Review

Removal of natural organic matter in drinking water treatment by coagulation: A comprehensive review

Mika Sillanpää [a, b], Mohamed Chaker Ncibi [a, *], Anu Matilainen [c], Mikko Vepsäläinen [d]

[a] Laboratory of Green Chemistry, School of Engineering Science, Lappeenranta University of Technology, Sammonkatu 12, 50130, Mikkeli, Finland
[b] Department of Civil and Environmental Engineering, Florida International University, Miami FL, 33174, USA
[c] Finnish Safety and Chemicals Agency, Kalevantie 2, 33100 Tampere, Finland
[d] CSIRO Mineral Resources Flagship, Box 312, Clayton South, VIC, 3169, Australia

HIGHLIGHTS

- Recent R&D studies in the field of NOM removal by coagulation are overviewed.
- Various metallic and polymeric coagulants are included.
- Biocoagulants are promising alternatives to conventional metal-based coagulants.
- Novel composites are enabling efficient NOM removal from drinking water supplies.
- Coagulation-based integrated processes for improved efficiency and resilience.

ARTICLE INFO

ABSTRACT

Natural organic matter (NOM) is a complex matrix of organic substances produced in (or channeled to) aquatic ecosystems via various biological, geological and hydrological cycles. Such variability is posing a serious challenge to most water treatment technologies, especially the ones designed to treat drinking water supplies. Lately, in addition to the fluctuating composition of NOM, a substantial increase of its concentration in fresh waters, and also municipal wastewater effluents, has been reported worldwide, which justifies the urgent need to develop highly efficient and versatile water treatment processes.

Coagulation is among the most applied processes for water and wastewater treatment. The application of coagulation to remove NOM from drinking water supplies has received a great deal of attention from researchers around the world because it was efficient and helped avoiding the formation of disinfection by products (DBPs). Nonetheless, with the increased fluctuation of NOM in water (concentration and composition), the efficiency of conventional coagulation was substantially reduced, hence the need to develop enhanced coagulation processes by optimizing the operating conditions (mainly the amount coagulants and pH), developing more efficient inorganic or organic coagulants, as well as coupling coagulation with other water treatment technologies. In the present review, recent research studies dealing with the application of coagulation for NOM removal from drinking water supplies are presented and compared. In addition, integration schemes combining coagulation and other water treatment processes are presented, including membrane filtration, oxidation, adsorption and others processes.

© 2017 Elsevier Ltd. All rights reserved.

Contents

* Corresponding author.
  E-mail address: chaker.necibi@lut.fi (M.C. Ncibi).

<table>
<tr><td colspan="2">List of abbreviations</td><td>HMM</td><td>High molar mass</td></tr>
<tr><td></td><td></td><td>NOM</td><td>Natural organic matter</td></tr>
<tr><td>AMW</td><td>Apparent molecular weight</td><td>PAC</td><td>Polyaluminum chloride</td></tr>
<tr><td>BOD</td><td>Biological oxygen demand</td><td>PACA</td><td>Polyacrylic acid-co-acrylamide</td></tr>
<tr><td>CLR</td><td>Charge loading rate</td><td>PAFS</td><td>Polymeric aluminum ferric sulfate</td></tr>
<tr><td>COD</td><td>Chemical oxygen demand</td><td>PAM</td><td>Polyacrylamide</td></tr>
<tr><td>DBPs</td><td>Disinfection by-products</td><td colspan="2">PDADMAC Polydiallyldimethyl ammonium chloride</td></tr>
<tr><td>DOM</td><td>Dissolved organic matter</td><td>PFC</td><td>Polyferric chloride</td></tr>
<tr><td>DSA</td><td>Dimensionally stable anode</td><td>PFAC</td><td>Polyferric aluminum chloride</td></tr>
<tr><td>Epi/DMA</td><td>Epichlorohydrin/dimethylamine</td><td>PFS</td><td>Polyferric sulfate</td></tr>
<tr><td>EPS</td><td>Exopolysaccharides</td><td>PFZS</td><td>Polymeric ferric zinc sulfate</td></tr>
<tr><td>CPAM</td><td>Cationic polyacrylamide;</td><td>PPAC</td><td>Polymeric phosphate aluminum chloride</td></tr>
<tr><td>FA</td><td>Fulvic acid</td><td>PTC</td><td>Polytitanium chloride</td></tr>
<tr><td>HA</td><td>Humic acid</td><td>SUVA</td><td>Specific ultraviolet absorbance</td></tr>
<tr><td>HS</td><td>Humic substances</td><td>THM</td><td>Trihalomethanes</td></tr>
<tr><td>HAA</td><td>Haloacetic acid</td><td>THMFP</td><td>Trihalomethanes formation potential</td></tr>
<tr><td>HAAFP</td><td>Haloacetic acid formation potential</td><td>TOC</td><td>Total organic carbon</td></tr>
<tr><td>HAN</td><td>Haloacetonitrile</td><td>UF</td><td>Ultrafiltration</td></tr>
</table>

1. Introduction

Natural organic matter (NOM) is complex matrix of organic substances commonly found in surface and ground waters, as a result of different hydrological, biological and geological interaction schemes. In general, NOM can be generated within the water source through biological activities, mainly algal and microbial (autochthonous NOM), or introduced to the water body via drainage within watersheds including substances generated during the breakdown of terrestrial organisms (allochthonous NOM).

Such differentiation is important because each of those two groups has specific characteristics which, once identified, are a useful tool to set suitable and efficient NOM removal processes. Thus, it was reported that the "outsider" autochthonous NOM (dark colored) is mainly constituted of humic substances and its composition is highly variable depending on potential geological and hydrological changes in the originating ecosystem and the watershed (Hudson et al., 2007). As for the "insider" autochthonous NOM (light colored), the biological activities are quite diverse depending on the metabolism of the involved algal and/or bacterial species. Such activities generally generate soluble extracellular and intracellular macromolecules such as carbohydrates, amino acids, peptides, enzymes and toxins (Her et al., 2004; Amy, 2008).

Along with the impact of its biochemical composition, other factors tend to influence the occurrence and fate of NOM in aquatic environments including water chemistry, pH, temperature and the various biological processes taking place in the water body. Therefore, the amount and composition of NOM could vary substantially from one location to another and also in the same water body after seasonal changes affecting natural phenomena such as floods, droughts, and rainfalls (Matilainen et al., 2002; Sharp et al., 2006a; Hirabayashi et al., 2008; Kundzewicz et al., 2014). The combination of those climatic, hydrological, biological, geological and chemical factors were reported to be the main reasons for *(i)* the frequent spatiotemporal variations of NOM in water sources and *(ii)* its increasing amounts recurrently monitored around the world during the past 10–20 years (Matilainen and Sillanpää, 2010; Couture et al., 2012; Sillanpää, 2015).

Inherently, NOM is not toxic, but its presence in water, especially in drinking water sources is highly detrimental. Indeed, the presence of NOM tends to downgrade the quality of potential potable waters by altering their organoleptic properties (color, taste and odor). NOM also could act as a carrier of toxic organic and inorganic pollutants such as such as pesticides and radionuclides (Knauer et al., 2017; Santschi et al., 2017). In this context, the presence of NOM in natural waters was reported to increase bioavailability of hydrophobic anthropogenic compounds by increasing their solubility in water (Reid et al., 2001). In addition, various components of