International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Low Pressure Membrane Technology for Treatment of Water Supply in Developing Countries

Ma. Catriona E. Devanadera[a]*, Fevi Rose C. Paro[b], Maria Lourdes P. Dalida[c]

[a,b]*Department of Community and Environmental Resource Planning, College of Human Ecology, University of the Philippines Los Baños, Los Baños, Laguna 4031, Philippines*

[c]*Department of Chemical Engineering, College of Engineering, University of the Philippines, Quezon City 1101, Philippines*

[a]*Email: medevanadera@up.edu.ph*

[b]*Email: fcparo@up.edu.ph*

[c]*Email: mariloudalida@yahoo.com*

Abstract

Algal bloom remains a pressing environmental issue due to toxin producing cyanobacteria and production of algal organic matter (AOM) in waterbodies. These conditions lead to deterioration in water quality and pose risk to public health upon direct use of contaminated water. Microfiltration, a low pressure membrane technology, is an effective water treatment system in removing algal organic matter and its components in contaminated water. However, upon prolonged use of membrane, its performance is reduced due to fouling. Coagulation as a feed pre-treatment step is employed in the study to test its ability to mitigate membrane fouling. This study showed that feed pre-treatment improved the performance of ceramic membrane in reducing the fouling potential caused by algal organic matter from stationary phase *Chlorella* sp. and *Microcystis aeruginosa*. Results have proven the efficiency of ceramic microfiltration coupled with coagulation as a water treatment technology for algal contaminated water.

Keywords: ceramic microfiltration; fouling impact of algal organic matter; coagulation as feed pre-treatment.

---

* Corresponding author.

1. Introduction

Joint reports from the WHO/UNICEF state that more than 783 million people all over the world still rely on unimproved drinking water supply [1]. In the Philippines, around 8.1 million out of 100 million Filipinos still depend on unimproved water sources [2]. Impurities in water supply are often caused by the presence of pollutants produced from algal growth and decay. Algal blooms present in surface water have been threatening the world for the longest time. More algal blooms thrive in waterbodies due to high concentration of nitrate and phosphorus coming from domestic and agricultural wastewater which are directly discharged to surface water such as lakes and streams, without prior treatment. Such greatly contributes to high water pollution loading, making it more conducive for the growth of algae. Algal blooms may not only result to eutrophication or the dying of lakes/waterbodies, but may present multiple risks that double the burden on ill-health and poverty, mostly on developing countries.

Chlorella species and *Microcystis aeruginosa* are the most commonly found organisms in reservoirs and surface water. These algae and cyanobacteria can be found in major water bodies in the Philippines, including Laguna de Bay. *Chlorella* sp. and *M. aeruginosa* produce algal organic matter (AOM) which is problematic in potable water supplies and waste stabilization ponds consequently affecting water treatment facilities such as membrane filtration. Membrane filtration is a pressure driven process in which the membrane acts as selective barrier, restricting the passage of pollutants. Categories of membrane filtration include low and high pressure membrane processes. Microfiltration (MF), a low pressure membrane technology, has a high potential in meeting the stringent quality requirements for water supply. However, membrane fouling – an accumulation of impurities and a complex phenomenon that blocks membrane pores during filtration, is inevitable and considered as a major problem to extensive use of membrane treatment facilities.

AOM released during algal growth and death contributes to fouling which decrease the performance of membrane treatment technologies. Understanding fouling potential and investigating on its mitigation may reduce impact on and provide better performance of membrane systems in algae-contaminated water. Studies on membrane filtration systems found that coagulation is an effective pre-treatment for algae-contaminated water supply. Coagulation was observed to be the most cost-effective and will remain the most dominant among the techniques in the coming years, according to the review on techniques for fouling abatement [3]. This study aims to explore the possibility of coagulation as a feed pre-treatment step together with microfiltration in reducing the effects of fouling on algal-contaminated water. With the increasing demand for safe and potable water supply, there is a great need for a water treatment technology that would maintain good water quality and secure the balance in the ecosystem.

2. Materials and Methods

Feed solutions (influent) used in the study were composed of the algal organic matter (AOM) released during the exponential (after 12 days of culture) and stationary phases (after 35 days of culture) for both *Chlorella* sp. and *Microcystis aeruginosa (M. aeruginosa).* Low pressure membrane technology such as microfiltration was evaluated based on the fouling impacts, membrane recovery, and removal rates of foulants from the algal

contaminated water. For fouling mitigation, alum coagulation was conducted as a feed pre-treatment process. The experimentation process was divided into two (2) parts: (a) without feed pre-treatment (microfiltration only) and (b) with feed pre-treatment process (alum coagulation + microfiltration) (refer to Figure 1).

This study was conducted as a preliminary testing for ceramic microfiltration membrane fouling impact due to soluble algal organic matter (sAOM) released from two organisms, *Chlorella* sp. and *M. aeruginosa* for both exponential and stationary phases. Membrane fouling was tested based on the flux decline at a given time. Analysis on the fouling characteristics were limited to dissolved organic (DOC), ultraviolet absorbance (UV_{254}), fluorescence excitation and emission matrices (EEMs), carbohydrates and protein content. For membrane recovery, backpulsing was conducted in each runs after membrane filtration. To minimize the fouling due to sAOM, coagulation was conducted as a feed pre-treatment process in method 2.

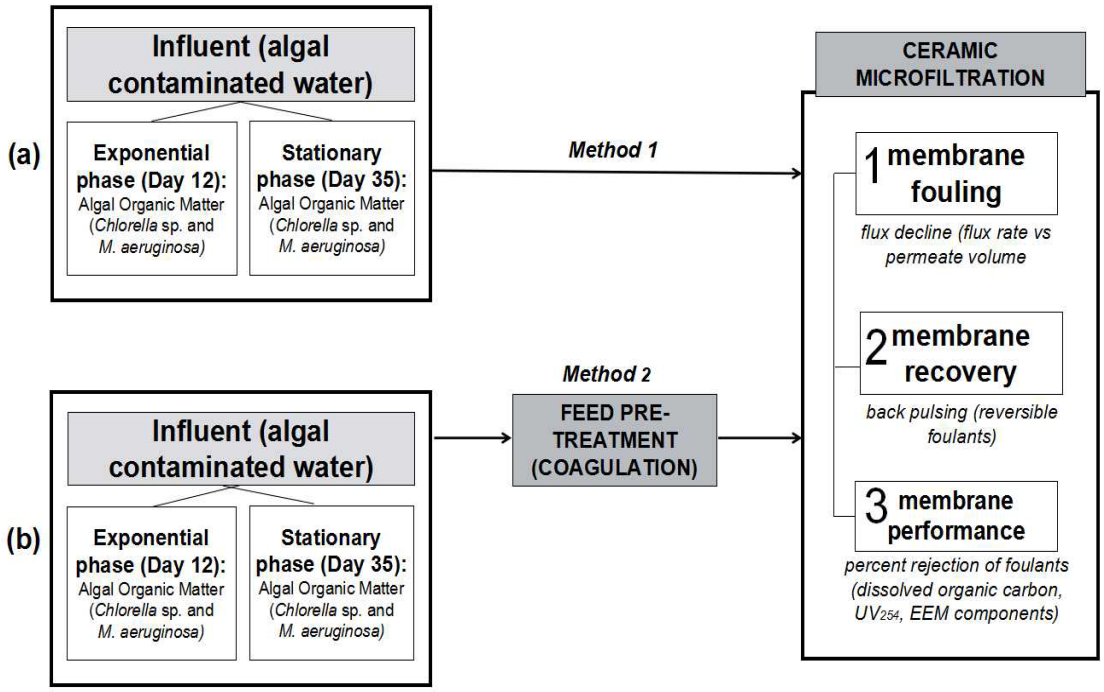

Figure 1: Overview of the experimentation process: (a) without Feed Pre-Treatment; (b) with Feed Pre-Treatment

2.1 Influent Water Sample/Feed solutions

Organisms used were *Chlorella* sp. and *M. aeruginosa*. *Chlorella sp.* was purchased from Victoria, Australia while *M. aeruginosa* from Tasmania, Australia. Both were cultured using MLA medium at 22ºC under humidified aeration [4]. *Chlorella* sp. was cultured in 1-L Schott bottles with a continuous light source while *M. aeruginosa* in 5-L Schott bottles at a 16/8 dark/light cycle. *Chlorella* sp. and *M. aeruginosa* used 684 nm to obtain the optical density (OD_{684}). Optical densities (algal concentration) were correlated with cell counts to establish their linear relationships (*Chlorella* sp.: R^2>0.96 and *M. aeruginosa* R^2>0.99).

2.2 Extraction of algal organic matter

2.2.1 AOM Extraction Procedure

Algal organic matter from *Chlorella* sp. (C-AOM) and *M. aeruginosa (*M-AOM) were extracted using the process: centrifugation at 4,000 x g and at 4ºC for 15 min and filtration of the supernatant through a 0.45 µm membrane filter. This is similar with the method used in the extraction of extracellular polymeric substances (EPS) and extracellular organic matter (EOM) from activated sludge and algae solution [5].

2.3 Ceramic microfiltration test for membrane fouling and recovery

Ceramic microfiltration membrane (Membralox by Pall) was used in the study. It is made of alumina with a 0.1 µm pore size and a membrane surface area of 50 cm^2. Feed tank held a volume of 3.5 L. Dead end filtration was used in the study. A transmembrane pressure (TMP) value of 50 kPa was used. All experiments were conducted at room temperature (20 ± 2°C). Clean water flux (CWF) was determined using Milli-Q (MQ) water for 10 minutes (flux of 480 ± 5% at 50 kPa). Permeate flux was determined using a top-loading electronic balance (OHAUS Explorer) with data logging function of 1-min interval. Hot sodium hypochlorite solution (70ºC; 45 minutes; 1000 ppm available chlorine) was used to restore the initial clean water flux (CWF) after each run. After fouling (observed after 80-90 mins), CWF (J_{TF} – total fouling) was taken by filtering MQ water for 5 minutes, then back pulsing (BP) was applied for 5 seconds. After BP, CWF (J_{BP}) was again measured for 5 minutes using Milli-Q water. Flux recovery, and resistances due to total fouling, irreversible fouling and reversible fouling were calculated using Equations 1-5.

$$\text{Flux recovery, } \% = (J_{BP}/J_o)*100 \quad (1)$$

$$\text{Resistance Membrane, } R_M = \Delta P / \mu J_o \quad (2)$$

$$\text{Resistance (Total Fouling), } R_{TF} = \Delta P / \mu J_{TF} - R_M \quad (3)$$

$$\text{Resistance (Irreversible fouling), } R_{IF} = \Delta P / \mu J_{BP} - R_M \quad (4)$$

$$\text{Resistance (Reversible fouling), } R_{RF} = R_{TF} - R_{IF} \quad (5)$$

where: change in transmembrane pressure, $\Delta P = P_2 - P_1 = 50{,}000$ *Pa*

$\mu = 0.000958$ *Pa•s*

J_{BP}; J_o; $J_{TF} = m^3/(m^2 \bullet s)$

All filtration tests for C-AOM and M-AOM were run in duplicate and a similar trend for each filtration was achieved (difference was less than 5%). As a result, only one set of filtration results for each run is shown.

2.4 Analytical methods

For membrane performance, parameters measured include dissolved organic carbon (DOC), ultraviolet absorbance at wavelength 254 ($UV_{254)}$, and fluorescent excitation emission matrices (EEMs), carbohydrates and proteins. DOC was measured using a Sievers 820 TOC analyser. UV/vis spectrophotometer (Shimadzu UV2700) was used to determine UVA_{254} (aromatic substances) and OD_{684}. pH was measured using a Hach Sension 156 pH meter. For carbohydrate and protein analysis, phenol-sulphuric method [6], and Quantipro™ BCA assay were employed, respectively. Three measurements for each trial were carried out with the average values reported.

With the use of Perkin Elmer Luminescence Spectrometer LS50B, EEMs were measured. Excitation and emission ranged from 200-600 nm and 200-540 nm, respectively. Fluorescence regional integration (FRI) technique was introduced to analyze fluorescence EEMs. Boundaries for each component were based on the EEM comprehensive study for natural organic matter (NOM) fractions and model compounds (e.g. humic acid) [7]. Five regions were identified as: Regions I and II, associated with protein-like extracellular organic matter (Aromatic proteins I and II); Region III - associated with fulvic acid-like compounds; Region IV - associated with soluble microbial by-product-like compounds (SMPS), mainly proteins and polysaccharides and lastly Region V - associated with humic acid-like compounds. Reduction in EEMs spectra per region were computed based on the difference between feed and permeate EEMs subjected to MF alone and MF + Alum coagulation methods.

2.5 Feed pre-treatment method

Coagulation was conducted as feed pre-treatment for the AOM feed solutions. Alum was used as coagulant with concentrations 0, 2.5, 5, 7.5, 10, and 15 mg/l using the laboratory jar tester with six 2-L square jars (PB-700, Phipps and Bird). Rapid mixing was employed for 1 min at 200 rpm followed by slow mixing for 20 min at 30 rpm. Solutions were allowed to settle and then analyzed based on DOC. Coagulant dose with the highest DOC removal was used for pre-treatment.

Results Feed solutions (influent) used in the study were composed of the algal organic matter (AOM) released during the exponential (after 12 days of culture) and stationary phases (after 35 days of culture) for both *Chlorella* sp. and *Microcystis aeruginosa (M. aeruginosa).* Low pressure membrane technology such as microfiltration was evaluated based on the fouling impacts, membrane recovery, and removal rates of foulants from the algal contaminated water. For fouling mitigation, alum coagulation was conducted as a feed pre-treatment process. The experimentation process was divided into two (2) parts: (a) without feed pre-treatment (microfiltration only) and (b) with feed pre-treatment process (alum coagulation + microfiltration) (refer to Figure 1).

3. Results and Discussion

This section details results of method (1) without feed pre-treatment (microfiltration only) and (2) with feed pre-treatment (alum coagulation + microfiltration). Results of the two (2) methods were compared to test the

efficiency of coagulation in reducing AOM fouling potential of *Chlorella* sp. and *M. aeruginosa*.

3.1 Membrane fouling and recovery

Membrane fouling due to AOM can be measured through flux decline (L/m^2) per unit time at a constant transmembrane pressure (TMP). For *Chlorella* sp. flux abruptly declined for both the exponential and stationary phase, though stationary phase (Day 35) C-AOM caused more fouling as compared with exponential (Day 12). In 90 min, serious flux decline (see Figure 2) was observed with around 68 and 75% reduction on the initial CWF for Day 12 and Day 35 C-AOM feed solutions, respectively.

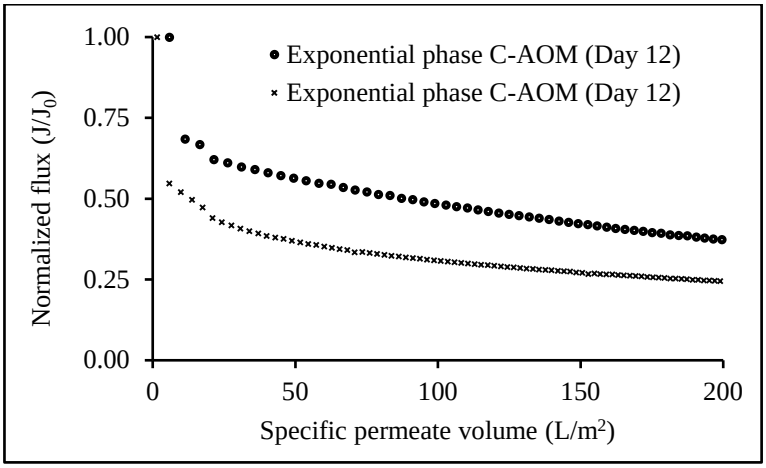

Figure 2: Flux decline due to exponential and stationary phase of *Chlorella* sp. algal organic matter (C-AOM)

In Figure 3, for M-AOM, final permeate flux declined to around 61 and 67% on the CWF for exponential and stationary phases, respectively. Fouling impact at an older culture was greater compared to the exponential phase. Similar with the results found in the study wherein *M. aeruginosa* caused more fouling potential to the ceramic membrane at stationary phase compared to exponential phase [8]. Severity of AOM fouling was due to the biopolymers present in the feed solution.

Reversible (physically removable foulants) and irreversible (chemically removable foulants) fouling occur in membrane filtration. To measure if reversible or irreversible foulants were present, five (5) second back pulsing was employed in the study. Back pulsing can remove reversible foulants and from Equations 1-5, reversible, irreversible fouling, and flux recovery can be computed. Flux recovery ranged from around 37-42% for C-AOM (Day 12 & Day 35) and M-AOM (Day 35), except for the exponential phase (80%) M-AOM (see Figure 4). Results indicated that algal organic matter composed of irreversible foulants. AOM from cultures at stationary phase led to a more critical problem in ceramic membrane fouling as compared to the exponential phase. The implication of low flux recovery (high irreversible fouling) means that chemical cleaning is needed to use ceramic membranes after being subjected to irreversible fouling. Regardless of membrane system used, repeated cleaning arise to concerns affecting membrane life, thus chemical cleaning should be limited [9]. Indeed, there is a great need for feed pre-treatment that can aid in fouling mitigation and prolong the useful life of ceramic membranes. From the review, biofouling in membrane systems caused severe loss of performance and the use of

costly cleaning procedure in order to maintain permeate quality [10]. Unable to maintain acceptable operation leads to membrane replacement.

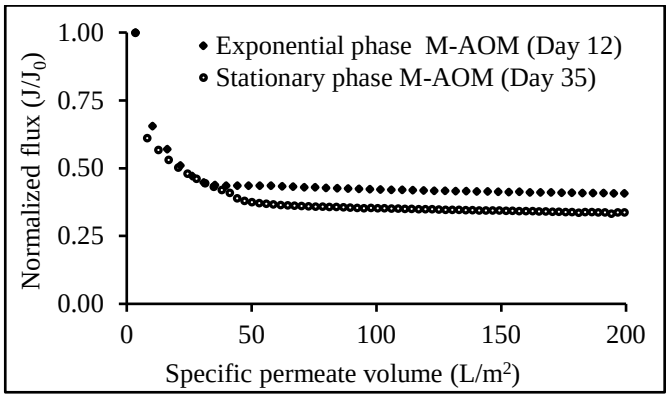

Figure 3: Flux decline due to exponential and stationary phase of *M. aeruginosa* algal organic matter (M-AOM)

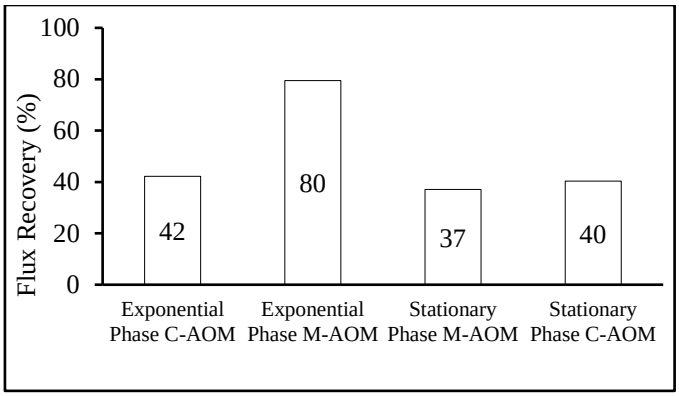

Figure 4: Flux recovery for all microfiltration runs

3.2 Microfiltration performance based on percent (%) removal of DOC, UV_{254}, carbohydrates and proteins

DOC and UV_{254} were used to test the performance of the microfiltration membrane. Percent removal ranged from 9-14% for DOC and 36-51% for UV_{254}, for C-AOM exponential and stationary phases (see Figure 5). Substances present in Day 35 C-AOM had higher fouling impact which must be due to the different organic molecules present in the DOC. For carbohydrates (44-52%) and proteins (36-45%) which could have greatly contributed to the fouling of ceramic membrane based from greater rejection of C-AOM at stationary phase. Characteristics of algal organic matter at an older culture could lead to more fouling of membranes due to production of proteins and carbohydrates during their growth and lysis. Similar with the results of previous studies, they found that proteins and polysaccharides released during the growth and lysis phases of algal cells were significant contributors to fouling of hydrophilic filtration membranes [11, 12]. Severe and irreversible fouling of algal exudates is mainly due to the biopolymer content such as polysaccharides and proteins in ceramic membrane fouling caused by marine organic matter such as *Chlorella* sp [13]. However, it was not purely the high molecular weight fractions, adsorption of low molecular weight molecules also plays a role in membrane fouling.

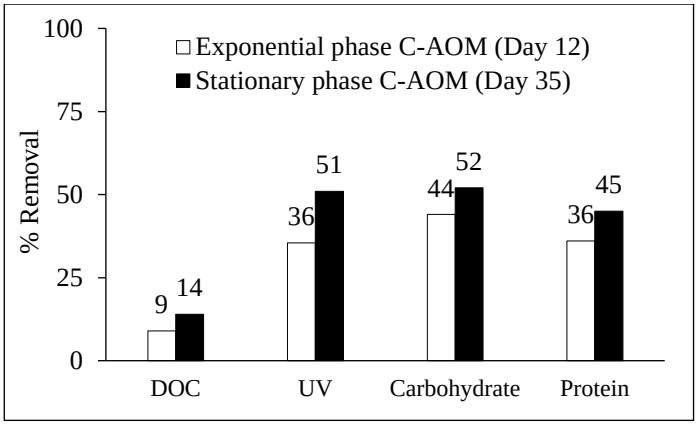

Figure 5: Removal of DOC, UVA, carbohydrate and protein after MF after microfiltration of *Chlorella* sp. *aeruginosa* algal organic matter (M-AOM)

For *M. aeruginosa*, membrane foulants were also identified through determination of DOC, UV_{254}, carbohydrate and protein concentrations for the feed and permeate (refer to Figure 6). High removal of DOC and protein were observed for the Day 12 filtration run (70% and 29%) compared to Day 35 (24% and 22%), respectively. For carbohydrates, an older culture (72%) got higher removal compared to Day 12 (20%). These results were consistent with the previous study who found that biopolymers such as polysaccharides was one of the major foulants during the ceramic microfiltration of AOM from stationary phase *M. aeruginosa* [8]. It is the deposition of macromolecular organics such polysaccharides and protein that caused serious flux decline in the membrane during the ultrafiltration of *M. aeruginosa* extracellular organic matter (EOM) [14]. EOM could also lead to serious irreversible fouling with adhesion of proteins characterized by its hydrophobicity, which could be the case for the protein reduction during the microfiltration.

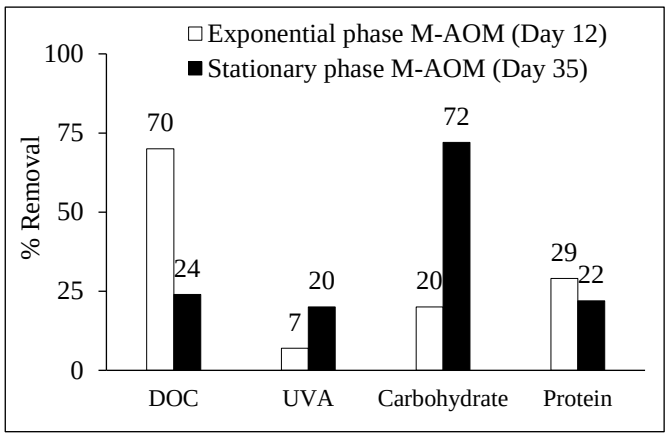

Figure 6: Removal of DOC, UVA, carbohydrate and protein after microfiltration of *M. aeruginosa* algal organic matter (M-AOM)

3.3 Membrane performance based on fluorescence EEMs removal

To further determine substances that caused ceramic membrane fouling, fluorescence emission-excitation

matrices was analyzed based on FRI. EEM components consisted of: (I) aromatic proteins I, (II) aromatic proteins II, (III) fulvic acid-like substances, (IV) soluble microbial products, and (V) humic acid-like substances.

In Figure 7, for Day 12 C-AOM, average removal for aromatic proteins I, aromatic proteins II, and soluble microbial product-like substances (SMPs) were 76, 24, and 13%, respectively. For Day 35 C-AOM, aromatic protein I & II, fulvic acid-like, SMPs, and humic acid-like substances were removed by 93, 74, 30, 70 and 13%, respectively. These indicated that aromatic proteins were one of the major foulants in ceramic microfiltration membrane for both exponential and stationary phase C-AOM. Fulvic acid-like and SMP substances in the stationary phase contributed to the fouling of the ceramic microfiltration membrane as well.

From the EEM analysis, removal of aromatic proteins, fulvic and humic acid-like substances were consistent with UV_{254} and protein being rejected by the ceramic microfiltration for the Day 35 C-AOM feed solution. While for the Day 12 C-AOM, as aromatic proteins were reduced, it could be related to the proteins being rejected; however, substances removed at exponential phase C-AOM were not enough to foul the ceramic membrane as compared to the fouling potential of stationary phase. Cake filter could have been formed during the microfiltration of C-AOM which led to greater flux decline.

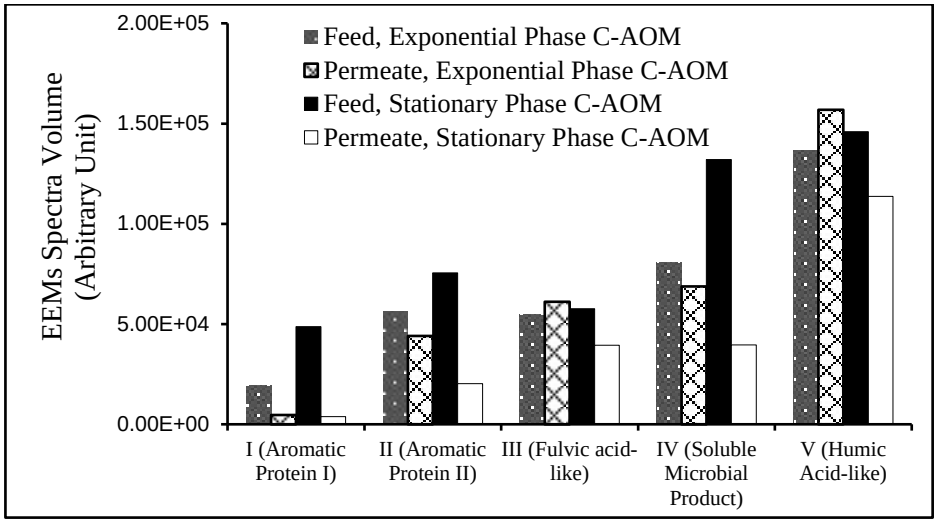

Figure 7: Excitation Emission Matrices (EEMS) for exponential and stationary phase C-AOM

For M-AOM, feed and permeate after microfiltration were analyzed using EEMs (Figure 8). Removals of aromatic protein I, aromatic protein II, fulvic acid-like substances, SMPs, and humic acid-like substances were 100, 83, 85, 47, and 21% for exponential phase and 87, 65, 54, 55, and 38% for stationary phase M-AOM, respectively. Aromatic proteins, SMPs and humic acid like substances were high in the feed solution for stationary phase M-AOM, while fulvic acid-like substances were higher for exponential M-AOM. As seen from the flux decline, compounds present in Day 35 M-AOM have more fouling potential than Day 12 M-AOM. More than 50% removal was observed for all the components in stationary phase M-AOM except for humic acid-like substances. This indicated that aromatic proteins, SMPs, and fulvic acid-like substances contributed to fouling of the membrane. Humic acid-like substances would have affected membrane fouling as significant

amount were removed during the microfiltration.

Similar with the results from the study, protein-like substances in M-AOM were rejected and contributed to the ceramic membrane fouling rather than humic-like substances [15]. Other researchers also found that at unfavourable conditions (e.g. higher temperature; more nutrients available), *Chlorella* cells become coated with extracellular organic matter (EOM) which causes higher filtration resistance [16]. Specific cake resistance was caused by either an increase in quantity of EOM or by changes in EOM characteristics. In a study on the effect of *M. aeruginosa* on membrane fouling, it showed that mid and late phase caused more fouling than the early growth phase leading to poorer flux profiles, lower permeate volumes and higher coagulant demand [17]

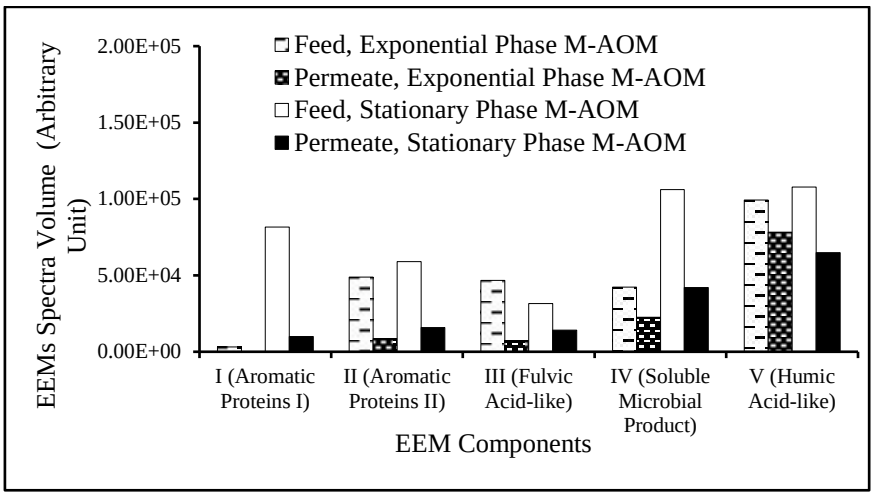

Figure 8: Excitation Emission Matrices (EEMS) for exponential and stationary phase M-AOM

3.4 Findings

From the flux decline and recovery, higher fouling potential in the ceramic microfiltration membrane was observed due to AOMs at stationary phase as compared to the exponential. This was due to high accumulation of extracellular organic matter at older culture. In comparing the fouling potential contributed by C-AOM and M-AOM, C-AOM at stationary phase had a slightly higher fouling potential than M-AOM. Flux declined to 76% and 72% from the initial CWF for C-AOM and M-AOM, respectively. However, both AOMs had similar irreversible fouling, with flux recovery of around 40%.

Based on the results of the study, higher concentration of proteins was rejected in C-AOM. For carbohydrate concentrations, almost similar amount were rejected for C-AOM and M-AOM. In DOC rejection, *M. aeruginosa* was favoured while UVA_{254} rejection for *Chlorella* sp. These results indicated that protein concentration and UV absorbing materials led to increase in fouling potential of *Chlorella* sp. compared to *M. aeruginosa*.

Considering the EEMs, high amount of aromatic protein II, fulvic acid-like substances, SMPs, and humic acid-like substances were present in C-AOM feed solution. However, only aromatic proteins and SMPS were greatly rejected while fulvic acid-like and humic acid-like substances were rejected more for M-AOM. With the higher

flux decline for *Chlorella* sp., aromatic proteins and SMPs (comprised of proteins and polysaccharides) could have contributed to its higher fouling potential.

3.5 Feed Pre-Treatment

To minimize the fouling impact caused by AOM, alum coagulation was introduced as a feed pre-treatment step before subjecting to ceramic microfiltration. Stationary phases of M-AOM and C-AOM were considered in this part of the study due to their high fouling potential, causing greater flux decline in the ceramic microfiltration.

3.6 Jar Test

The amount of alum concentration (coagulant) used for feed pre-treatment was determined using the Jar Test. Alum concentrations with the highest % DOC removal for both AOMs were used in the feed pre-treatment step before MF.

It was observed in Figure 9 that at 2.5 mg/l of alum, C-AOM substances were removed (coagulated and settled) while 5.0 mg/l for M-AOM. Minute and charged particles, along with the suspended materials were removed and settled which lessens the fouling potential caused by AOMs in ceramic microfiltration membranes.

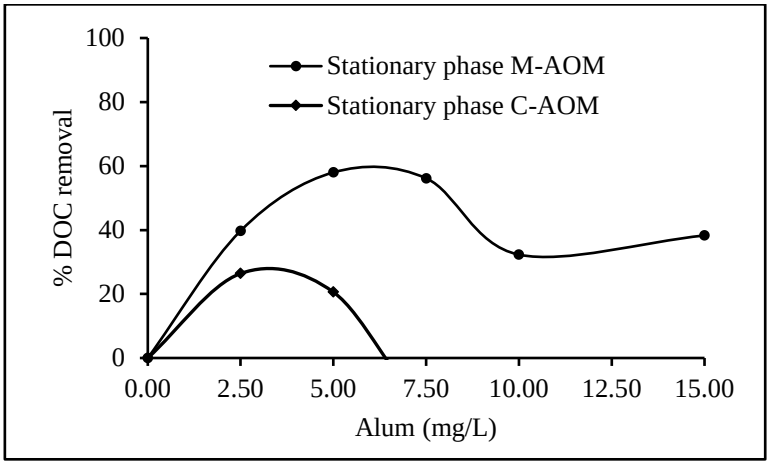

Figure 9: Jar test for stationary phase *Chlorella* sp. and *M. aeruginosa*

3.7 Membrane fouling and recovery after coagulation

Comparison of the flux decline for method 1: microfiltration only (MF) & method 2: alum coagulation coupled with microfiltration (alum + MF) were conducted to evaluate the effect of alum coagulation in membrane fouling. Flux decline for filtration runs treated with coagulation is given in Figure 10.

Both feed pre-treated AOM samples at stationary phase achieved lower flux decline as compared to untreated AOM. Fouling potential due to M-AOM and C-AOM was minimized based from the decrease in flux decline from 60-75% for microfiltration only to around 25% for alum coagulation coupled with microfiltration.

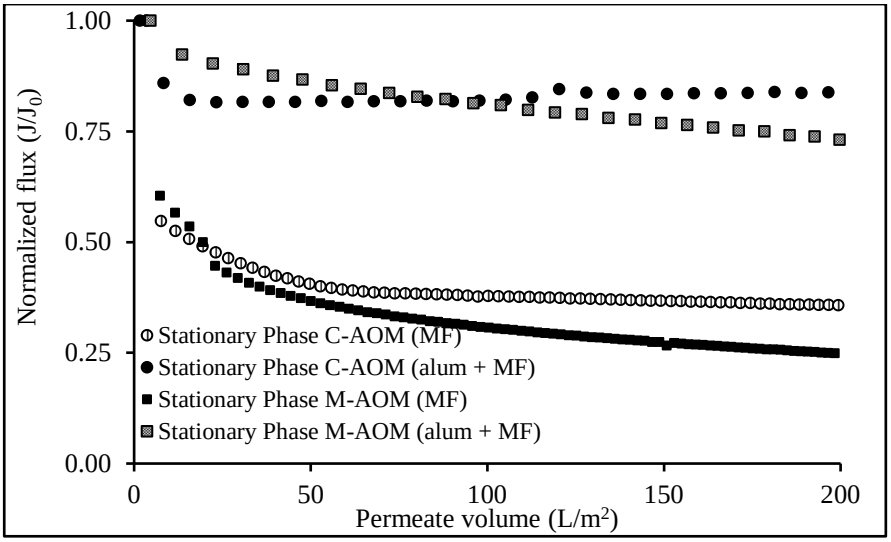

Figure 10: Comparison of flux decline for M-AOM and C-AOM at stationary phase (MF & alum coagulation + MF)

In Figure 11, flux recoveries for feed pre-treated C-AOM and M-AOM increased from around 37-40% to 84-86%, respectively. Irreversible fouling was reduced to 40% with the employment of alum coagulation. This study showed that AOM fouling potential caused by *Chlorella* sp. and *M. aeruginosa* can be minimized by incorporating a feed pre-treatment process such as alum coagulation before ceramic microfiltration.

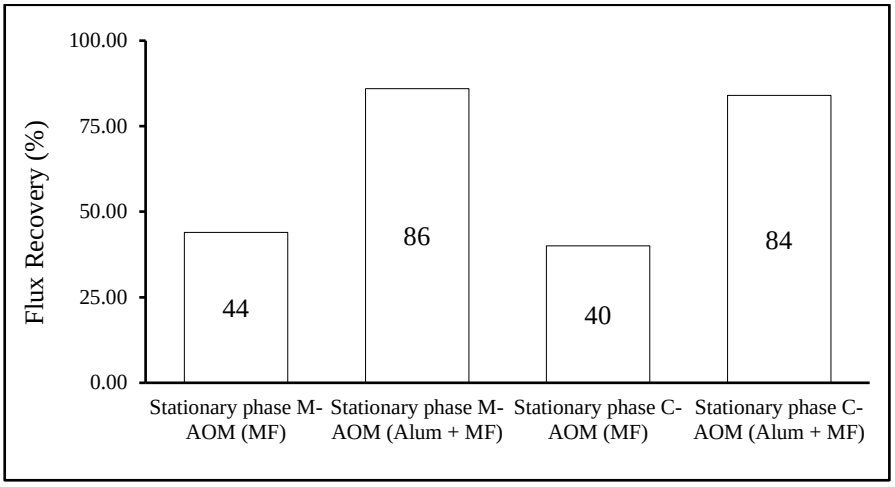

Figure 11: Flux recovery for stationary phases *Microcystis* (M-AOM) and *Chlorella* sp. (C-AOM) after alum coagulation

3.8 Microfiltration performance based on percent (%) removal of DOC, UV_{254}, CH_2O, proteins after coagulation pre-treatment

The performance of coagulation coupled with microfiltration was evaluated based on the removal of DOC, UV, carbohydrates and proteins (see Figure 12). It was then compared with removal rates for the ceramic microfiltration runs. Results showed that after coagulation pre-treatment, high removal of organic molecules

was observed. DOC removal increased from 14-24% (MF only) to 58-64% (alum + MF) for C-AOM and M-AOM, respectively. However, other parameters showed no significant difference with respect to the removal rates of UV, CH2O, and proteins in ceramic microfiltration alone.

High percentage of organic molecules (% DOC) removed during alum coagulation could have been the reason for the decrease in flux decline due to AOMs. Based on the findings of researchers, majority of the flux decline in the ceramic microfiltration was due to the large amount of organic matter present in the feed of M-AOM [18]. Around 51% of total DOC of feed, primarily with high molecular weight (MW) hydrophobic molecules deposited on the ceramic membrane surface formed into a thick and dense outer layer. These organic molecules and UV absorbing materials together with macromolecular characteristics of AOM could have contributed to higher fouling impact to the ceramic membrane. Different characteristics of the organic molecules present in *Chlorella* sp. and *M.aeruginosa* feed solutions could have interacted to form larger structure due to its surface charge, and so were more easily rejected by the membrane after coagulation pre-treatment.

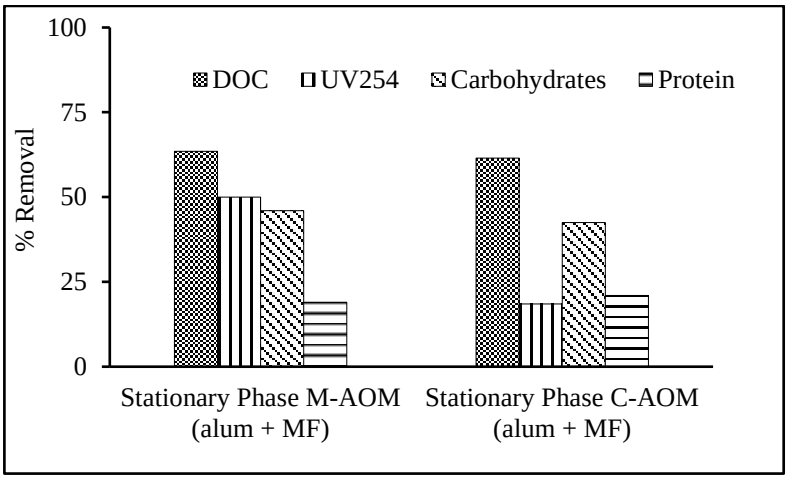

Figure 12: Removal of DOC, UVA, carbohydrate and protein for stationary phase M-AOM and C-AOM (alum + MF)

3.9 Membrane performance based on fluorescence EEMs removal after coagulation pre-treatment

High removal for all EEM components was observed in both AOM (refer to Figure 13). This could be attributed as reversible foulants and thus resulted to higher flux recovery. Coagulation as a feed pre-treatment resulted to the removal of high and low molecular weight substances present in AOM. These substances could have caused the reduction of fouling potential contributed by AOM. Similar with the findings in a study, which resulted to removal of high molecular weight algal compounds due to ability of coagulation process in removing EOM polysaccharides of several algal species, C*hlorella* sp., and *Cyanobacterium pseudonabaena* [19]. Removal of high molecular weight molecules (biopolymers) reduced the fouling due to AOM [20]. Low MW AOM compounds were also reduced with the application of coagulation as a feed pre-treatment [18]. The use of alum and aluminium chlorohydrate (ACH) reduced reversible and irreversible fouling caused by C-AOM and M-AOM at stationary phase, achieving 70% improvement in the flux as compared to untreated feed AOM [15].

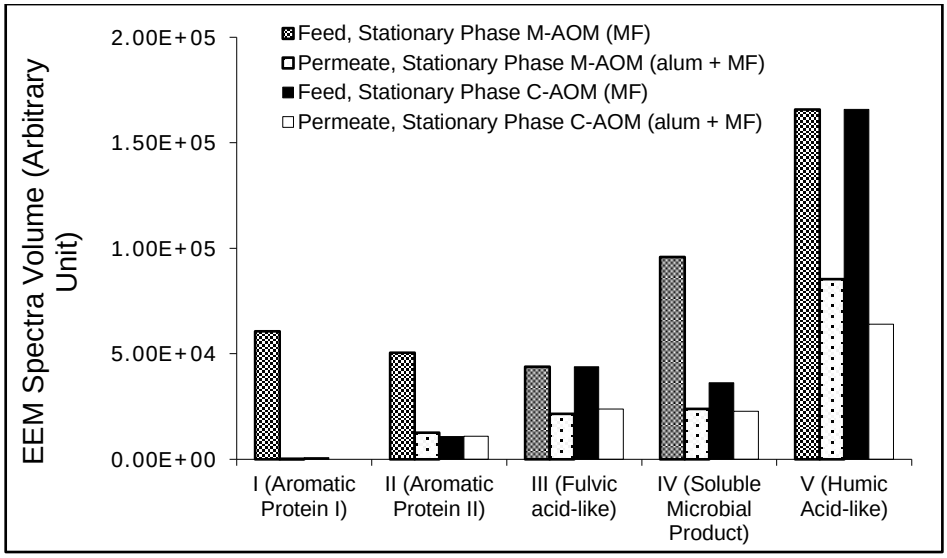

Figure 13: Removal in EEM components of stationary phase C-AOM and M-AOM

4. Conclusion and Recommendations

Coagulation as a pre-treatment is effective in reducing the fouling potential of algal organic matter from *Chlorella* sp. and *M. aeruginosa.* Flux recovery, a measure of fouling reversibility in the ceramic microfiltration membrane increased from 40% to 80% with the application of alum coagulation as a feed pre-treatment step. This is very significant to membrane processes as fouling is the major drawback of membrane filtration system. Coagulation pre-treatment is indeed effective in reducing the flux decline and improving the fouling reversibility in the ceramic microfiltration system. The need to use chemical treatment for membrane cleaning will possibly be reduced, thus prolonging the life of ceramic membranes. However, there is a need for further evaluation on specific characteristics of AOM excreted by algae to improve fouling mitigation in ceramic microfiltration systems.

Low pressure membrane technology coupled with coagulation as a feed pre-treatment process is effective in treating algal contaminated water sources. More than the ability of the technology to minimize the impacts of fouling, the technology has also demonstrated that algae-contaminated water can still be a source of potable water. As water scarcity is becoming an issue all over the world, research scientists and engineers should pursue development of new technologies so that people can adapt with the increasing demand for water and the continuous change in the environment. Watersheds which are critical sources of water supply have been deteriorating due to anthropogenic activities and change in land use. The need to adopt a more advanced and efficient technology is needed to maximize the available water supply, address demand and achieve water security and ensure public health safety, particularly in the developing countries.

References

[1] UNICEF. 2013. UNICEF. Water, Sanitation and Hygiene Annual Report. Retrieved December 10, 2016, from http://www.unicef.org/wash/files/WASH_Annual_Report_Final_7_2_Low_Res.pdf

[2] WHO/UNICEF JMP. 2015. WHO/UNICEF Joint Monitoring Programme for Water and Sanitation. Philippines: Estimates on the Use of Water Sources and Sanitation Facilities (1980-2015). June 2015. Retrieved December 10, 2016, from http://www.wssinfo.org/documents/?tx_displaycontroller%5Btype%5D=country_files

[3] S. Arhin, N. Bannadda, A. Komakech, I. Kabenge, J. Wanyama. "Membrane fouling control in low pressure membranes: A review on pretreatment techniques for fouling abatement." Environmental Engineering Research, vol. 21(2), pp. 109-120, June 2016.

[4] C. Bolch, and Blackburn, S.I. "Isolation and purification of Australian isolates of the toxic cyanobacterium Microcystis aeruginosa Kutz." Journal of Applied Phycology, vol 8, pp. 5-13, Jan. 1996.

[5] L. Domínguez, M. Rodríguez, D. Prats. "Effect of different extraction methods on bound EPS from MBR sludges. Part I: influence of extraction methods over three-dimensional EEM fluorescence spectroscopy fingerprint." Desalination, vol 261 (1-3), pp. 19-26, Oct 2010.

[6] M. Dubois, K. Gilles, J. Hamilton, P. Rebers, and F. Smith. "Colorimetric method for determination of sugars and related substances." Anal. Chem, vol. 28, pp. 350-356, Mar. 1956.

[7] W. Chen, P. Westerhoff, J. Leenheer, and K. Booksh. "Fluorescence excitation emission matrix regional integration to quantify spectra for dissolved organic matter." Environmental Science and Technology, vol. 37 (24), pp. 5701-5710, Nov. 2003.

[8] X. Zhang, L. Fan, and F. Roddick. "Influence of the characteristics of soluble algal organic matter released from Microcystis aeruginosa on the fouling of ceramic microfiltration membrane." Journal of Membrane Science, vol. 425-426, pp. 23-29, Jan. 2013.

[9] A. Abdelrasoul, H. Doan, H., and A. Lohi. "Fouling in membrane filtration and remediation methods, mass transfer – advances in sustainable energy and environment oriented numerical modeling." Dr. Hironori Nakajima Ed. Department of Chemical Engineering, Ryerson University, Victoria Street, Toronto, Ontario, Canada, 2013, pp. 195-218, 2013.

[10] J. Baker, and Dudley, L. "Biofouling in membrane systems - A review." Desalination, vol. 118 (1-3), pp. 81-89, Sep. 1998.

[11] N. Her, G. Amy, H. Park, and S. Myoungsuk. "Characterizing algogenic organic matter (AOM) and evaluating associated NF membrane fouling." Water Research, vol. 38, pp. 1427-1438, Mar. 2004.

[12] N. Park, B. Kwon, S. Kim, and J. Cho. "Characterizations of the colloidal and microbial organic matters with respect to membrane foulants." Journal of Membrane Science, vol. 275 (1-2), pp. 29-36, Apr. 2006.

[13] L. Dramas, and JP. Croue. “Ceramic membrane as a pretreatment for reverse osmosis: interaction between marine organic matter and metal oxides.” Desalination and Water Treatment, vol. 51 (7-9), pp. 1781-1789, 2013.

[14] F. Qu, H. Liang, J. He, J. Ma, Z. Wang, H. Yu, and G. Li. “Characterization of dissolved extracellular organic matter (dEOM) and bound extracellular organic matter (bEOM) of Microcystis aeruginosa and their impacts on UF membrane fouling.” Water Research, vol. 46 (9), pp. 2881-90, June 2012.

[15] X. Zhang, M. Devanadera, F. Roddick, L. Fan, and M. Dalida. “Impact of algal organic matter release from Microcystis aeruginosa and Chlorella sp. on the fouling of a ceramic microfiltration membrane.” Water Research, vol. 103, pp. 391-400, Oct. 2016.

[16] S. Babel, S. Takizawa, and H. Ozaki. “Factors affecting seasonal variation of membrane filtration resistance caused by Chlorella algae.” Water Research, vol. 36 (5), pp. 1193-1202, Mar. 2002.

[17] Y. Goh, J. Harris, and F. Roddick. “Impact of Microcystis aeruginosa on membrane fouling in a biologically treated effluent.” Water Science and Technology, vol. 63 (12), pp. 2853-2859, 2011.

[18] X. Zhang, L. Fan, and F. Roddick. “Understanding the fouling of a ceramic microfiltration membrane caused by algal organic matter released from Microcystis aeruginosa.” Journal of Membrane Science, vol 447, pp. 362-268, Nov. 2013.

[19] H. Bernhardt, O. Hoyer, H. Schell, and B. Lusse. “Reaction mechanisms involved in the influence of algogenic matter on flocculation.“ Zeitschrift fu Wasser- und Abwasser-forschung, vol. 18 (1), pp. 18-30, 1985.

[20] X. Zhang, L. Fan, and F. Roddick. “Feedwater coagulation to mitigate the fouling of a ceramic MF membrane caused by soluble algal organic matter.” Separation and Purification Technology, vol. 133, pp. 221-226, Sep. 2014.