Strategies of coagulant optimisation to improve the removal of turbidity and *Ceratium hirundinella* cells during conventional drinking water purification

H. Ewerts, S. Barnard, A. Swanepoel, H. H. du Preez and S. Janse van Vuuren

**ABSTRACT**

The dinoflagellate, *Ceratium hirundinella* (*C. hirundinella*) cells are known to cause many problems when source water due for purification contains relatively high concentrations. The objective of this study was to investigate strategies for the effective and simultaneous removal of turbidity and *C. hirundinella* cells using turbidity and total photosynthetic pigments (TPP) as indicators of appropriate coagulant dosages during conventional drinking water purification. Source water samples with low turbidity, and high number of *C. hirundinella* cells were collected. A laboratory-scale conventional water purification plant was used to simulate coagulation, flocculation, sedimentation and sand filtration. Various coagulant options were dosed as part of conventional coagulation. The coagulant option Ca(OH)$_2$–organic polymer achieved the best removal of both turbidity (50%) and *C. hirundinella* cells (75–82%) after sedimentation using TPP as an indicator. Ca(OH)$_2$–SiO$_2$ and organic polymer alone achieved better removal of *C. hirundinella* (57–75%) and turbidity (33–50%) respectively when TPP was used as an indicator rather than turbidity. Sand filtration removed the remaining turbidity and *C. hirundinella* cells from the supernatant completely. Implementing new purification strategies may increase treatment costs, but the focus of drinking water purification utilities should always be primarily the production of safe and aesthetically acceptable drinking water.

**Key words** | lime, organic polymer, photosynthetic pigments

**INTRODUCTION**

Different water purification processes are used in sequence in order to produce drinking water of desired quality (Schutte 2006). Water purification plants can either be conventional or advanced in design and operation. In conventional water purification works, suspended matter is removed in clarifiers or sedimentation tanks and sand filters after coagulation and flocculation (Schutte 2006). The primary aim of coagulation and flocculation is to remove suspended and dissolved particles that may be undesirable in the final effluent (Leopold & Freese 2009). Research on conventional water purification processes such as coagulation, flocculation, sedimentation and filtration contribute to a better understanding of these processes and improves performance (Schutte 2006).

The choice of purification processes to produce drinking water will be influenced or governed by the quality of source water and the quality standards that must be met (Prévost et al. 2005). The quality of source water may be influenced by a number of factors, such as suspended matter clay, fine particulate matter, colloids, organic and inorganic precipitates (Schutte 2006). Algae and cyanobacteria (phytoplankton) form part of organic suspended matter in water. Phytoplankton cells such as the dinoflagellate *Ceratium hirundinella* (*C. hirundinella*) are known to cause major water purification problems, especially during bloom forming periods (Pieterse et al. 2000; Swanepoel et al. 2008a).
C. hirundinella is found in some of South Africa’s fresh water impoundments such as the Hartbeespoort Dam (Van Ginkel et al. 2001), Vaal River (Swanepoel et al. 2008a) and Albert Falls Dam (Hart & Wragg 2009). The frequency of occurrence and concentration of C. hirundinella during spring and autumn has increased significantly, especially in the Vaal River catchment. C. hirundinella cells are described to be relatively large in size, up to 450 μm long and 30–100 μm wide (Janse van Vuuren et al. 2006). Due to large cell size, it contributes significantly to total photosynthetic and accessory pigment concentrations in the source water (Van Ginkel et al. 2001; Swanepoel et al. 2008a; Hart & Wragg 2009). Photosynthetic and accessory pigments associated with the dinoflagellate, C. hirundinella are green pigments (e.g. chlorophyll-α and -b) and golden-brown pigments known as peridinin (Janse van Vuuren et al. 2006).

Characteristics of phytoplankton cells such as morphology, motility, surface charge and cell density have been reported to influence the performance of water purification works (Henderson et al. 2007). Coagulation is mostly affected by the changes in phytoplankton characteristics, but is considered as the main process in removal of phytoplankton during water purification (Henderson et al. 2007). Pieterse et al. (2000) concluded that flagellated cells, such as C. hirundinella are more difficult to remove, because they prevent floc formation and consequently avoid removal by sedimentation. When C. hirundinella is present in high concentrations in the source water, many water purification problems arise, like the disruption of floc formation, clogging of sand filters and the production of fishy taste and odours that may penetrate into the final drinking water.

Turbidity removal experiments by means of jar stirring tests are often applied to determine the appropriate coagulant dosages (Bolto 1995; Zhu et al. 1995; Eikebrokk et al. 2006; Liu et al. 2006). However, the settling turbidity after sedimentation achieved by jar stirring test experiments or in water purification works does not necessarily indicate the removal of phytoplankton cells (e.g. C. hirundinella). In contrast, total photosynthetic pigment (TPP) removal has shown a better correlation with C. hirundinella cell removal (when compared to turbidity after sedimentation). Chlorophyll analysis is described to be an easy and more accurate method to determine phytoplankton removal from source water (Knappe et al. 2004; Swanepoel et al. 2008b). Therefore, chlorophyll analyses rather than settling turbidity measurements may be a better indicator of appropriate coagulant dosages when water contains high C. hirundinella concentrations. It is therefore recommended that TPP (e.g. chlorophyll-α and accessory pigments) analyses after jar stirring tests should be included in purification strategies when phytoplankton blooms occur in source water.

Some conventional water purification utilities in South Africa dose hydrated lime (e.g. Ca(OH)₂), activated silica (SiO₂) and organic coagulants (e.g. organic polymer) during coagulation and flocculation to remove turbidity, phytoplankton and other impurities. Turbidity and C. hirundinella removal when dosing a combination of coagulants may be a challenge to water purification utilities if coagulant dosages and processes are not optimised. Therefore, the objectives of this study were to: (1) investigate the use of turbidity and TPP as indicators for the selection of appropriate coagulant dosages during screening jar stirring tests; (2) compare the efficacy of appropriate coagulant dosages determined by these indicators in removing turbidity, TPP and C. hirundinella cells simultaneously; and (3) evaluate the removal abilities put on each unit process when dosing various coagulants.

MATERIAL AND METHODS

Source water

Source water samples containing relatively high C. hirundinella concentrations (>500 cell/ml) were collected from Benoni Lake, South Africa (26°10′50.40″S; 28°17′50.11″E) in plastic containers. Results from ten sampling occasions were used to perform a principal component analysis (PCA) and four sampling occasions were used to simulate the conventional water purification processes.

Coagulant chemicals used to conduct jar stirring test experiments

The following coagulant chemicals and dosages were used to perform screening jar stirring tests to select appropriate dosages.
(a) **Hydrated lime in combination with activated silica** ($\text{Ca(OH)}_2$-$\text{SiO}_2$): $\text{Ca(OH)}_2$ dosages ranged from 60 to 160 mg/l (with increments of 20). $\text{SiO}_2$ dosages of 4 mg/l were dosed as a coagulant aid.

(b) **Hydrated lime in combination with organic polymer:** Organic polymer dosages ranged from 4 to 14 mg/l (with increments of 2). $\text{Ca(OH)}_2$ dosages of 10 mg/l were added as a coagulant aid.

(c) **Organic polymer:** Organic polymer dosages ranged from 4 to 14 mg/l (with increments of 2).

**Experimental design**

Figure 1 illustrates the experimental setup used to simulate conventional water purification processes (coagulation, flocculation, sedimentation and sand filtration). The experimental setup consisted of a six paddle jar stirrer apparatus and a column sand filtration system (Phipps and Bird models).

Benoni Lake source water samples (Figure 1(a)) containing a known number of *C. hirundinella* cells were used to simulate the purification process of the water treatment works at Zuikerbosch, Rand Water, South Africa on a laboratory-scale procedure under laboratory conditions ($\pm 22^\circ$C). Conventional coagulation, flocculation and sedimentation unit processes was carried out in 21 jar stirring test beakers (Figure 1(b)). The 21 source water samples were subjected to high energy flash mixing conditions of 300 rpm (G-value of 400/s) for 30 s. Different coagulant dosages were added with syringes and allowed to disperse uniformly at high energy flash mixing conditions for another 30 s. Three decreasing energy stages of 125, 54 and 14/s were applied for 8, 1.5 and 1 min respectively. Stirring paddles were switched off to allow flocs to settle for 20 min. Samples of the supernatants were collected to investigate the efficacy of coagulation, flocculation and sedimentation after dosing various coagulants. After sedimentation, the supernatant in the jar beakers (Figure 1(b)) were drained through the sand filter beds (Figure 1(c)) at a filtration rate of 4 m/h. Subsequently, the filtrate was collected in glass beakers (Figure 1(d)) to investigate the efficacy of sand filtration.

![Figure 1](https://iwaponline.com/ws/article-pdf/14/5/820/415772/820.pdf)
**Turbidity and TPP analyses**

Turbidity and TPP analyses were used to determine the efficacy of coagulant dosages. Turbidity measurements were determined using a HACH 2100AN model. TPP analyses were determined by extracting pigments from phytoplankton cells using methanol and analysed with a Beckman spectrophotometer (650i) as described by Swanepoel et al. (2008b). The TPP method used in this study determines the concentration of chlorophyll-\(a\) (including pheophytin) and chlorophyll-\(b\) (Steynberg 1986).

**C. hirundinella analyses**

Identification and enumeration of *C. hirundinella* cells in (a) source water, (b) after sedimentation, and (c) after filtration were determined using a modified sedimentation technique (Swanepoel et al. 2008b). The concentration (cells/ml) and physical integrity of *C. hirundinella* cells were determined using a light microscope.

**Determination of appropriate coagulant dosages**

Within the screening coagulant dosage range, the dosage that is the most cost effective in removing turbidity to values below 5 NTU (nephelometric turbidity units) were selected as an indicator of appropriate coagulant dosage. Good TPP removal usually occurs at the highest coagulant dosage which is not always the most cost effective; however, to achieve the best removal of *C. hirundinella*, TPP should be included as an indicator during the selection of an appropriate coagulant dosage.

**Statistical analysis**

PCA was carried out to determine the correlation between appropriate coagulant dosages and parameters (turbidity, TPP and *C. hirundinella*) after sedimentation. The computer package CANOCO, version 4.5 was used (TerBraak 1988). Ordinations were interpreted using the following rationale: parameters are positively correlated with each other if their arrows subtend a small angle, no correlations if their arrows are 90° and negatively correlated if their arrows are directed in opposite directions. Parameters with the longest arrow relative to an axis have the greatest influence on that axis.

**RESULTS**

**PCA analyses of turbidity, TPP and *C. hirundinella* and coagulants to determine appropriate indicators of coagulant dosages**

Samples (\(n = 10\)) were analysed for appropriate coagulant dosages (based on turbidity as an indicator), and the parameters: turbidity, TPP, and *C. hirundinella* cell counts. The first axis of the PCA ordination (Figure 2) described 61.7% of the variance in the data. The second axis of the PCA ordination described another 28.9% of variance in the data (Figure 2). A close correlation was observed between the parameters TPP and *C. hirundinella* cell counts. Ca(OH)\(_2\)–SiO\(_2\) as coagulant correlated strongly with turbidity, while appropriate dosage samples for Ca(OH)\(_2\)–organic polymer and organic polymer as coagulants associated mostly with TPP and *C. hirundinella* cell counts. This indicates that the coagulant option of Ca(OH)\(_2\)–SiO\(_2\) resulted in high levels of turbidity after sedimentation. Ca(OH)\(_2\)–organic polymer correlated with the presence of *C. hirundinella* cells, while organic polymer correlated with the TPP content in the supernatant.

![Figure 2](https://iwaponline.com/ws/article-pdf/14/5/820/415772/820.pdf)
The efficacy of turbidity, TPP and *C. hirundinella* removal when the parameters’ turbidity and TPP were used respectively as indicators of appropriate coagulant dosages

Turbidity is mostly used as an indicator when choosing appropriate coagulant dosages. The South African standard/guideline for aesthetic turbidity values of treated water are set at ≤5 NTU (SANS 2411 2011). The source water used during this investigation contained low turbidity levels (6 NTU), but high *C. hirundinella* concentrations (>500 cells/ml) which may pose challenges for removal during the conventional water purification process. This was evident in four sampling occasions when turbidity was used as an indicator of appropriate coagulant dosages (Table 1). The Ca(OH)$_2$–SiO$_2$ treatment was responsible for a major increase in turbidity levels after sedimentation putting strain on the subsequent sand filtration step. Better turbidity removal was achieved by Ca(OH)$_2$–organic polymer (~17%), although it has also increased the initial turbidity levels. Both these coagulant options managed to remove TPP and *C. hirundinella* cells fairly well (83 and 51% respectively). The organic polymer achieved the best turbidity removal. However, this coagulant option was not effective in removing TPP or *C. hirundinella* cells, removing only 38 and 39% respectively.

Although no specific guideline for TPP after sedimentation is currently set, the coagulant dosage that achieved the best TPP removal should be taken into account during the selection of an appropriate dosage. The average TPP concentration, originating mostly from *C. hirundinella* cells in source water was high (41 μg/l). Therefore, TPP can be used as an indicator of appropriate coagulant dosages to ensure good *C. hirundinella* removal (Table 2). Results obtained when using turbidity as an indicator of appropriate coagulant dosage (Table 1) are compared to results obtained when using TPP as an indicator of coagulant dosage (Table 2) to investigate removal efficacies.

When TPP was used as an indicator of appropriate coagulant dosages, an increase in supernatant turbidity was again recorded when dosing Ca(OH)$_2$–SiO$_2$ (Table 2). In the light of this observation, increasing turbidity is rather a result of residual high Ca(OH)$_2$ dosages used during Ca(OH)$_2$–SiO$_2$ treatment. However, when using TPP as an indicator of appropriate dosages, both Ca(OH)$_2$–organic polymer and organic polymer achieved higher removals of turbidity (50% in both cases), TPP (76 and 51% respectively) as well as *C. hirundinella* cells (82 and 84% respectively).

High variability in percentage removal was recorded for turbidity, TPP and *C. hirundinella* after sedimentation when dosing various appropriate coagulants dosages as determined by different indicators (Tables 1 and 2). However, improved TPP and *C. hirundinella* removal (indicated as percentage removal) were recorded when using TPP as an indicator. Irrespective of the percentage removal achieved

| Table 1 | The average values for parameters measured (n = 4) in the source water, after sedimentation and after filtration when turbidity was used as an indicator of appropriate coagulant dosages |

<table>
<thead>
<tr>
<th>Coagulant and average appropriate dosage</th>
<th>Parameters</th>
<th>Units</th>
<th>Source water average</th>
<th>After sedimentation</th>
<th>After filtration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca(OH)$_2$–SiO$_2$</td>
<td>Turbidity</td>
<td>NTU</td>
<td>6</td>
<td>29</td>
<td>– 383</td>
</tr>
<tr>
<td>Ca(OH)$_2$ 135 mg/l and [SiO$_2$ 4 mg/l]</td>
<td>TPP</td>
<td>μg/l</td>
<td>41</td>
<td>7</td>
<td>83</td>
</tr>
<tr>
<td>C. hirundinella cells/ml</td>
<td>510</td>
<td>130</td>
<td>75</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>Ca(OH)$_2$–organic polymer</td>
<td>Turbidity</td>
<td>NTU</td>
<td>6</td>
<td>7</td>
<td>– 17</td>
</tr>
<tr>
<td>Ca(OH)$_2$ 10 mg/l and [organic polymer 6.5 mg/l]</td>
<td>TPP</td>
<td>μg/l</td>
<td>41</td>
<td>20</td>
<td>51</td>
</tr>
<tr>
<td>C. hirundinella cells/ml</td>
<td>510</td>
<td>125</td>
<td>75</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Organic polymer</td>
<td>Turbidity</td>
<td>NTU</td>
<td>6</td>
<td>4</td>
<td>33</td>
</tr>
<tr>
<td>[Organic polymer 4 mg/l]</td>
<td>TPP</td>
<td>μg/l</td>
<td>41</td>
<td>25</td>
<td>39</td>
</tr>
<tr>
<td>C. hirundinella cells/ml</td>
<td>510</td>
<td>314</td>
<td>38</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>
by various appropriate coagulant dosages or indicators after sedimentation, the sand filtration step removed almost all of the remaining turbidity, TPP and *C. hirundinella* contents.

In both cases when using turbidity and TPP as an indicator (Tables 1 and 2), maximum percentage removals were achieved (83–100%) for the full-scale conventional water purification process.

### Table 2

The average values for parameters measured (*n* = 4) in the source water, after sedimentation and after filtration when TPP was used as an indicator of appropriate coagulant dosages

<table>
<thead>
<tr>
<th>Coagulant and average appropriate dosage</th>
<th>Parameters</th>
<th>Units</th>
<th>Source water</th>
<th>After sedimentation</th>
<th>After filtration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca(OH)(_2)–SiO(_2) and [Ca(OH)(_2) 150 mg/l and [SiO(_2) 4 mg/l]</td>
<td>Turbidity</td>
<td>NTU</td>
<td>6</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>TPP</td>
<td>μg/l</td>
<td>41</td>
<td>6</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td><em>C. hirundinella</em></td>
<td>cells/ml</td>
<td>510</td>
<td>217</td>
<td>57</td>
</tr>
<tr>
<td>Ca(OH)(_2)–organic polymer and [Ca(OH)(_2) 10 mg/l and [Organic polymer 14 mg/l]</td>
<td>Turbidity</td>
<td>NTU</td>
<td>6</td>
<td>3</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>TPP</td>
<td>μg/l</td>
<td>41</td>
<td>10</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td><em>C. hirundinella</em></td>
<td>cells/ml</td>
<td>510</td>
<td>90</td>
<td>82</td>
</tr>
<tr>
<td>Organic polymer and [Organic polymer 13.5 mg/l]</td>
<td>Turbidity</td>
<td>NTU</td>
<td>6</td>
<td>3</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>TPP</td>
<td>μg/l</td>
<td>41</td>
<td>20</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td><em>C. hirundinella</em></td>
<td>cells/ml</td>
<td>510</td>
<td>83</td>
<td>84</td>
</tr>
</tbody>
</table>

### Impacts of different coagulants on the physical integrity of *C. hirundinella* cells after sedimentation

The appearance of *C. hirundinella* cells in the source water (Figure 3(b)) is used as a control for the impacts of coagulants on the physical integrity of cells. The coagulant Ca(OH)\(_2\)–SiO\(_2\) is characterised by relatively high dosages...

![Figure 3](https://iwaponline.com/ws/article-pdf/14/5/820/415772/820.pdf)
of Ca(OH)$_2$ which increase the pH levels to 11 and above. This coagulant treatment caused major damage to the cells (Figure 3(b)). Broken cells of *C. hirundinella* may also have contributed to increasing turbidity levels (Tables 1 and 2). This therefore could explain the negative values obtained for percentage turbidity removals recorded. Less damaging effects to *C. hirundinella* cells were observed when Ca(OH)$_2$–organic polymer and organic polymer coagulant treatment options were used (Figures 3(c) and 3(d)) respectively. Less damaging effects to cells may be a result of lower Ca(OH)$_2$ dosages used during Ca(OH)$_2$–organic polymer treatment. Ca(OH)$_2$–organic polymer and organic polymer treatment options were also characterised with an overall good turbidity removal.

**DISCUSSION**

It is a well-known fact that the occurrence of phytoplankton (cyanobacteria and algae) in source water due for drinking water purification may lead to many water-related problems (Knapp et al. 2004). *Ceratium* genera have been identified as a problem-causing organism for water purification plants and may pose risks to water quality (Knapp et al. 2004; Ewerts et al. 2013). Swanepoel et al. (2008a) reported the penetration of *C. hirundinella* cells into the final purified water at South Africa’s largest conventional water purification works. Findings made by Swanepoel et al. (2008a) indicate that highly motile *C. hirundinella* cells are able to disrupt coagulation and flocculation, and therefore, these cells remain in the supernatant after sedimentation (Ewerts et al. 2013).

In order to address these challenges to drinking water purification, managers and operators should implement strategies to assist unit processes to remove problem-causing algae, like *C. hirundinella*. The application of phytoplankton removal strategies should include jar stirring test experiments to optimise coagulation and flocculation in order to effectively remove phytoplankton cells from source water during the sedimentation stage. In this study, a laboratory-scale conventional water purification apparatus was used to simulate the conventional water purification processes using different coagulant options.

Due to their large cell size, *C. hirundinella* cells contribute to significant amounts of chlorophyll and accessory pigments in water (Janse van Vuuren et al. 2006; Swanepoel et al. 2008a). Since *C. hirundinella* cells contribute to large quantities of chlorophyll and other accessory pigments, TPP measurements can be used as an indication of *C. hirundinella* concentrations present in source water, and after different stages of the conventional water purification process. Therefore, when source water due for drinking water purification contains *C. hirundinella* cells in either moderate or abundant quantities, TPP measurements after sedimentation should be included during jar screening tests to select appropriate coagulant dosages for the removal of *C. hirundinella* (as indicated by the strong correlation between TPP and *C. hirundinella* in Figure 2).

Turbidity measurements, traditionally used as an indicator of appropriate coagulant dosages, correlated positively with Ca(OH)$_2$–SiO$_2$ (Figure 2). This suggests that the high turbidity levels in the supernatant, showed after sedimentation, may have originated from Ca(OH)$_2$ and other impurities (Figure 2). High Ca(OH)$_2$ (80–160 mg/l) dosages remove *C. hirundinella* and TPP effectively, but cause major damaging effects to cells and increase turbidity.

Organic polymer dosages were dosed as primary coagulant during Ca(OH)$_2$–organic polymer and organic polymer treatments respectively. The purpose of Ca(OH)$_2$ in combination with organic polymer is mostly for pH adjustment (WHO 2004). The use of organic polymer is not linked to pH adjustments and only low dosages are required for effective turbidity removal (Ebeling et al. 2005). However, in both these coagulant choices, a positive correlation was recorded with *C. hirundinella* and TPP (Figure 2) when turbidity was used as an indicator. Thus, although the use of organic polymer achieved maximum turbidity removal after sedimentation, it was not effective in removing *C. hirundinella*.

The chlorophyll concentrations after sedimentation and filtration should be lower than concentrations in source water (Tables 1 and 2). Therefore, the determination of TPP is an appropriate indicator to determine coagulant choice for the removal of *C. hirundinella* cells. In both cases where either turbidity or TPP was used as an indicator, turbidity increased, or the removal thereof was poor in the events where the coagulant Ca(OH)$_2$–SiO$_2$ was dosed. The
coagulant treatment option, Ca(OH)\textsubscript{2}–organic polymer performed better in removing turbidity, TPP and \textit{C. hirundinella}, where the parameter TPP was used as an indicator. Organic polymer also functions as an appropriate coagulant for turbidity removal when using TPP as an indicator of coagulant dosages.

The use of coagulants together with dosages of Ca(OH)\textsubscript{2}, results in a ‘pH-shock’. Similar observations with regards to ‘pH-shock’ and the removal enhancement of micro-organisms during coagulation are also described by Hoko & Makado (2011) and Ferreira & Du Preez (2012). This study showed that the coagulant option Ca(OH)\textsubscript{2}–SiO\textsubscript{2} increased pH levels to above 11, with major damage to the physical integrity of \textit{C. hirundinella}. However, when Ca(OH)\textsubscript{2}–organic polymer was used as coagulant the Ca(OH)\textsubscript{2} dosage only increased the pH to between 9 and 10, leaving the cells intact. It therefore can render cells immobile and assist the coagulation process without contributing to turbidity levels. Consequently, water purification plants should investigate the impacts of high Ca(OH)\textsubscript{2} dosages further. In addition, cell damage which results in the release of organic cell content into the supernatant, may pose major health risks to consumers. Organic material (e.g. chlorophyll) can form harmful organic by-products such as trihalomethanes when reacting with chlorine at the disinfection stage of water purification (Van der Walt \textit{et al.} 2009). Broken cells (e.g. theca plates) may be carried over to sand filters and can cause filter clogging and reduced filter run-times.

Using turbidity as an indicator of appropriate coagulant dosages is more cost effective than using TPP as an indicator. However, turbidity as an indicator potentially results in a higher organic loading onto the sand filters, which may increase purification costs significantly. Increased purification costs can be attributed to increased back-wash frequencies, intensified filter backwash water purification and the probability of discarding high volumes of filter backwash water.

**CONCLUSIONS**

Strategies used for optimising conventional water treatment processes should not only be based upon purification costs but also upon consumer health aspects and aesthetic water quality. Thus when source water due for purification contains highly motile nuisance algae such as \textit{C. hirundinella} in either moderate or abundant quantities, it is advisable to conduct jar stirring test experiments using both turbidity and TPP analyses as indicators of appropriate coagulant choice and dosages. This study showed that TPP was the most effective indicator of coagulant choice and dosage when source water contain high concentrations of \textit{C. hirundinella} cells and that Ca(OH)\textsubscript{2} dosages can assist the coagulation and flocculation process of the algal cells by rendering them immobile.

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