Sizes of flocs were analyzed to identify characteristics of the particle size distribution optimal for separation by dissolved air flotation (DAF). Optical microscopes and two particle counters were used for floc sizing. A Brightwell Technologies particle counter was found to provide floc size measurements in agreement with improved microscopic methods. The particle counter provided distribution of flocs with sizes down to 1 micron (μm). This allowed for inclusion of flocs with size ranging from 5 to 1 μm, which were excluded from the analyses in the earlier study. Four alum dosages were applied: 15, 25, 40, and 60 mg/L. The turbidity and colour of the DAF effluent at alum dosages of 25, 40, and 60 mg/L were very similar. However, the analysis of the flocs in the treated effluent revealed that, at the alum dose of 60 mg/L, particle removal was the best. Therefore, this dosage was selected as optimal for the solid/liquid separation process. The average size of coagulation flocs at 60 mg/L was approximately 30 μm, and was equal to the estimated size of air bubbles produced by the saturator. Therefore, this study confirms the finding of the earlier work claiming that the optimum DAF performance is attained when the mean floc size and the bubble size are equal. Similar size of floc and bubble indicates that flocs act predominantly as nuclei for bubble formation. This finding contributes to the knowledge of mechanisms of floc air bubble attachment in DAF.

Key words: flocs, air bubbles, dissolved air flotation (DAF), microscope-particle counter

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**Introduction**

Chemical coagulation precedes dissolved air flotation (DAF) in the water treatment process. Therefore, the efficiency of the DAF clarification unit is largely determined by the coagulation conditions.

**Coagulation and Flocculation Before DAF**

In water treatment, flotation is not successful without coagulation. Two conditions are necessary for favourable particle flotation in water treatment: (1) particle charge neutralization and (2) particle hydrophobicity (Edzwald 1995). Addition of appropriate doses of chemicals (coagulant) is the most common method for particle charge neutralization. Bubble attachment to particles requires hydrophobic particle surfaces or hydrophobic spots on particles (Goochin and Solari 1983). freshly precipitated or amorphous aluminium hydroxides have polar surface groups and are hydrophilic; however, this hydrophilic effect may be reduced by charge neutralization.

**Review of Floc Sizes in DAF Process**

Different opinions still exist over the optimum floc size for the DAF process and the coagulation conditions related to it. For example, Edzwald et al. (1992) emphasized that long flocculation was not needed, and pin-floc sizes between 10 to 30 μm were most favourable. In his study, the flocculation time of 5 to 15 minutes and a ferric chloride dosage as low as about 25 mg/L was sufficient for successful DAF operation. Edzwald et al. (1992) measured the floc size with a particle counter operating on the light blocking principle. The flocs with diameters ranging from 2 to 120 μm were measured. The average floc diameter for flocculated water was about 15 μm. Although Tambo (1979) and Gorczyca and Ganczarczyk (1995) reported presence of flocs larger than 120 μm at coagulant dosages applied by Edzwald et al. (1992), these large particles were not included in the average floc size calculations. Consequently, the reported average floc size could have been underestimated. The details on the floc sampling and sizing methods are also not provided; for example, it is not clear how ‘floc diameter’ was calculated.

Fukushi et al. (1995) suggested that larger flocs are preferred for the DAF process. Fukushi et al. (1995) measured flocs using a microscope with video photography in a specially designed flow cell. Again, the details on the floc sizing technique are not provided. For example, the authors claim to be able to identify flocs with sizes ranging from 1 to 1,000 μm. Yet, many earlier studies that used the same floc sizing technique were not able to identify flocs smaller than 20 μm (Tambo 1979; Gorczyca and Ganczarczyk 1995). The floc size is also not defined in the paper.

Vlaski et al. (1997) measured sizes of flocs formed in FeCl₃ coagulation prior to DAF. Natural waters spiked with cyanobacteria were used in laboratory and pilot scale DAF experiments. The mean size of flocs at the optimum dose of 10 mg of Fe (III) per litre was about 25 μm. The saturator operated at the pressure of 5 bar (505 kPa) and a 5% recycle ratio. The authors concluded that small, shear-resistant flocs are not necessary for efficient DAF. Larger flocs, formed at a low flocculation velocity
gradient (G) floated as well as the small flocs produced at high G values. Compared with the laboratory scale studies, larger G values had to be applied at the pilot test. This increased flocculation energy input was necessary to create better contact opportunities for the particles in the larger water volumes used in the pilot studies.

Han et al. (2007) measured sizes of particles at several full-scale DAF water treatment plants operating in Korea. A laser particle counter was used. The reported size of particles varied from 1 to 100 μm, with logarithmic averages between 20 to 30 μm.

Sizes of Air Bubbles in DAF

In the DAF unit, typically 5 to 10 % of the raw or treated water is saturated with air under pressure (414 to 586 kPa). The saturated water (recycle) is introduced into the front of the DAF tank by means of specialized nozzles and consequently undergoes a pressure drop. The pressure change results in the formation of small bubbles with diameters between 10 to 100 μm, with most of the bubbles with sizes between 40 to 80 μm (Edzwald 2007).

The operating pressure of the saturator is the main factor affecting bubble size (Han et al. 2002). Han et al. (2002) measured bubbles formed at different saturator pressures using a Laser Trac PC 2400 D particle counter and a microscope coupled with an image analysis system. The reported bubble sizes ranged from 10 to 100 μm. The saturator pressures varied from 2 to 6 atm. The mean bubble size at the saturator pressure higher than 3.5 atm (353 kPa) remained steady at about 30 μm.

Mechanisms of Floc Bubble Attachment and Relationship of Floc and Bubble Sizes

The bubbles may attach to the suspended particles and cause them to float to the surface of the water. The exact mechanism of floc-bubble attachment is not well understood. The preformed bubbles may adhere to a preformed floc, or may become entrapped within the floc. The floc particle may also act as nuclei for bubble formation (Crittenden et al. 2005).

In the first two mechanisms, the bubbles are much smaller than the floc. In the third mechanism, the bubble is about equal to the floc size.

Park et al. (2001) reported that most efficient bubble-particle collision was achieved when the average floc size was close to the bubble size. It was also shown that particles with diameters smaller than 20 μm were not removed easily in the DAF process (Han et al. 2002); the reported removal of these particles was only 10% at a mean bubble size of about 40 μm.

Preliminary Studies with the City of Winnipeg Tap Water

Gorczyca and Zhang (2007) conducted a bench-scale continuous flow DAF experiment using Winnipeg tap water. Three different dosages of alum were applied: 15.5, 25.5, and 41.7 mg/L. Sizes of flocs formed at different coagulant dosages were analyzed to identify characteristics of the particle size distribution optimal for separation by flotation. An alum dose of 25.5 mg/L was found to be optimal based on the best treated effluent.

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**TABLE 1. Operating conditions of pilot and bench scale DAF unit**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pilot plant study results</th>
<th>Bench studies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gorczyca and Zhang</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td>(2007)</td>
<td></td>
</tr>
<tr>
<td>Raw water flow rate (L/min)</td>
<td>-333</td>
<td>1.03</td>
</tr>
<tr>
<td>Raw water temperature (°C)</td>
<td>4–15</td>
<td>7–11</td>
</tr>
<tr>
<td>Alum dosage (mg/L)</td>
<td>60†</td>
<td>15.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>41.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>Coagulation time (sec)</td>
<td>In-line mixing</td>
<td>120</td>
</tr>
<tr>
<td>Flocculation time (min)</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>DAF hydraulic loading rate (m/hr)</td>
<td>10–20</td>
<td>2.2</td>
</tr>
<tr>
<td>DAF saturator pressure (psi)</td>
<td>70–80</td>
<td>90</td>
</tr>
<tr>
<td>Recycle ratio (%)</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Effluent pH</td>
<td>6.6</td>
<td>6.4–6.8</td>
</tr>
</tbody>
</table>

*From Winnipeg Water Consortium 1999.*

†With 2 mg/L of CatFloc 2 polymer and pH adjustment.
turbidity of 0.25 Nephelometric Turbidity Units (NTU) and colour of 3.8 True Colour Units (TCU). At this dose, alum coagulation flocs had the average size of 37 μm. The bubble sizes were not measured in this early study. The average size of the air bubbles in the DAF unit was assumed to be 30 μm based on the bubble measurement conducted by Han et al. (2002) at the same saturator pressure. Therefore, the main conclusion of the Gorczyca and Zhang (2007) study was that the best DAF effluent quality can be attained when floc and bubble size are equal. This finding confirmed the relationship between the floc and the bubble reported earlier by Park et al. (2001) and suggested that it may be true for other water matrices.

Size of the coagulation flocs in this early study was estimated with a microscope using 4 x objectives (40 x magnification). Flocs smaller than 5 μm could not be detected under this magnification and were therefore excluded from the analyses. As a result of this exclusion, the calculated mean floc size may have been overestimated. Also, the average floc sizes were calculated from the measurements of about 200 randomly selected flocs only. This sample size was not statistically designed; it was simply based on the sample size used in the earlier floc sizing studies (Li and Ganczarczyk 1986; Gorczyca and Ganczarczyk 1995).

The operating conditions of the bench-scale DAF unit, such as coagulation/flocculation time, alum dose, saturator pressure, and recycle ration, were based on the pilot-scale DAF unit operated by the City of Winnipeg (Table 1). Yet, the optimum coagulant dosage identified in the pilot study, which is 60 mg/L of alum, was not even tested in the earlier bench-scale study. There were several other differences between the pilot- and bench-scale units used in the study of Gorczyca and Zhang (2007). The bench-scale unit operated at longer coagulation/flocculation detention times and much lower hydraulic loading rates compared with the pilot-scale unit. The effects of these differences were discussed in details elsewhere (Gorczyca and Zhang 2007).

Objectives of this Study

The purpose of this study was to continue earlier research on determining the optimum floc sizes for the DAF separation initiated by Gorczyca and Zhang (2007). The bench-scale DAF apparatus used in the early study was modified to bring the coagulation/flocculation conditions closer in line with the parameters used in City of Winnipeg pilot DAF plant research. Also in this study, the applied alum dose range was increased up to 60 mg/L to include optimum dosages identified during the City of Winnipeg pilot studies.

Another purpose of this study was to determine the reliability of the particle counter for providing accurate measurement of floc sizes. The flocs were sized using two techniques, microscopes, and two particle counters to improve the precision of the mean size estimate. This improved floc sizing technique permitted inclusion of flocs in the range of 1 to 5 μm in the distribution. These flocs were not measured in the earlier study. In this study, particles in the treated effluents were also analyzed to estimate particle removal efficiency in the DAF process.

**Experimental Methods**

**Water Source**

All the experiments were conducted using the tap water at the Environmental Laboratory of the University of Manitoba, Winnipeg, Manitoba (Canada).

**City of Winnipeg water supply.** Drinking water in Winnipeg comes from Shoal Lake, located on the border between Manitoba and Ontario. It is transported via an aqueduct to Deacon Reservoir, an 8,400 million litre reservoir located on the eastern edge of the city. Deacon Reservoir supplies three smaller reservoirs in the city, which, in turn, supply the distribution system. The treatment and storage system currently used in Winnipeg is shown below in Fig. 1. The water treatment system is currently very simple, consisting only of chlorination. In addition to chlorination, fluoride and orthophosphates are added to the water prior to distribution to the public. Beyond this chemical dosing, there are no other treatment procedures (Winnipeg Water Consortium 2001).

The quality of Winnipeg tap water, which is essentially chlorinated raw lake water, is generally within the Canadian Drinking Water Quality Guidelines (Health Canada 2007), but there are several areas in which performance is poor (Table 2). Turbidity can be as high as 2.6 NTU, while the guideline recommends a value below 0.3 NTU. High total organic carbon (TOC) levels in the range of 4 to 17 mg/L are present. Due to the high dose of chlorine (about 7 mg/L), the trihalomethane (THM) concentration ranges from 50 to 205 mg/L, and is frequently over the guideline of 100 ppb (Health Canada 2007). High algae levels in Deacon Reservoir or Shoal Lake are the cause for noticeable taste and odour of the tap water.

Fig. 1. Current drinking water supply system in Winnipeg.
A pilot-scale water treatment plant (WTP) was designed to define a state-of-the-art and cost-effective water treatment process for the City of Winnipeg. It was operated continuously from June 1996 through the spring, summer, fall, and winter Shoal Lake water quality seasons (16 months). Direct filtration and DAF processes were investigated in the pilot studies. The finished water quality goals used in the evaluation of the pilot study performance are listed below:

- Filtered water turbidity, <0.1 NTU;
- Concentration of particles (>2 μm), <20 particles/mL;
- TOC removal, >40%;
- Taste and odour control, <10 Threshold Odour Number;
- Filter water production rate, >200 m³/m².

The DAF process was found to be superior in all the experimental categories investigated. A four-step water treatment process was developed and recommended for Winnipeg (Fig. 2): (1) DAF for suspended solids, mainly algae removal; (2) ozonation for primary disinfection and taste and odour control; (3) biological activated carbon (BAC) filters as a secondary barrier for pathogen and organics removal; and (4) chloramination for disinfection throughout the distribution system (Winnipeg Water Consortium).

### Bench-Scale DAF Apparatus

The bench-scale DAF apparatus used in this study has been described in detail in the earlier study (Gorczyca and Zhang 2007). In this study, several modifications to the operating conditions of the unit were made to match the conditions in the pilot plant. A schematic diagram of the apparatus is presented in Fig. 3.

![Bench-Scale DAF Apparatus](image)

The water depth was decreased from 19.3 cm in the earlier study to 8.7 cm here to achieve a shorter coagulation time. After the raw influent and alum were mixed in the rapid mix chamber, the process water passed to the first of two flocculation tanks. The water depth in the flocculation tanks was decreased, from 39 cm in the earlier study to 26 cm here, to achieve the lower flocculation time of 10 min. Also in this study, the applied alum dose range was increased up to 60 mg/L to include optimum dosages identified during the City of Winnipeg pilot studies. Comparison of the operating conditions of City of Winnipeg pilot- and the bench-scale units used in this and the earlier study is shown in Table 1.

The hydraulic loading rate of the bench-scale DAF unit was 2.3 m/hr, which is much smaller than the typical values in most full-scale DAF units. However, this low hydraulic loading rate is a constraint of the geometry of the apparatus used. Since the flocculation time and hydraulic loading rate in the flotation chamber are both

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**Table 2. Typical quality of Winnipeg tap water**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Winnipeg tap water</th>
<th>GCDWQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity (NTU)</td>
<td>0.3–2.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Colour (TCU)</td>
<td>5–10</td>
<td>&lt;15</td>
</tr>
<tr>
<td>TOC (mg/L)</td>
<td>4–17</td>
<td>No guideline</td>
</tr>
<tr>
<td>THM (μg/L)</td>
<td>50–205</td>
<td>100</td>
</tr>
<tr>
<td>Particles &gt; 2 μm</td>
<td>1000–10,000</td>
<td>No guideline</td>
</tr>
<tr>
<td>Taste and odour (TON)</td>
<td>10–&gt;200</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>


*GCDWQ - Guidelines for Canadian Drinking Water Quality (Health Canada 2007).
Optimization of Solid Separation in DAF

controlled by the flow rate, a higher hydraulic loading rate of 10 to 20 m/hr, more in line with the pilot plant study, would have reduced a flocculation time to only 1 to 2 minutes.

Bench-Scale DAF Operation

The bench scale experiments were conducted in March 2006. Tap water from the Environmental lab at the University of Manitoba was used as the raw water.

The DAF treated effluent was analyzed for turbidity, colour, and pH every 30 minutes during each test run. The samples for particle analysis were collected only when the best and most steady DAF effluent quality was reached. Particles suspended in the raw water were fixed on glass slides using the procedure described elsewhere (Gorczyca and London 2003). Five replicate glass slide samples were prepared from raw water.

The floc samples were collected near the effluent of the second flocculation tank. The sampling point for coagulated samples is shown on Fig. 4 by the arrow. Approximately 1-mL samples containing flocs were withdrawn using a large-mouth pipette and placed in a Petri dish. Three replicate Petri dishes were prepared for each coagulant dosage. The samples were diluted with tap water to prevent the flocs from coming into contact with each other in the Petri dish.

DAF effluent samples were collected from the spigot as shown in Fig. 5. The sludge was skimmed off from the water surface manually at 15-minute intervals.

Particle Size Measurements

Microscopic analysis. Microscope particle size analysis was performed for the influent raw water and coagulated water; however, only sizes of coagulation flocs were used in the treatment performance evaluation. A standard trinocular polarizing microscope (Nikon 400) was used to view the influent samples, while a stereoscopic microscope (Nikon SMZ 800) was used to view the coagulated samples.

Fig. 3. Bench-scale DAF apparatus used in this study.

Fig. 4. Bench-scale DAF apparatus: flocculation tanks.
Particles in raw water. Samples of raw water fixed on a glass slide were photographed under 400 x magnification (40 x objective lens) using a Nikon 400 microscope connected to a digital microscope camera (Olympus DP70). The images of particles were saved for further measurements with an image analysis system, Image Pro Plus version 4.5 (Media Cybernetics Inc. 2002). For particle image detection and sizing, an automatic mode, was chosen. The system was calibrated according to the procedure described in the image analysis system manual. The projected area (cross-sectional area) of the particles was measured and the equivalent diameter was calculated as follows:

$$
\text{Equivalent diameter} = \left(\frac{4 \cdot \text{Projected area}}{\pi}\right)^{1/2}
$$

To obtain representative distribution of particle and flocs from the microscopic analyses, all particles identified on 20 randomly selected fields of views were measured (Parker 1972). Particles with equivalent diameters ranging from 1 to 70 μm could be identified at 400 x magnification. Particle measurement techniques are described in more detail elsewhere (Gorczyca and London 2003; Gorczyca and Zhang 2007).

Coagulation flocs. The stereoscopic microscope allowed direct observations of coagulation flocs without agar embedding. Alum flocs are almost translucent, and small flocs blend in well with an agar background. Flocs were measured at a magnification of 63 x using the same procedure as for raw water particles. Flocs with equivalent diameters ranging from 3.5 to 350 μm could be measured at this magnification.

Particles in DAF effluent. The particles in the DAF treated effluent were not analyzed with the microscopes for reasons explained later.

Particle Counter Analyses

Two particle counters were used to analyze particles in tap water, coagulated water, and DAF effluent. The Spectrex PS-2200 uses laser light scattering technology, and it can be used to measure particle size and concentration in a sample automatically. About 25 mL of a floc-containing sample was placed in the measurement compartment. Before each reading, the sample was gently agitated for 30 seconds.

The Brightwell Technologies Dynamic counter (DPA 4100) works on the principle similar to microscopic analyses: particles in the suspension are photographed and analyzed automatically by the image analysis system (Brightwell Technologies Ltd. 2007). Both particle counters could measure particles down to an equivalent circular diameter of 1 μm.

Results and Discussion

Table 3 shows the treated water quality and sizes of particles obtained in this study. For comparison, the results obtained in the earlier study by Gorczyca and Zhang (2007) are also shown in Table 3.

Figure 6 shows alum coagulation floc size distributions as obtained with the Spectrex particle counter. Figure 7 shows a typical floc size distribution as obtained with the Brightwell Dynamic particle counter. The average floc sizes obtained with the microscope and the Brightwell Technologies counter were reasonably close, within 0.5 to 2.2 μm. This indicates that the Brightwell particle counter can be used to determine distributions of flocs larger than 1 μm.

Unlike the microscopic analyses, the determinations with particle counters are quick and do not require sample preparation, and, therefore, the particles in DAF effluent were measured using the particle counters only. The highest difference in the average particle size as measured using the particle counter and the microscopes was found for raw (tap) water. That could be due to the fact that many particles in the tap water were algal filaments. The particle counter will report different sizes of such elongated particles depending on the particle orientation. Therefore, the results obtained for tap water presented in this paper are not used in any further analyses and comparisons.

The DAF effluent colour and turbidity after coagulation with 25, 40, or 60 mg/L of alum was very similar. After 60 mg/L of alum, the concentration and size of particles in DAF effluent were the smallest (Table 3). This indicates that the particle removal was best at 60 mg/L. Therefore, the dose of 60 mg/L of alum was considered optimum for solid/liquid separation in the DAF unit in this study. At this dosage, the mean size of coagulation flocs was found to be about 30 μm.
Several novel microscopic floc sizing procedures have been introduced in this paper as compared with the earlier study conducted by Gorczyca and Zhang (2007). The stereoscopic microscope (Nikon SMZ 800) used for floc sizing in this study allowed for elimination of agar which improved detection of flocs smaller than 5 μm. Application of the particle counter further improved detection of small particles down to an equivalent diameter of 1 μm. Particle counters used in this study also allowed for rapid measurements of the particles in the DAF treated effluent and provided information on particle removal efficiency. In this study, significantly

### Table 3: Bench scale DAF study results

<table>
<thead>
<tr>
<th>Alum dosage (mg/L)</th>
<th>DAF effluent (this study)</th>
<th>Coagulation floc average size (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Turbidity (NTU)</td>
<td>Colour (TCU)</td>
</tr>
<tr>
<td>0</td>
<td>0.73</td>
<td>4.0</td>
</tr>
<tr>
<td>15</td>
<td>1.65</td>
<td>3.5</td>
</tr>
<tr>
<td>25</td>
<td>0.67</td>
<td>2.5</td>
</tr>
<tr>
<td>40</td>
<td>0.88</td>
<td>2.2</td>
</tr>
<tr>
<td>60</td>
<td>0.68</td>
<td>2.5</td>
</tr>
</tbody>
</table>

\(^a\) As measured by Spectrex PS-2200.  
\(^b\) n.a. = not applicable.

Fig. 6. Alum floc size distributions at different coagulant dosages as obtained with Spectrex PS-2200 particle counter.

Fig. 7. Typical alum floc size distribution as obtained with Brightwell Technologies Dynamic particle counter (DPA 4100).
larger numbers of flocs have been measured as the random floc sampling was conducted based on the statistical design.

As a result of these significant improvements to the operation of the DAF unit and particle sizing procedures, a dosage of 60 mg/L of alum was considered optimum as compared with 25 mg/L selected in the earlier paper (Gorczyca and Zhang 2007).

Floc to Bubble Size Relation

The sizes of air bubbles were not measured in this study. Assuming the average size of the bubbles of 40 μm (Edzwald 1995, 2007), the average sizes of flocs was smaller but close to the size of the air bubbles produced by the saturator. Unfortunately, the estimates provided by Edzwald are not based on measurement of bubble sizes; these numbers simply provide some guidelines as to the bubble size range.

Han et al. (2002) actually measured bubble size, and provided distribution of these sizes. The reported distribution of sizes of bubbles at the saturator pressure of 550 kPa in DAF at the saturator pressure of is lognormal, with the mean size around 30 μm, which is smaller than the average bubble size suggested by Edzwald (2007).

In this study, the mean floc size at the optimum dosage of 60 mg/L was about 30 μm and was similar to the mean size of the air bubble measured by Han et al. (2002). Similar size of floc and bubble indicates that flocs act predominantly as nuclei for bubble formation.

Comparison of Bench- and Pilot-Scale DAF Studies

There were many differences between the bench- and pilot-scale DAF studies besides those listed in Table 1. The pilot study influent water was taken directly from Deacon Reservoir and contained less chlorine than the Winnipeg tap water. Additional chlorine content in the water may have reduced the coagulant demand in the bench-scale study. Coagulant aid and pH adjustment were applied in the pilot-scale but not in the bench-scale study described in this paper. In addition, the selection of optimum dose in the pilot study was based not only on turbidity and colour, but also on the removal of the TOC. TOC was not analyzed in this study due to the lack of laboratory equipment. Despite many differences between the DAF pilot- and the bench-scale study described in this paper, the same optimum coagulant dosages were found in both cases.

Conclusions

Bench-scale DAF experiments were conducted to study optimal floc size distribution for separation in flotation. Tap water in the City of Winnipeg, Manitoba, (Canada) was used in the tests. The following conclusions were made:

1. The average floc sizes obtained with the microscope and the Brightwell Technologies counter were reasonably close, within 0.5 to 2.2 μm. This indicates that the Brightwell particle counter can be used to determine distributions of flocs larger than 1 μm. Unlike the microscopic analyses, the determinations with particle counters are quick and do not require sample preparation.

2. Analyses of particles in the DAF effluent indicated that at the coagulation with 60 mg/L of alum, the removal of particles was best; therefore, this coagulant dosage was considered optimal. The average size of floc at the dose of 60 mg/L of alum was about 30 μm. This is similar to the size of the bubbles measured at the pressure of 530 kPa reported in the literature.

3. Predominantly similar size of floc and bubble indicates that during the optimal DAF operation, flocs act as nuclei for bubble formation.

Acknowledgments

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