Activated starch as an alternative to polyacrylamide-based polymers for in-line filtration of low turbidity source water

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ABSTRACT

Polyacrylamide-based polymers are commonly used as coagulant aids in water treatment, but there is some concern about their potential toxicity. This work investigated a novel alternative, Hydrex[TM] 3841 activated starch polymer, as a coagulant aid for alum to treat low turbidity source water at pilot scale using in-line filtration. Compared to two typical polyacrylamide-based polymers, Magnafloc® LT22S and Superfloc® A-100, at an alum dose of 0.95 mg Al/L, activated starch could reach a similarly optimal unit filter run volume ($\sim$116 m^3/m^2), while the required dose (0.48 mg/L) was approximately 2–10 times higher than those for the other two types of polymers. Since polymer cost has been reported to be a minimal proportion of the total chemical cost at a water treatment plant, activated starch may be a promising alternative to polyacrylamide.

Key words | in-line filtration, low turbidity, polyacrylamide, polymer, starch

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INTRODUCTION

In-line filtration is a water treatment process that includes coagulation but no subsequent flocculation and sedimentation. It is suitable to treat low turbidity source water at a lower cost with simpler operation than that of a conventional process (McCormick & King 1982; Edzwald *et al.* 1987; Ngo *et al.* 1995). A previous study (results to be published elsewhere) indicated that in-line filtration was capable of clarifying a typical source water with a turbidity of 1.5 NTU originating from the Canadian Rocky Mountains, when using alum associated with a polyacrylamide-based polymer, Magnafloc® LT22S. However, the use of polyacrylamide as a coagulant aid has drawn more concern recently. Its monomer, acrylamide, which may be contained in commercial polyacrylamide products, has been reported to be toxic to humans and animals (Rice 2005; Bolto & Gregory 2007). A large fraction of acrylamide ingested by both rats and mice can convert to glycidamide, a genotoxic and carcinogenic epoxide compound, in their bodies. Epidemiologic studies also indicate cancer risk in humans after exposure to acrylamide (Rice 2005). As a result, the acrylamide concentration in drinking water has been regulated by multiple countries, such as the USA and UK. The limit is suggested to be less than 0.5 μg/L, which can be reached by 1 mg/L polyacrylamide containing 0.05% monomer by weight (USEPA 2009; WHO 2011).

Activated starch polymer manufactured from potato starch is recognized to be non-toxic, biodegradable, and cost-effective (Lapointe & Barbeau 2015). To activate the product, dry starch polymer needs to be dissolved into water using a high shear rotating impeller (approximately 3,000–3,500 rpm) until a homogeneous solution is obtained in approximately 15–30 min. However, as a relatively new product, the investigation of its performance in water treatment is limited. Lapointe & Barbeau (2015, 2016) explored the potential application of activated starch in ballasted flocculation and found that it could reduce water turbidity to a

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level comparable to that of polyacrylamide under parallel conditions. In theory, similar to synthetic polymers, when activated starch is used as a coagulant aid, the polymer chains can adsorb particles and bridge them together (Bolto & Gregory 2007). Therefore, the performance of activated starch depends highly on the particle characteristics and concentrations, leading to possibly variable performance of this product in different waters and treatment processes. In the previous studies reported by Lapointe & Barbeau (2015, 2016), activated starch effectiveness was only investigated in jar tests simulating ballasted flocculation conditions at raw water turbidities higher than 2.5 NTU. Their results are unlikely to be appropriate to make an accurate prediction for in-line filtration treating low turbidity source water that is commonly found in western Canada. This study was thus carried out in this scenario using a pilot-scale filter plant, and to expand our horizons of the potential application of this product as an alternative to the traditional polyacrylamide.

METHODS

Experimental setup

The details of the experimental equipment were described by Scott (2008). In brief, a pilot-scale in-line filtration plant located at the Glenmore Water Treatment Plant (Calgary, Canada) was used to carry out the experiments from January to March, 2017. Raw water to be treated was taken from the Elbow River, originating from the Rocky Mountains, with temperature of ~1 °C, pH of ~7.7, turbidity of ~0.7 NTU, and total organic carbon (TOC) of ~0.9 mg/L. During the experiments, raw water quality was constant with a standard deviation of turbidity of ~0.08 NTU. It is noted that turbidity in treated water was monitored, while unfortunately TOC was not, because of the lack of analytical instrument access. However, Lapointe & Barbeau (2015) indicated that TOC was reduced after the treatment with addition of activated starch. A similar trend of TOC reduction could be anticipated in this study. The water was first dosed with alum and a polymer (to be specified below) through static mixers, as well as sodium hypochlorite at ~1 mg/L as free chlorine to suppress microorganism growth in filter media.

The water was then distributed to two parallel filter columns (7.6 cm in inner diameter, named Columns 1 and 2) that contained dual media with an anthracite layer on the top (depth: 45.7 cm, effective size: 1.0–1.1 mm) and a sand layer underneath (depth: 30.5 cm, effective size: 0.45–0.50 mm). The filters ran in the mode of constant head (3.65 m) and declining filtration rate (decreasing from approximately 15 to 12 m/h). Turbidities and particle counts in the upstream and downstream of the filters were monitored continuously using in-line turbidimeters (model: 1720E low range, Hach Company) and in-line particle counters (model: 2200 PCX, Hach Company), respectively.

Chemical addition

Alum (prepared from a concentrated solution provided by Chemtrade Logistics Inc.) was used as the coagulant at 0.95 mg Al/L, which was determined to be the optimal dose based on a preliminary jar test and a zeta-potential analysis, as well as preliminary pilot-scale tests (results not shown). Alum was dosed associated with one of three types of polymers, including: Magnafloc® LT22S (a low cationic and high molecular weight polyacrylamide-based polymer, industrial grade, provided by BASF Canada Inc.), which was used at the Glenmore Water Treatment Plant, Superfloc® A-100 (a low anionic and high molecular weight polyacrylamide-based polymer, industrial grade, provided by Kemira), which is also a commonly used polymer, and Hydrex™ 3,841 (a low anionic and low molecular weight starch polymer, industrial grade, provided by Veolia Water Technologies Canada), which is commercially available and was suggested to be the optimal type of starch polymers by Lapointe & Barbeau (2015). The concentration ranges tested in this work were 0.01–0.14, 0.02–0.36, and 0.08–0.56 mg/L as product for Magnafloc LT22S, Superfloc A-100, and Hydrex 3841, respectively, determined based on their effects to be discussed in detail later.

Filter column operation

A filtration cycle was started after a fresh backwash. The ripening period was determined as the duration from the beginning of the cycle to the point when the filtrate turbidity and particle count both decreased to below 0.1 NTU and 50

counts/mL, respectively. The filter run entered into a stable period after successful ripening until one of three termination criteria was met, whichever was earlier: effluent turbidity >0.1 NTU, effluent particle count >50 counts/mL, or headloss >2.0 m.

RESULTS AND DISCUSSION

As shown in Figure 1, successful ripening was observed when Magnafloc LT22S, Superfloc A-100, and Hydrex 3841 doses were higher than 0.02, 0.16, and 0.36 mg/L, respectively, indicating that polymer addition with a sufficient amount was necessary for ripening and for producing acceptable effluent quality. The minimum dose of Hydrex 3841 required for successful ripening was higher than those of the other two polymers. In addition, the shortest ripening time for Hydrex 3841 (∼31 min) was longer than those for Superfloc A-100 (∼19 min) and Magnafloc LT22S (∼16 min), observed when the three polymers were dosed at 0.40, 0.36, and 0.10 mg/L, respectively. Ripening happens when clean filter media captures particles and becomes more efficient at capturing additional particles. The process is influenced by the interactions among alum, polymer, particles, and filter media. The details of this mechanism related to the specific polymers were beyond the scope of this study.

When the filter was producing water with acceptable quality (turbidity <0.1 NTU and particle count <50 counts/mL), the duration was counted as the effective run time. The corresponding unit filter run volume (UFRV) was considered to be the effective UFRV (unit: m^3/m^2), which is illustrated in Figure 2.

According to Figure 2, each polymer had an optimal dose to achieve the highest effective UFRV. The optimal doses for Magnafloc LT22S, Superfloc A-100, and Hydrex 3841 were 0.05, 0.24, and 0.48 mg/L, respectively, corresponding to effective UFRVs of 144, 111, and 116 m^3/m^2, and effective run times of 10.5, 8.5, and 8.5 h. These UFRVs were lower than the full-scale values (150–200 m^3/m^2), primarily because a clarification tank was applied upstream of filtration at full scale, where most of the flocs were removed to reduce the filter headloss accumulation rate. The best performance under the tested conditions was associated with Magnafloc LT22S at a concentration of 0.05 mg/L. This polymer was used at the full-scale plant. On the other hand, Superfloc A-100 and Hydrex 3841 could almost reach the same filtration performance as Magnafloc LT22S, except that the doses required for Superfloc A-100 and Hydrex 3841 were approximately 3–5 times and 8–10 times higher, respectively. If it is conservatively assumed that all solids in the water were captured by the filter media, then with a UFRV of 100 m^3/m^2 (a round number close to the optimal values), there were 5, 24, and 48 g of Magnafloc LT22S, Superfloc A-100, and
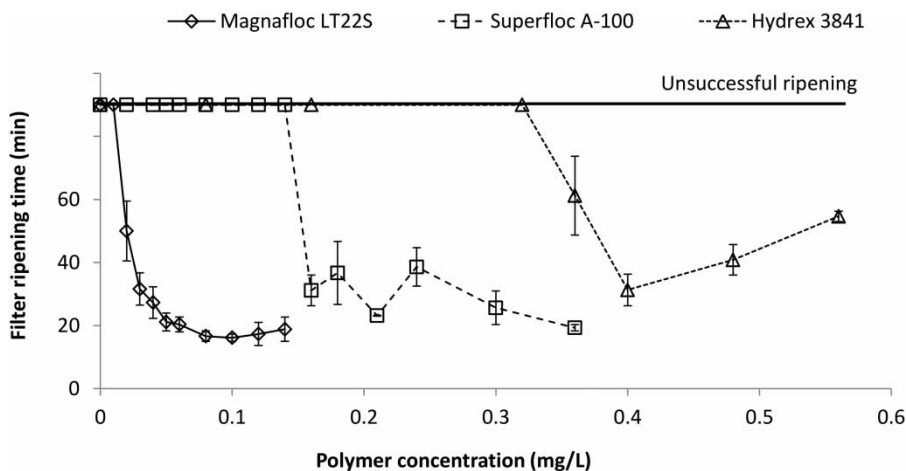

Figure 1 | Relationship between polymer dose and filter ripening time. Points on the bold horizontal line represent the dosing conditions where unsuccessful ripening was observed. Error bars stand for the duplicates obtained simultaneously from Columns 1 and 2 running in parallel. The running sequence for each polymer type was in random order.
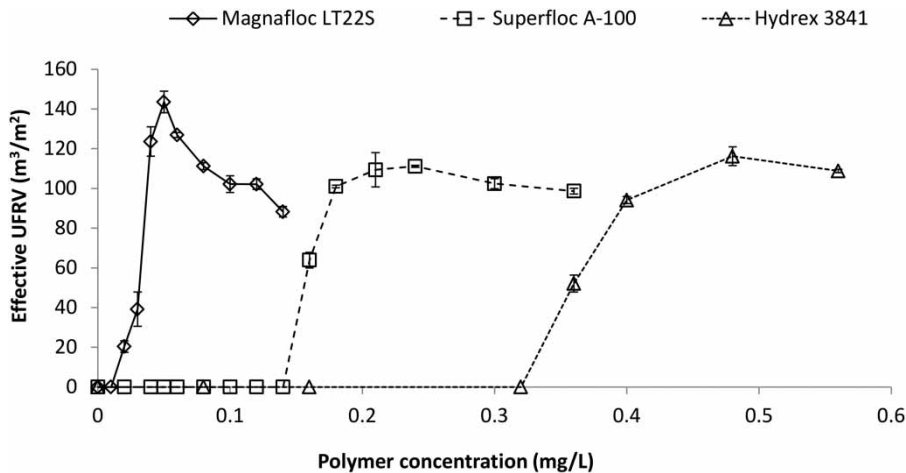
Figure 2 | Effective unit filter run volume (UFRV) varied with polymer types and concentrations. Error bars stand for the duplicates obtained simultaneously from Columns 1 and 2 running in parallel. The running sequence for each polymer type was in random order.

Hydrex 3841, respectively, intercepted per filter unit area (1 m^2) at their doses of 0.05, 0.24, and 0.48 mg/L, respectively. Thus, the amount of sludge associated with Hydrex 3841 was highest. Lapointe & Barbeau (2015) found that the Hydrex 3841 concentration was approximately four times higher than that of Superfloc A-100 to reach a comparable performance. However, their results were obtained from jar tests simulating ballasted flocculation, under conditions very different from this work. Based on the evaluation made by Lapointe & Barbeau (2015) that the polymer cost used for flocculation is less than 1% of the total chemical costs in conventional processes and the assumption that in-line filtration requires chemical doses similar to those in conventional processes, to apply a higher dose of Superfloc A-100 or Hydrex 3841 would not significantly influence the overall plant operating cost. However, sludge processing cost would increase, and would have to be considered.

In theory, when a polymer with a low charge density is applied, the polymer chain will stretch and absorb particles to bridge them together. The formed flocs are then strengthened, and flocculation and filtration processes become more efficient (Adin *et al.* 1979; Yeh & Ghosh 1981). This bridging mechanism is related to the observations that a higher dose of Hydrex 3841 was required to reach equivalent performance, compared to those of Superfloc A-100 and Magnafloc LT22S. As indicated by Lapointe & Barbeau (2015), a polyacrylamide molecule has a structure more linear than starch, leading to a longer polymer chain and a higher molecular weight, which results in a higher efficiency of polyacrylamide in bridging particles. However, no quantitative analysis of the chain length and molecular weight of activated starch has been reported. Furthermore, the interactions between polymer and particles are believed to be complicated, which are outside the scope of this work.

CONCLUSIONS

Among the three tested polymer types used for in-line filtration, Magnafloc LT22S was the best in the presence of 0.95 mg Al/L alum, while Superfloc A-100 and Hydrex 3841 could also reach a similar performance under most dosing conditions with optimal UFRVs of 110–116 m^3/m^2. However, to achieve equivalent performance, Hydrex 3841 required a higher dose, approximately 2 and 8–10 times higher than Superfloc A-100 and Magnafloc LT22S, respectively. Considering that polymer cost is minimal compared to the total chemical cost at a water treatment plant and the activated starch is greener than polyacrylamide-based polymers, activated starch polymer is a potential alternative, and is worth being investigated further.

It is noted that this short technical report was based on a case study with a single water. Although the results are limited, they are valuable in terms of supplementing the previous limited studies, and help to contribute

incrementally to a better understanding of the performance envelope of this newly emerging treatment chemical. In addition, further study is suggested to examine potentially negative side effects of residual starch, such as changed chlorine demand or DBP formation, so that both strengths and limits of this product can be understood.

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