size distribution (PSD) measuremets showed substantial changes over flocculation time [5]. Also application of oxidants can bring effect on particles aggregation during coagulation [6]–[9]. Preoxidation can be presumed to have pronounced effect on parametres of adopted PSD function.

It has been shown that low doses of the ozone applied to a raw surface water rich in colloidal particles lead to a lowering of the number of small particles and a simultaneous increase in the number of larger size particles [10], [11]. MATHONET et al. [12] observed different phenomenon where ozone application caused a diminition of the large particles percentage of the entire particles population of the Seine river water and an increase in population of average particles due to disaggregation of clay particles agglomerated between themselves by the organic material.

Pre-ozonation has been widely reported to assist coagulation in the removal of some algae during surface water treatment. Dosages necessary for this type of treatment are usually in the range of 0.2 to 1.0 mg O_3/dm^3. SAUNIER et al. [6] concluded that the increase in particle removal appeared to stem partly from increase in floc size. SUKENIK et al. [7] showed that pre-treatment of algal culture suspension with ozone enhanced algal flocculation with alum. JANSSENS et al. [13] found that pre-ozonation had a strong positive effect on direct filtration performance of algal laden water com-

ing from storage reservoir. Also EDZWALD and PARALKAR [14] found that ozone tended to improve algal particles flocculation performance although they noticed an important role of extracellular organic matter (EOM) in the agglomeration process. The results of the researchers mentioned provide some information that algal cells are easier to incorporate into hydroxide floc structure when they previously are subjected to the attack of ozone or ozonolysis products.

The purpose of the present study was to determine the effect of pre-ozonation on the agglomeration efficiency of chosen green algae species after their coagulation by ferric chloride. The objective was also to investigate the changes in PSD of algal agglomerates as a result of pre-ozonation/coagulation process application. The changes in PSD of agglomerated algal particles are important issue since they have direct effect on the separation processes such as flotation or direct filtration efficiency. Agglomerates produced during flocculation period under certain hydrodynamic conditions should be of the proper size, depending on the separation process applied [15].

2. MATERIALS AND METHODS

2.1. SELECTED ALGAL SPECIES CULTIVATION AND RAW WATER PREPARATION

The two green algae (*Chlorophyceae* family) species, *Chlorella pyrenoidosa* and *Scenedesmus quadricauda*, were selected for the experiments. *Chlorella* is a nanoplanktonic microalgae of a spherical shape with a diameter of 4±1 μm, while *Scenedesmus quadricauda* is a chainforming organism containing two, four or eight single cells with a breadth of 12 μm and a length between 8 and 42 μm, depending upon the number of single cells.

Monoalgal cultures were grown for a definite period in 300 cm^3 Erlenmayer flasks filled with an inorganic medium. Algae were cultured in a modified Bold's Basal medium at a temperature of 20 °C. Mixing was performed by a laboratory shaker. The cultures were used for the experiments after reaching certain optical density according to the growth phase (e.g. stationary phase after 7–10 days). The optical density of algal laden water at 750 nm was about 1.3 for *Chlorella* and about 1.0 for *Scenedesmus* suspensions in 1 cm cuvette.

In order to obtain raw water for the investigations, a defined volume of algal culture, including cells and extracellular organic matter, was thoroughly mixed with 10 dm^3 of tap water filtered through 0.2 μm Sartorius membrane filter. The optical density of raw water containing algal suspension was adjusted at 0.01 according to light absorption at the wavelength of 750 nm in 1 cm cuvette. The homogeneity of the raw water was maintained by continuous stirring, and its pH was kept at a level of 7.0 by adding HCl.

The pH of the algal suspension after cultivation was higher than 7.0 due to the CO_2 consumption by the algal cells.

2.2. PRE-OZONATION AND FLOCCULATION PROCEDURE

The batch ozonation apparatus used in this study is shown in figure 1. The ozone was produced by LABO 70 ozone generator (Trailigaz Co.) cooled by flowing water. Dry air was passing through a pressure reducer and got into the ozone generator where it was affected by effluvium due to high-tension electric discharge produced by a transformer.

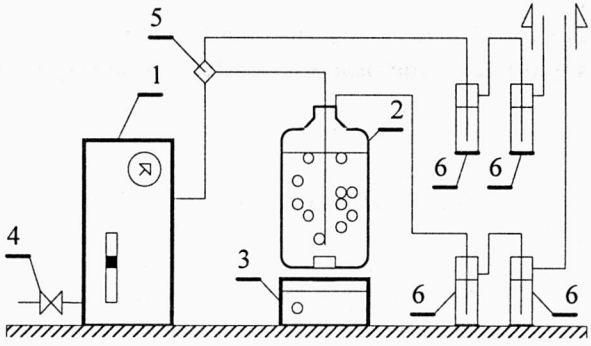

Fig. 1. Lay-out of ozonation apparatus: *1* – ozone generator, *2* – reactor, *3* – mixing device, *4* – control valve, *5* – flowthrough valve, *6* – KI solution flask

The ozone–air mixture was introduced into a glass reactor of the volume of 2.5 dm^3 filled with water under controlled flow rate. The amounts of the introduced and residual ozone were measured by iodometric/thiosulfate titration. The unozonated and ozonated water samples were than transferred to the 2 dm^3 flocculation vessel (diameter of 12.5 cm, height of approximately 18.0 cm). The stirring paddle made of stainless steel sheets of the dimensions: 7.4 cm in width, 2.5 cm in height was connected to an infinitely variable gear.

Ferric chloride was used as the coagulant. Stock solution was prepared by dissolving 13.332 g of analytical grade reagent, $FeCl_3 \times 6H_2O$, in 1 dm^3 of distilled water. Such a solution of 4 g Fe(III)/dm^3 concentration was acidified by adding some drops of hydochloric acid. Rapid mixing was continued for approximately one minute at 300 rpm corresponding to an energy input of G of 1000 s^{-1}. Subsequently the suspension was stirred for 10 minutes at 120 rpm (G of 200 s^{-1}) for aggregation. The samples of water containing agglomerates formed as a result of pre-ozonation/coagulation/flocculation process were subjected to measurements.

2.3. DETERMINATION OF PARTICLE SIZE AND PARTICLE-SIZE DISTRIBUTION

Water samples were slowly withdrawn from the flocculation vessel by a pipette with tapered end removed to avoid floc breakup. The cuvette of 35 mm in diameter and 1 mm in depth was filled up with the sample, covered with a covering glass and placed on the microscope stage.

The particle size and the PSD in the raw and treated water were determined by means of the Mini-Magiscan/IAS 25 analysis system produced by Joyce–Loebl company. Samples were analyzed using a ccd-camera of 604×289 pixels resolution, which was mounted on a Nikon Optiphot light biological microscope (with the phase contrast objectives). The layout of the measuring system is shown in figure 2.

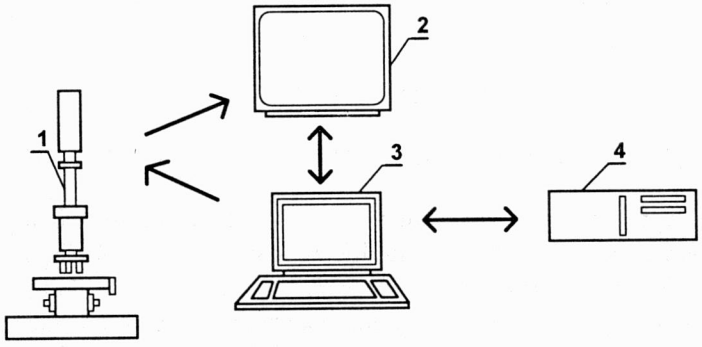

Fig. 2. Lay-out of image analysis system used during investigations:
1 – microscope with video camera, *2* – monitor of high resolution,
3 – control terminal, *4* – computer system

During the measurements of *Chlorella* agglomerates the assumption was made that single cells lying together within a certain distance would have a high probability of belonging to the same agglomerate. This distance was found out experimentally and was determined as 5–10 single cell diameter. The size of agglomerates was approximated by the use of an "expansion" operator of GENIAS 25 program. This operator increased the size of each particle up to 8 single cells diameters. The "erosion" operator was used after that with the same number of steps. This way the prepared picture of the agglomerated cells was subsequently taken for the measurements.

The images from the camera were fed into a HP-Vectra ES/12 computer. The images were analyzed by the image analysis program GENIAS 25 (version 1.2). Magiscan automatically stored each key-press selection and was then able to play back the whole sequences. Having processed the incoming signal, the system was able to capture an image and carry out image analysis. Magiscan stored the acquired data on the computer's disc. A separate powerful statistical analysis program was used next. Permanent records of image and data could be stored safely onto mass storage devices.

The same procedure was used for the particle-size distribution measurements in the raw and treated water.

On the basis of the projected area of the particles obtained from the image analyser measurements a spherical shape was assumed for further analysis because of irregular shape of the particles. The projected area diameter of a circle having an area equal to the projected area of the particle was used during the measurements analysis.

Tests and analyses were performed using the statistical software package STATISTICA version 5.0. The frequency distributions of data from each sample were shown to be generally log-normally distributed. The differences between the measured values and theoretical distribution were checked using the Kolmogorov–Smirnov test. Skewness and excess (kurtosis) were also used as a discordance measure of experimental particle-size distributions and log-normal distribution.

3. RESULTS AND DISCUSSION

3.1. SIZE DISTRIBUTION OF ALGAL CELLS BEFORE TREATMENT

The algal suspensions in raw water under investigation were composed of particles of a certain range of diameters and different shapes of PSD. Typical examples of PSD of *Chlorella pyrenoidosa* and *Scenedesmus quadricauda* cells in raw water samples are shown in figure 3. *Chlorella* cells appeared in the raw water as single particles or sometimes as grouped cells, which gave their bimodal distributions. *Scenedesmus* cells were counted as one organism for each cell packet suggesting at first sight that the particles were unimodally distributed.

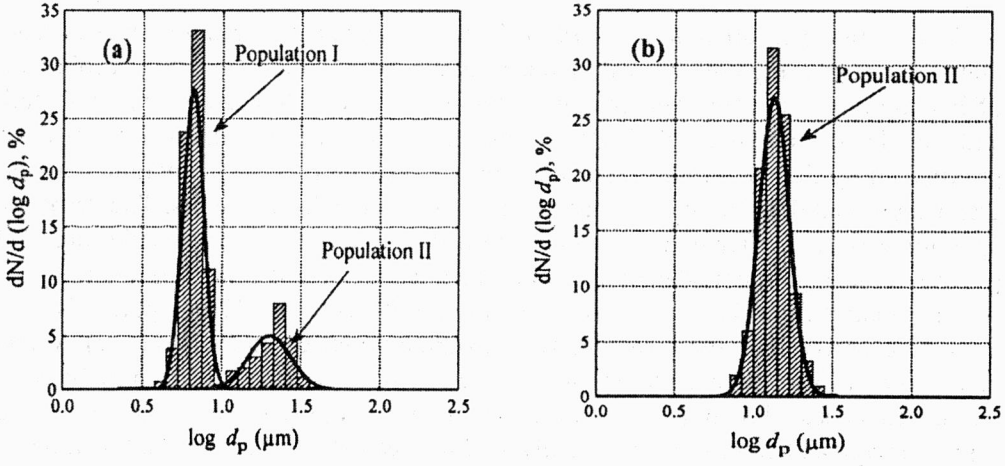

Fig. 3. Particle-size distributions of algal suspensions under investigation: *Chlorella pyrenoidosa* (a), *Scenedesmus quadricauda* (b)

Populations of bimodally distributed particles were arbitrarily divided into two portions. The dominant part in the population of *Chlorella* cells consisted of particles of the diameter of 6 μm (population I). Some of *Chlorella* cells were stuck together having a form of grouped cells bringing about the other peak of the mode value of 23 μm (population II) which reflected naturally agglomerated particles. Populations of *Scenedesmus* cells were built up from discrete particles falling in the range of diameters from 8 to 30 μm.

The distribution of algal particles fitted well to log-normal distribution functions [14], [15]:

$$f(d_p) = \frac{1}{2.303 \log \sigma \sqrt{2\pi}} \exp\left(- \frac{(\log d_p - \log M)}{2 \log^2 \sigma} \right),$$

where d_p is the diameter of the particle or floc, M is the geometric mean of particle or floc diameter and σ is the geometric standard deviation of $\log d_p$.

Table 1

Results of statistical analysis of particle-size distribution of *Chlorella* primary particles and agglomerates due to their coagulation by $FeCl_3$ (t_F = 10 min, G = 10 s^{-1})

Coagulant dose (mg Fe^{3+}/dm^3)	Population I				Population II			
	Distribution parameters (μm)		Skewness	Excess	Distribution parameters (μm)		Skewness	Exceess
	$\log d_p$	$\log \sigma$			$\log d_p$	$\log \sigma$		
0.0	0.818	0.067	–0.218	0.524	1.314	0.122	–0.629	–0.326
0.6	0.763	0.109	–1.252	2.544	1.456	0.303	0.491	–1.000
1.0	0.747	0.101	–0.707	1.516	1.340	0.221	0.978	1.395
2.0	0.728	0.099	–0.914	1.129	1.240	0.125	0.068	–1.204

The parameters obtained during PSD analysis of the distribution functions are presented in table 1 in the case of no coagulant applied. The Kolmogorov–Smirnov test as well as the values of skewness and excess (kurtosis) supported the assumption that the PSD analysed fitted well to log-normal distribution.

3.2. EFFECT OF FERRIC CHLORIDE COAGULATION/FLOCCULATION ON ALGAL PARTICLES' AGGLOMERATION

The iron(III) dosage varied in the range of 0.2–2.0 mg Fe^{3+}/dm^3 during the experiments with *Chlorella* suspension. Three doses of ferric chloride were applied during coagulation of *Scenedesmus* suspension (0.5, 1.0 and 1.5 mg Fe^{3+}/dm^3). Because most coagulant doses used in this investigation significantly exceeded the solubility limit, sweep-floc coagulation was more likely to predominate, although the doses were maintained as small as possible.

The agglomerates obtained as a result of the coagulant introduction into algal suspensions had arbitrary shapes. Some of them were three-dimensional, while the others were flat. A large distance between single cells was characteristic of all agglomerates.

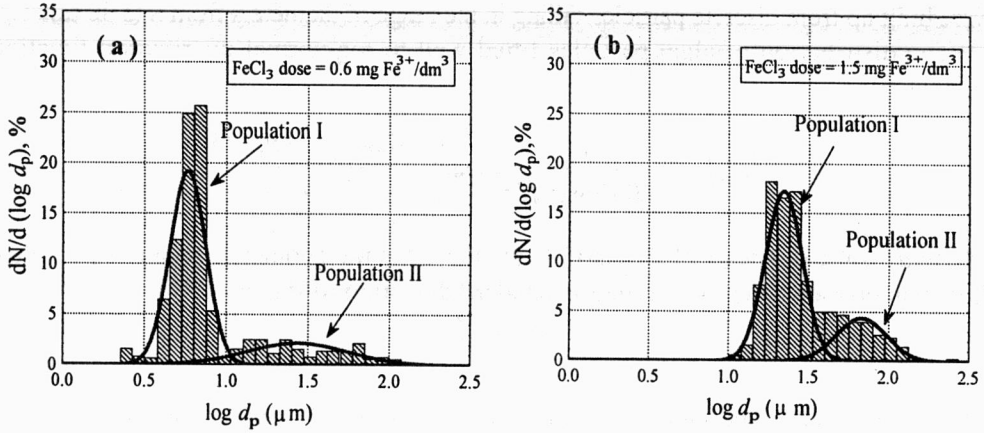

Fig. 4. Particle-size distributions of *Chlorella* (a) and *Scenedesmus* (b) after coagulation by $FeCl_3$

Table 2

Results of statistical analysis of particle-size distribution of *Scenedesmus* primary particles and agglomerates due to their coagulation by $FeCl_3$ (t_F = 10 min, G = 10 s^{-1})

Coagulant dose (mg Fe^{3+}/dm^3)	Population I				Population II			
	Distribution parameters (μm)		Skewness	Excess	Distribution parameters (μm)		Skewness	Excess
	log d_p	log σ			log d_p	log σ		
0.0	1.176	0.140	–0.001	–0.717				
1.0	1.342	0.107	0.107	2.068				
1.5	1.344	0.239	0.116	0.028	1.830	0.156	0.507	–0.731

The results of statistical analysis of PSD of agglomerates revealed that there occurred some changes in distribution parameters of population I and population II (table 1). While the value d_p of the population I slightly decreased due to the transfer of bigger and more susceptible to coagulation *Chlorella* particles to the population II (from 6.58 μm to 5.80 μm), the distinct increase of d_p was observed in the population II (up to 28.7 μm). Also the values σ changed as a result of particles' agglomeration. A small increase in the population I (from 1.16 μm to 1.28 μm) and distinct increase in the population II (from 1.32 μm to 2.01 μm) occurred. It should be noticed that

autoflocculated cells were mainly built in the larger flocs. Especially "the second mode" of the bimodal PSD curve was distinctly changed in the samples after coagulation and as a result the curve was flattened (figure 4a).

The agglomeration of *Chlorella* cells caused by coagulation at the above dosage of $FeCl_3$ was not very effective, especially in the case of discrete particles. A relatively large number of "free" cells, which were not incorporated into agglomerates (flocs), remained. Simultaneously large flocs appeared reaching an equivalent floc diameter of 280 μm, depending on the increase in the coagulant dose (2.0 mg Fe^{3+}/dm^3) (figure 4a).

Coagulation of *Scenedesmus* cells by ferric chloride also seriously diminished the number of discrete algal particles and increased the number of large agglomerates (figure 4b). The results of statistical analysis of the PSDs obtained are shown in table 2. The transformation of unimodal distribution into bimodal one was caused by the coagulant dose increase. Two populations appeared at the coagulant dose of 1.5 mg Fe^{3+}/dm^3 (figure 4b). It could be suspected that the *Scenedesmus* population comprised two distinct groups of cells. One of them was more susceptible to agglomeration than the other. While d_p in the raw water sample containing cells was 15 μm, it increased up to 22 μm in the population I and up to 68 μm in the population II. The value of σ was also changed from 1.38 μm in the raw water sample to 1.73 μm in the population I and to 1.43 μm in the population II.

Coagulation of algal particles by $FeCl_3$ caused in both cases of algal suspension (*Chlorella* and *Scenedesmus*) partial agglomeration of algal cells, which was equivalent to bimodal distributions of populations containing large agglomerates and great number of discrete particles not incorporated into flocs.

3.3. EFFECT OF PRE-OZONATION ON FLOC-SIZE DISTRIBUTION

The results of statistical analysis of PSD of *Chlorella* cells agglomerates obtained due to their $FeCl_3$ coagulation preceded by the pre-ozonation are shown in table 3. Ozone dosage expressed as the difference between the applied and not utilized pre-oxidant varied within the range of 0.8–4.5 mg O_3/dm^3. The dose of $FeCl_3$ was kept as a constant value of 0.5 mg Fe^{3+}/dm^3.

An increase in the utilized ozone dosage up to 2.6 mg O_3/dm^3 caused the improvement of algal cells agglomeration compared to the sole coagulation (figure 5a). The discrete number of cells decreased, while the agglomerates number simultaneously increased. The values of d_p in the population I slightly decreased (from 5.3 to 4.5 μm) as well as in the population II (from 22.4 to 21.9 μm). It colud be caused by the better packing of cells in the floc structure. The value of σ increased in the population I (from 1.30 to 1.42 μm), but it substantially decreased in the population II (from 1.54 to 1.35 μm). The distinct changes of the values σ in the population II indicated higher concentration of agglomerates when their particle diameters (d_p) approached mean value.

Table 3

Results of statistical analysis of particle-size distribution of *Chlorella* after pre-ozonation followed by coagulation by 0.5 mg Fe^{3+}/dm^3 (t_F = 10 min, G = 10 s^{-1})

Ozone dosage ($mg\ O_3/dm^3$)	Population I				Population II			
	Distribution parameters (μm)		Skewness	Excess	Distribution parameters (μm)		Skewness	Excess
	$\log d_p$	$\log \sigma$			$\log d_p$	$\log \sigma$		
0.0	0.723	0.113	–0.803	0.981	1.357	0.186	–0.067	–0.365
0.8	0.793	0.112	–1.220	2.113	1.397	0.174	–0.068	–0.446
1.1	0.728	0.118	–0.718	0.852	1.379	0.183	0.344	0.050
2.6	0.649	0.152	–0.013	–0.686	1.341	0.130	0.184	0.268
2.9	0.683	0.137	–0.343	–0.028	1.365	0.133	–0.196	0.514

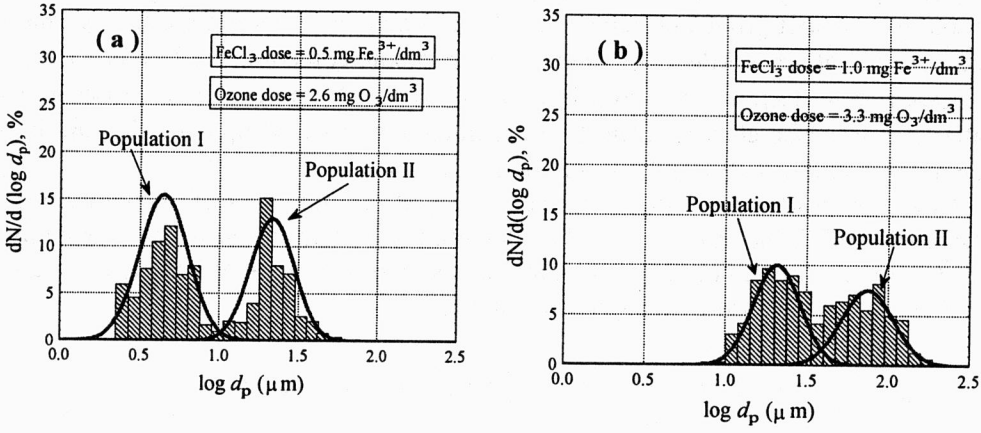

Fig. 5. Particle-size distributions of *Chlorella* (a) and *Scenedesmus* (b) after pre-ozonation and coagulation

Table 4

Results of statistical analysis of particle-size distribution of *Scenedesmus* after pre-ozonation followed by coagulation by 1.0 mg Fe^{3+}/dm^3 (t_F = 10 min, G = 10 s^{-1})

Ozone dose ($mg\ O_3/dm^3$)	Population I				Population II			
	Distribution parameters (μm)		Skewness	Excess	Distribution parameters (μm)		Skewness	Excess
	$\log d_p$	$\log \sigma$			$\log d_p$	$\log \sigma$		
0.0	1.344	0.116	–0.045	–0.262	1.830	0.156	0.531	–0.676
1.3	1.360	0.126	–0.553	0.624	1.810	0.131	0.293	–0.911
3.3	1.317	0.144	–0.066	–0.786	1.873	0.159	0.221	–0.771

The advantage of pre-ozonation was observed for ozone doses up to 2.9 mg/dm^3, but at the ozone doses exceeding 4.5 mg/dm^3 the algal cells disruption was observed.

The coagulant dose was kept at 1.0 mg Fe^{3+}/dm^3 during the tests on *Scenedesmus* cells suspension, while the ozone dosage varied in the range of 0.7–3.3 mg/dm^3. Pre-ozonation caused the decrease in the number of particles in the population I and the increase in the population II as well as in the case of *Chlorella* cells. The results of statistical analyses (table 4) proved that due to pre-ozonation of samples by a dose of 3.3 mg O_3/ dm^3 the value of d_p in the population I decreased (from 22.1 to 20.7 μm) and simultaneuously increased (from 67.7 to 74.2 μm.) in the population II. The values of σ were somewhat decreased in the population I (1.31 to 1.40 μm) and almost not changed in the population II.

Pre-ozonation caused similar changes in PSD of both algal systems under investigation. The distinct decrease in the number of particles in the population I and the increase in the number of particles in the population II after coagulation at constant dosage of $FeCl_3$ took place. It is obvious that the partial transfer of particles from population I to population II occurred because of their greater ability to agglomerate. Mean particle diameter in the population I was slightly reduced in the case of *Chlorella* and *Scenedesmus* suspensions, it decreased in *Chlorella* suspensions and increased in *Scenedesmus* suspensions.

3.4. DISCUSSION

The agglomeration (coagulation/flocculation) step is likely to be the most critical in the removal of algae during potable water treatment. As it was demonstrated, not all algal cells were incorporated into agglomerate structure, especially at low coagulant dosage. The agglomeration was improved by the modification of algal surface properties by pre-oxidation. The results of this research indicate that pre-ozonation improved coagulation efficiency of green algae. Destabilization of particles by ozone and coagulant introduction yielded their better aggregation compared with not pre-ozonated particles. Ozone attack modified active sites on the algal envelope reducing colloidal stability of the cells entailing the enhancement of flocculation after coagulant introduction. The differences in the PSD changes after pre-ozonation observed for the suspensions of two algal species lead to the conclusion that EOM accumulated on the algal envelope can play an important role during agglomeration. EDZWALD and PARALKAR [12] assessed that *Scenedesmus* cells produced 10 times more EOM than *Chlorella* cells. About 70% of EOM prior to ozone attack was of high molecular weight. After ozone attack about 40–50% of the EOM was of intermediate or high molecular weight. The remaining EOM compounds of lower molecular weight on the surface of *Scenedesmus* cells facilitated their flocculation. Small amounts of the *Chlorella* EOM of low molecular weight after ozonation did not affect in any way the cell agglomeration after coagulant introduction.

Chlorophyll bleaching following ozone overdosing indicated damage to the algal photosynthetic apparatus. Algal cells disruption made the coagulation of the system impossible.

4. CONCLUSIONS

1. The PSD of algal discrete particles and agglomerates fitted well to log-normal distribution functions.

2. Coagulation by limited dosage of $FeCl_3$ of both algal suspensions under investigation caused partial agglomeration of discrete particles and appearance of large flocs in the systems.

3. Pre-ozonation modified to some extent granulometric distribution of the algal suspensions after their coagulation by $FeCl_3$. It caused shifts towards smaller particles grouped in the populations I and towards smaller particles in the population II of *Chlorella* suspension and towards larger particles in *Scenedesmus* suspension.

4. The ozone overdosage led to the deterioration of the agglomeration process efficiency and finally to algal cells disruption.

5. Pre-ozonation/ferric chloride coagulation produced algal flocs of a higher compactness than coagulation without pre-ozonation.

REFERENCES

[1] WALKER W.W., *Significance of eutrophication in water supply reservoirs*, Jour. AWWA, 1983, **75** (1), 38–42.

[2] WARDLAW V.E., PERRY R., GRAHAM N.J.D., *The role of algae as trihalomethane precursors – a review*, J. Water SRT-Aqua, 1991, **40**(6), 335–345.

[3] BERNHARDT H., CLASEN J., *Flocculation of micro-organisms*, Water SRT Aqua, 1991, **40**(2), 76–87.

[4] BERNHARDT H., CLASEN J., *Investigations into the flocculation mechanisms of small algal cells*, Water SRT Aqua, 1994, **43**(5), 222–232.

[5] LAWLER D.F., IZURIETA E., KAO C.P., *Changes in particle size distributions in batch flocculation*, Jour. AWWA, 1983, **75**(12), 604–612.

[6] SAUNIER B.M., SELLECK R.E., TRUSSELL R.R., *Preozonation as a coagulant aid in drinking water treatment*, Jour. AWWA, 1983, **75**(5), 239–246.

[7] SUKENIK A., TELTCH B., WACHS W., SHELEF G., NIR I., LEVANON D., *Effect of oxidants on microalgal flocculation*, Wat. Res., 1987, **21**(5), 533–539.

[8] MAIER D., *Microflocculation by ozone. Oxidation techniques in drinking water treatment*, EPA-70/9-79-020, Washington D.C., 1979, 394–417.

[9] CHEDAL J., *Raw water preozonation*, Handbook of Ozone Technology and Applications. Vol. II (Rice R.G. and Netzer A. eds), Butterworth Publishers, 1984.

[10] MATHONET S., CASELLAS C., BABLON G., BONTOUX J., *Impact of preozonation on granulometric distribution of materials in suspension*, Ozone Sci. Engrg, 1985, 7, 107–120.

[11] JANSSENS J.G., VAN HOOF F., DIRICKX J.J., *Comaprative study on preozonation and prechlorination applied in the treatment of surface waters from impounding reservoirs*, AWWA Annual Conference Proceedings, Kansas City, MO, June 15–19.

[12] EDZWALD J.K., PARALKAR A., *Algae, coagulation, and ozonation, chemical water and wastewater treatment II*, Proceedings of the 5th Gothenburg Symposium, Klute R., Hahn H.H. (eds.), Nice, France, 1992, 263–279.

[13] REED G.D., MERY P.C., *Infuence of floc size distribution on clarification*, Jour. AWWA, 1986, 78(8), 75–79.

[14] IRANI R.R., CALLIS F.F., *Particles Size: Measurement, Interpretation and Application*, John Wiley and Sons Inc., N.Y., London, 1963.

[15] SMITH J.E., JORDAN M.L, *Mathematical and graphical interpretation of the log-normal law for particle size distribution analysis*, Jour. Coll. Sci., 1964, **19**, 549–559.

WPŁYW WSTĘPNEGO OZONOWANIA I KOAGULACJI NA ROZKŁAD WIELKOŚCI AGLOMERATÓW GLONOWYCH

Badano aglomerację dwóch rodzajów zielenic następującą w wyniku koagulacji i wstępnego ozonowania. Podczas doświadczeń wykorzystano zielenice *Chlorella pyrenoidosa* i *Scenedesmus quadricauda*. Występują one w zbiornikach, z których pobiera się wodę zasilającą systemy wodociągowe. Do koagulacji zastosowano chlorek żelaza. Wstępne ozonowanie miało poprawić aglomerację następującą w wyniku koagulacji. Wielkości cząstek mierzono, korzystając z komputerowego analizatora obrazu przed i po procesie wstępnego ozonowania i koagulacji. Metoda ta umożliwiła ilościowe określanie wpływu zmiennych dawek ozonu na wielkość i rozkład wielkości aglomeratów glonowych. Stwierdzono, że niewielkie dawki ozonu powodowały zmniejszanie się liczebności pojedynczych cząstek glonów, a jednocześnie rosła liczebność aglomeratów. Obserwowano także przesuwanie się wartości modalnej rozkładów wielkości cząstek w kierunku większych średnic. Gdy dawki ozonu były zbyt duże, wtedy skuteczność procesu zmniejszała się w wyniku destrukcji komórek glonów. Wyniki badań dostarczyły dowodów, że wstępne ozonowanie znacząco zmieniało właściwości powierzchni glonów, poprawiając aglomerację cząstek glonów bez zwiększania dawki koagulantu.