Water Research 147 (2018) 25–32

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

Selection of media for the design of ballasted flocculation processes

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ARTICLE INFO

Article history:
Received 14 June 2018
Accepted 25 September 2018
Available online 27 September 2018

Keywords:
Ballasted flocculation key criteria
Ballast media
Specific gravity
Surface concentration
Turbidity removal
Floc size

ABSTRACT

Conventional clarification processes imply specific facility footprints that translate into important capital costs. Ballasted flocculation, consisting of injecting ballast medium to increase floc specific gravity and size, is being increasingly used in the water industry owing to its potential for design with very high superficial velocities. However, no systematic approach has yet been proposed to compare and select an appropriate ballast medium with respect to its specific gravity and size. In order to facilitate this procedure, this research project explores the hypothesis that flocculation performance is controlled by the surface area of the medium available for ballasted flocculation. This hypothesis was tested at laboratory scale by evaluating five ballast media with differing specific gravity and size: granular activated carbon, anthracite, silica sand, ilmenite, and magnetite sand having specific gravities of 1.24, 1.45, 2.62, 3.70, and 5.08, respectively. Flocculation kinetics were monitored by measuring floc size through microscopy and with a camera installed directly on the jar-test beaker. Settling performance was monitored using turbidity measurements. This study shows that all ballast media, when expressed as total surface available during flocculation, required similar surface concentrations to achieve settled water turbidity near 1 NTU and lower. In addition, the effects from the ballast media size and specific gravity were lowered for settling time longer than 3 min. Inversely, for settling time of 12 s, larger and denser media produced lower settled water turbidity. For certain applications, lighter ballast media may be more economical because they offer more available surface area for a given mass concentration, hence reducing the amount of ballast media required in the flocculation tank. Finally, the ballast media point of zero charge and shape were not identified as key criteria for ballasted flocculation.

1. Introduction

Clarification processes require specific footprints that translate into important capital costs, especially in the Nordic climate where settling basins must be located inside heated buildings. Ballasted flocculation, consisting of injecting micron-sized granular media to increase the specific gravity (SG) and size of flocs, is being used increasingly in the water industry owing to its potential for achieving very high superficial design velocities (as high as 85 m/h; MDDEP (2009)). This advantage offers a more compact process (i.e., smaller footprint), stable suspended solids removal performance, faster start-up, and important savings compared to conventional flocculation (Desjardins et al., 2002; Guibelin et al., 1994). In earlier studies, we showed that the floc SG and size were two important factors for predicting settling performance (Lapointe et al., 2017). The final SG of flocs depends on the SG of the medium: a denser ballast medium (BM) leading to denser flocs. However, a denser medium requires a higher velocity gradient (i.e., *G* value in s^{-1}) to maintain it in suspension. This leads to lower average floc diameters owing to floc break-up, and to higher fraction of unballasted flocs. Therefore, with reference to the design criteria (minimizing footprint or minimizing settled water turbidity); an optimal BM can be selected for a given application.

The concentration of BM inside the flocculation tank (typically referred to as the maturation tank) is very high, in the range of 4–10 g silica sand (SS)/L for industrial applications. The BM concentration depends on the particle concentration in the flocculated waters (which is linked to the coagulant dosage and the source-water particle concentration). For example, in jar testing, a higher BM concentration was necessary for a wastewater application compared to a drinking water application (2 g of SS/L for surface water of 12 NTU and 3 g of SS/L for municipal wastewater of 130 NTU (Lapointe and Barbeau, 2017; Lapointe et al., 2017)). Apart from the BM concentration, its particle size distribution is also expected to impact ballasted media performance. A medium of

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https://doi.org/10.1016/j.watres.2018.09.041
0043-1354/

smaller particles translates into a higher number of available BM particles for a given mass concentration. Flocculation performance is known to be a function of $G \times t \times N_o$, where G is the mean velocity gradient, t the flocculation time, and No, the initial number of particles to flocculate. However, large BM media can produce larger flocs, which settle more rapidly. Consequently, similar to the selection of a BM SG, there is an optimum selection of the medium size to achieve the best overall flocculation/settling performance.

In summary, the selection of an appropriate BM medium is dictated by its SG, size, and the need to minimize un-ballasted flocs. This is because the latter are not well removed during settling at high superficial velocity. In addition, BM availability and cost, its resistance to abrasion, and the effectiveness of its recovery by hydrocyclone are important criteria to consider (Desjardins et al., 2002; Sibony, 1981; Young and Edwards, 2003). However, no systematic approach has yet been proposed to compare and select an appropriate BM with respect to its SG and size for a given application. In order to facilitate this procedure, this research project explored the hypothesis that flocculation performance is controlled by the surface area of BM available for ballasted flocculation, expressed as m^2 of surface per L of water. We hypothesized that differing media density and particle size distributions impact ballast media performance by increasing/reducing the reaction surface. This hypothesis was tested at laboratory scale by evaluating five ballast media with differing SG, all of which were sieved to produce three different particle size distributions. Flocculation kinetics were monitored by measuring floc size by microscopy and with a camera installed directly on the jar-test beaker. Settling performance was monitored using turbidity measurements. Recommendations are made for guiding the selection of an adequate BM to achieve turbidity removal for a specific design superficial velocity.

2. Material and methods

2.1. Water characteristics

All experiments were conducted at laboratory scale at 21 ± 1 °C using surface water from the Sainte-Rose drinking water treatment plant (10 ± 2 NTU; pH 6.9), which is fed by the Mille-Îles River (Quebec, Canada). The tested surface water exhibits a relatively low alkalinity (30 mg $CaCO_3$/L) and a significant dissolved organic carbon (DOC) concentration (6.9 mg C/L). The raw water was collected just past the 10 mm influent bar screens and refrigerated at 4 °C during the experiments (2 weeks).

2.2. Jar test procedure

The jar test sequence and protocol sampling are presented in Fig. 1. Jar tests were performed in Phipps & Bird equipment (Richmond, VA) equipped with six square *B-Kers*^{TM} jars of 2 L, each having a sampling port 10 cm from the top. Water samples were first flash mixed ($G = 300\ s^{-1}$) during 2 min at 21 °C with a simultaneous injection of alum (2.73 mg Al/L = 30 mg dry alum/L) and a pre-hydrolyzed coagulant (polyaluminum chloride PAX XL6 with a 56% basicity; 0.40 mg Al/L). Optimal coagulant conditions were chosen based on settled water turbidity, pH, and streaming current value (SCV; Chemtrac® Systems, Inc.; ECA-2100 charge analyzer). This dual injection strategy is currently used at the full-scale plant to improve coagulation/flocculation performance, especially under cold water conditions. The pH targeted after coagulation was 6.15 ± 0.05. Hydrex 3551 polymer (Veolia Water Technologies Canada), an anionic and high molecular weight polyacrylamide (PAM), was used to bridge BM with coagulated microflocs (mean diameter < 10 μm). The optimal PAM dosage selected was 0.4 mg/L because this provided the lowest settled water turbidity for all BM without causing floc restabilization. The BM was entirely injected at the onset of flocculation (i.e., after the 2-min flash-mix). The PAM dosage was equally divided: 50% at the onset of flocculation and 50% after 30 s (Fig. 1; expressed in min). After additional floc maturation of 30 s, turbidity measurements were assessed on settled waters after 12, 60, and 180 s of settling (Turbidimeter, Hach 2100N, SM 2130 B (APHA, AWWA, & WEF, 2012)). Approximately 12 s corresponds to a typical superficial velocity of 40 m/h as used for industrial application. In this case, 60 and 180 s were selected to simulate intermediate and lower superficial velocity (Desjardins et al., 2002). BM dosages spanning from 0.2 to 7.0 g/L were tested.

2.3. Floc analysis

Flocs size and SG were characterized during flocculation by optical microscopy with a counting cell of 2 mm depth, as described in Lapointe and Barbeau (2016b). To evaluate the floc rate of aggregation, a camera (FlocCAM™; time exposure: 1/1000 s) was also installed on the jar-test beaker. This equipment measured the mean floc equivalent diameter as function of time (Lapointe and Barbeau, 2017). Because the floc properties impact this analysis, the equipment was first calibrated using optical microscopy measurements as a benchmark.

2.4. Media properties

The media characteristics are presented in Table 1. Five different BM with SG ranging from 1.24 to 5.08 were evaluated: granular activated carbon (GAC), anthracite (ANT), silica sand (SS), ilmenite (IL), and magnetite sand (MS) (Table 1). All five media were sieved to generate three particle size distributions: 80–125 μm ($\overline{D}$:103 μm), 125–160 μm ($\overline{D}$:143 μm), and 160–212 μm ($\overline{D}$:186 μm).

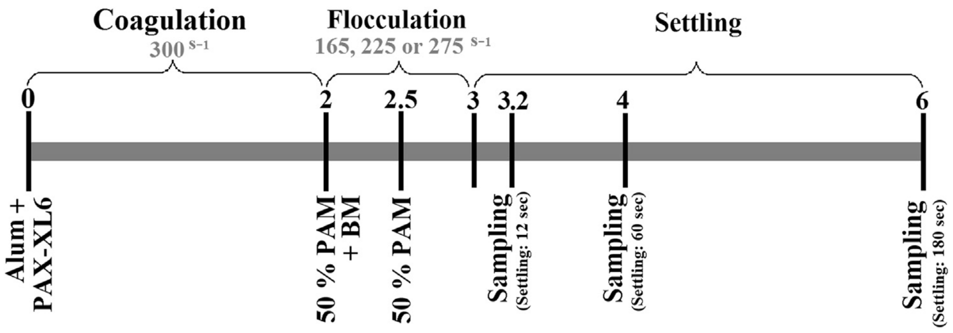

Fig. 1. Jar test and sampling sequence.