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RESEARCH PAPER

Optimization of Detention Time for Domestic Wastewater Treatment using Phycoremediation

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Abstract

In developing countries, wastewater treatment is confined to secondary systems. Hence even after treatment, wastewater effluent has a high level of nutrients which causes eutrophication and has destructive impacts on receiving bodies. Literature reveals that phycoremediation can be the best solution to address the problem faced but is time-consuming, ranging from days to weeks. Hence, the present study aimed to determine an optimum detention time for the microalgal system to treat domestic wastewater. The retention time for treatment in the study was divided into an aeration and settling periods. During the study, aeration time varied from 2 hours to 24 hours, followed by 1-hour settling period for each aeration time. Optimum detention time for microalgal treatment was obtained at 11 hours of detention time (10 hours aeration and 1-hour settling). Parameters analyzed during the study were pH, EC, TS, TSS, TDS, nitrate, phosphate, ammonia, COD and DO. However, the main focus was on nutrients (phosphate and ammonia) and organics (COD) removal while determining the optimum detention time. Maximum removal efficiency obtained for COD, ammonia and phosphate for non-filtered effluent was 75.61%, 90.63% and 83.29%, respectively. However, removal efficiency further increased for filtered effluents to 86.34%, 100% and 91.12% for COD, ammonia and phosphate, respectively. Algal treatment offers an ecologically safe and more affordable system for nutrient removal and eliminates the need for tertiary treatment.

Keywords: Chlorella Vulgaris, ammonia, phosphate, photosynthesis.

INTRODUCTION

Urbanization and industrialization impact the utilization of water assets in daily exercises, which leads to the depletion of water resources. At present, nearly 50% of the global population is suffering from water scarcity at least 30 days a year, and the number might increase to 75% by 2050 (Boretti and Rosa, 2019). The wastewaters originating from the point or non-point sources, if disposed in a nearby water body without any treatment, adversely affect the water quality and aquatic ecosystem (Renuka et al., 2013). In the present scenario, the main aim of wastewater treatment is to treat sewage to the permissible limits and reuse the treated wastewater to retain the accessible freshwater.

In India, only one-third of the total sewage is treated, generating a massive amount of untreated sewage, which prompts natural issues, eutrophication, algal boom, uncontrolled spread of macrophytes, oxygen exhaustion, and loss of critical species (Renuka et al., 2013). As freshwater bodies have a limited self-purification capacity, the introduction of untreated sewage can result in water scarcity. In developing countries, wastewater treatment is confined to

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secondary systems. Hence even after treatment, wastewater effluent has a high level of nutrients which causes eutrophication and has destructive impacts on receiving bodies (Moondra et al., 2021b). As water resources are depleted and polluted by an increasing human population globally, there is an ever-growing need for sustainable, productive, and economically viable wastewater treatment systems (Denny, 1997). Therefore, the current need is to minimize water consumption and return it to the earth with minimum possible pollution because of the limited potential of self-purification in water bodies (Brenner et al., 2008).

Improved innovation for expelling nutrients would require an expansion in vitality utilization of about 60–80%. The absolute worldwide measure is still deficient in addressing present issues, particularly in financially insufficient municipalities or under-developed countries (Cabanelas et al., 2013).

Domestic wastewater treatment methods depend on physico-chemical and, most importantly, biological processes, where multiple mixes of anaerobic, aerobic and anoxic zones are required. For the most part, these procedures involve high maintenance and operational costs, complex tasks, and vast volumes of waste sludge (Arbib et al., 2014). Tertiary treatment innovations are coagulation–sedimentation, adsorption, biological nutrient removal (BNR) processes, ion exchange, membrane technology, biological filtering, ozonation, etc. However, these systems have numerous limitations; for instance, the precariousness of the treatment impact, high speculation, high treatment cost and trouble in being promoted on an enormous scale (Lv et al., 2017). Going into a low-carbon time, vitality sparing with low CO_2 creating and supplement reusing wastewater treatment procedures are of tremendous interest (Sukacova et al., 2015). Thus proficient, steady and minimal effort for tertiary wastewater treatment frameworks are basics in decreasing nitrogen and phosphorus concentrations in secondary effluent.

Researchers have recommended that microalgae for wastewater treatment are suitable for controlling pollution, eutrophication in water bodies and providing potable water (Abdel-Raouf et al., 2012). Wastewater constitutes an excellent opportunity for microalgae as it can be considered a medium for growing them at a low cost (Delrue et al., 2016). Domestic wastewater is enriched with a substantial amount of NH_3-N, PO_4-P and other essential nutrients, which support algal biomass production (Feng et al., 2011, Lee et al., 2015). Microalgal-based treatment is also one of the best solutions for ecological issues like global warming (Lu et al., 2010, Olguin et al., 2013). However, various literature shows that though microalgae is an efficient technology for organics and nutrient removal, the removal mechanism is time-consuming, with detention time ranging from days to weeks (Sydney et al., 2011). Detention time is the most influential factor which directly affects the nutrient removal rate, growth rate and biomass concentration in a microalgal treatment system (Xu et al., 2015). It also influences energy consumption, cost and footprint of the treatment. Thus, the present study focuses on working out the optimum detention time required for microalgal treatment of domestic wastewater, which could be effectively executed in a real-life scenario.

MATERIALS AND METHODS

In the present study, domestic wastewater treatment was done using *Chlorella Vulgaris,* provided by Phycolinc Technologies Pvt. Ltd., an Ahmedabad-based consultancy. The sewage pumping station near the experimental site was the source of the domestic wastewater. No pre-treatment of wastewater was done before the study. The best removal of physico-chemical parameters was observed during the previous analysis at 30% microalgal concentrations compared to other concentrations studied (Moondra et al., 2020b). Hence 30 % microalgal concentration is taken for the present study to optimize the detention time for microalgal treatment. The optimum detention time is the one on which the system should run to have the highest possible reductions in organic load and nutrients in the least durations.

Fig. 1. Experimental setup for the study

Table 1. Aeration timings and duration for both the beakers

Beaker A	Beaker B	Duration (Hrs.)
10:00 am – 12:00 noon		02
	10:00 am - 2:00 pm	04
1:00 pm – 7:00 pm		06
	3:00 pm - 9:00 am	18
8:00 pm - 10:00 am		14
	10:00 am- 8:00 pm	10
11:00 am- 7:00 pm		08
	9:00 pm - 9:00 am	12
8:00 pm - 12:00 noon		16
	10:00 am - 10:00 am	24
1:00 pm - 9:00 am		20
	11:00 am - 9:00 am	22

In the present study, the system was operated at various aeration times, i.e., 2, 4, 6, ……, 24 hours followed by 1 hour of settling time respectively for each aeration time. The optimum detention time was determined using two borosilicate glass beakers of 2-L capacity with a working volume of 1800 mL, i.e., 540 mL (30% microalgae) and 1260 mL of raw domestic wastewater, shown in Figure 1.

Before starting the study, the mixture (microalgae and domestic wastewater) in both beakers was aerated for the first 24 hours to acclimatize the microalgae to the new environment. After the acclimatization period, the supernatant was decanted after one hour of settling. After that, raw wastewater was again added to both the beakers and aerated at different aeration times, which varied from 2 hours to 24 hours. The time slot for aeration in both the beakers to evaluate optimum detention time is shown in Table 1. Similar timings were applied for different sets to match the duration.

The parameters analyzed during the study were pH, ammonia, phosphate, chemical oxygen demand (COD), electrical conductivity (EC), total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), nitrate and dissolved oxygen (DO) via standard testing procedures

Table 2. Raw wastewater characteristics

Parameter	Unit	Mean ± SD.
pH		7.62 ± 0.87
EC	mS/cm	1.76 ± 0.91
TDS	mg/L	881.94 ± 96.45
TSS	mg/L	1331.11 ± 282.83
TS	mg/L	2213.06 ± 351.31
COD	mg/L	154.7 ± 46.70
Phosphate	mg/L	9.17 ± 0.60
Ammonia	mg/L	2.32 ± 0.97
Nitrate	mg/L	1.79 ± 0.39
DO	mg/L	0.14±0.17

as prescribed in APHA 2012. Filtration is considered one of the most economical harvesting methods for microalgae (Hwang et al., 2016); hence a coarse filter of pore size 4.0 - 5.5 μm was used to filter the effluent. The variation in parameters after treatment was studied in both conditions, i.e., before and after the filtration.

Microalgae were added only on the first day of the study. The study was repeated thrice to observe the effect of detention time and understand how long microalgae can effectively sustain the system.

RESULTS AND DISCUSSION

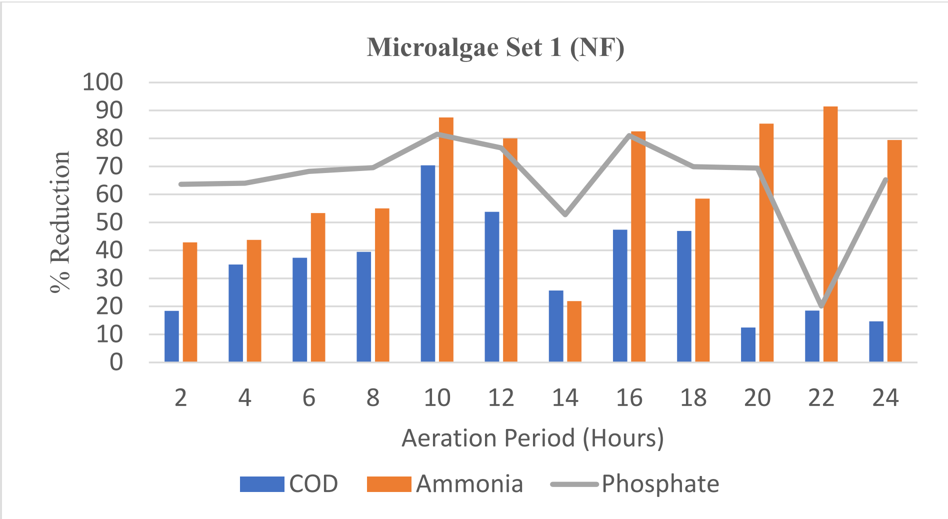
The productivity of the microscopic photosynthetic organisms is influenced by the availability of nutrients and other physico-chemical factors, for example, pH, the intensity of light, photoperiod, temperature and biological variables, i.e., availability of pathogen and competition with micro-organisms over the accessible nutrients (Delgadillo-mirquez et al., 2016).

Different aeration periods followed by settling in both the reactor was arranged so that the system worked continuously. The reactor was continuously working once its start till the end of the study to determine the effectiveness of microalgae as the bioagent for nutrient and organic removal. Raw domestic wastewater collected to study nutrient and organic load removal through microalgae at different detention times showed huge variations. Mean and standard deviation (SD) is reported in Table 2 for all the parameters analyzed during the study.

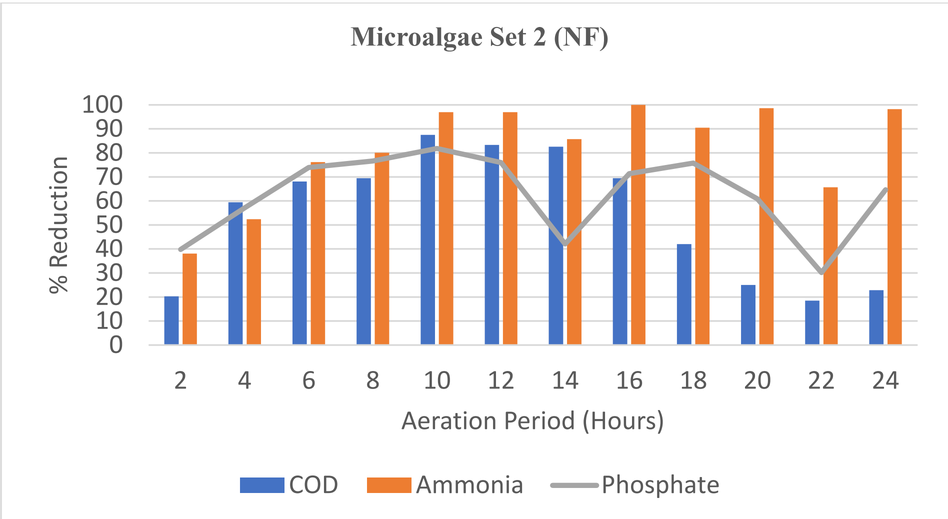
Chlorella Vulgaris efficiently removed the pollutants from the raw wastewater (without pre-treatment) even at a lower detention time. In the case of non-filtered effluent, the COD reduction was 18.37%, i.e., just after the 3 hours of starting the experiment, i.e., 2 hours aeration time and 1 hour settling time, whereas maximum reduction, i.e., 87.5% (28.8 mg /L), was obtained at 10 hours of aeration time, as shown in Figure 2.

Chlorella Vulgaris showed higher efficiency in the case of nutrient removal in comparison to organic matter. In the case of ammonia, removal efficiency ranged from 21.87% to 100%. When the detention time was 11 hours (10 hours aeration and 1-hour settling), removal was maximum in ammonia concentration, i.e., below the detectable limit. Reduction in ammonia leads to an increase in nitrate concentration due to the nitrification process (Cuellar-Bermudez et al., 2017). Nitrate concentration in non-filtered effluent at 11 hours detention time reached 9.48 mg/L. However, a reduction in phosphate concentration was observed between 20.15% to 85.00%, as shown in Figure 2. The lowest phosphate concentration observed was 0.28 mg/L at 11 hours of detention time.

While determining the optimum detention time for microalgal treatment main focus was on



(a)



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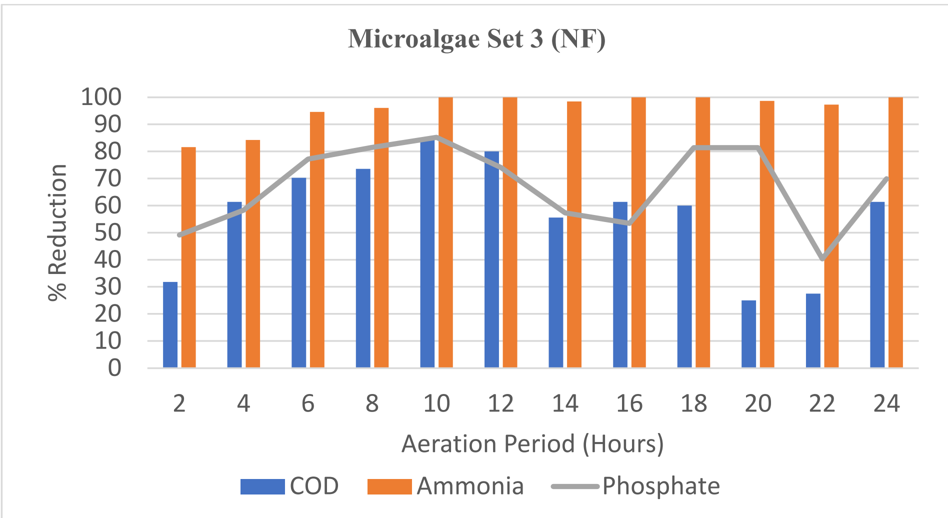


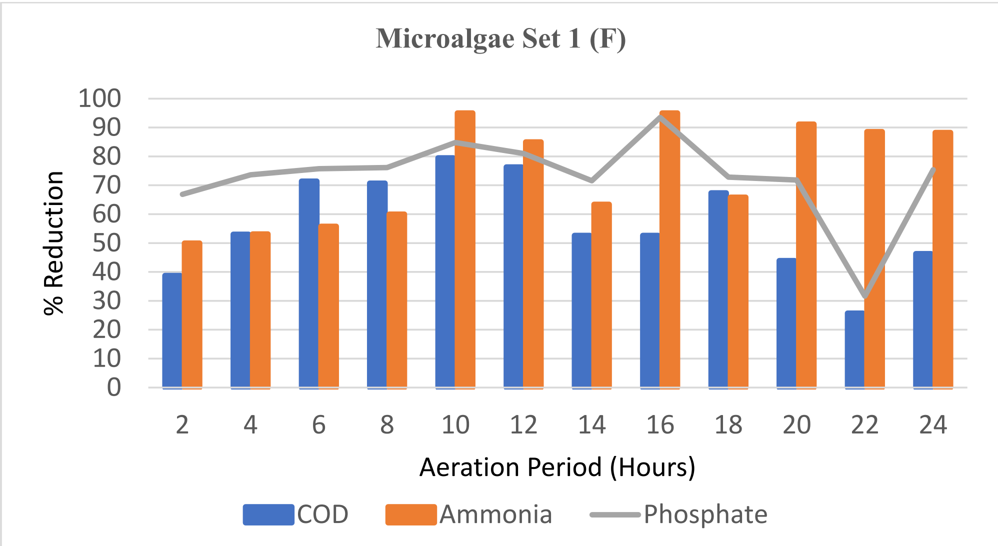
(c)

Fig. 2. Reduction in COD, ammonia and phosphate at different aeration times for non-filtered effluents when treated with microalgae (a) Set 1 (b) Set 2 (c) Set 3

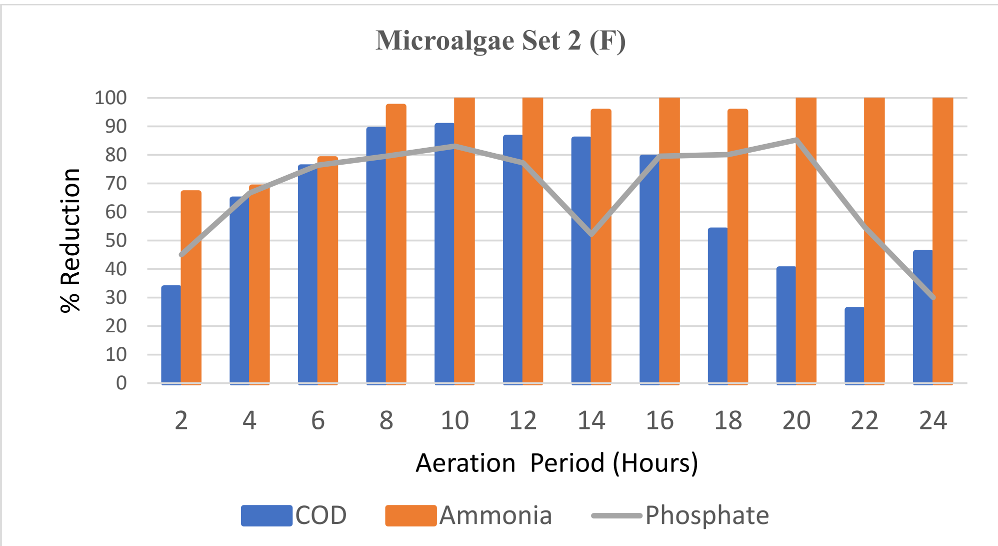
organic load and nutrients (ammonia and phosphate). However, reductions in solids (TS, TDS and TSS) and EC were also studied. The maximum reduction observed was 11.17%, 33.33%, 20.55% and 12.71%, respectively, for TDS, TSS, TS and EC in non-filtered effluents. pH and DO were also analyzed in the effluents. Both pH and DO were increased in the effluent during all the detention time. DO and pH concentration reached 6.90 mg/L and 8.90, respectively, at 11 hours of detention time.

Similarly, the study was conducted on filtered effluents also. In filtered effluent, reductions in all the parameters were increased compared to the non-filtered effluents. The reduction observed in COD was least at 2 hours aeration time (33.33%) and a maximum reduction of 92.5% at 10 hours aeration time, as shown in Figure 3.

Similar trends were observed in the case of nutrients (ammonia and phosphate) also. Ammonia reduction ranged between 50% to 100%. The least reduction was observed during

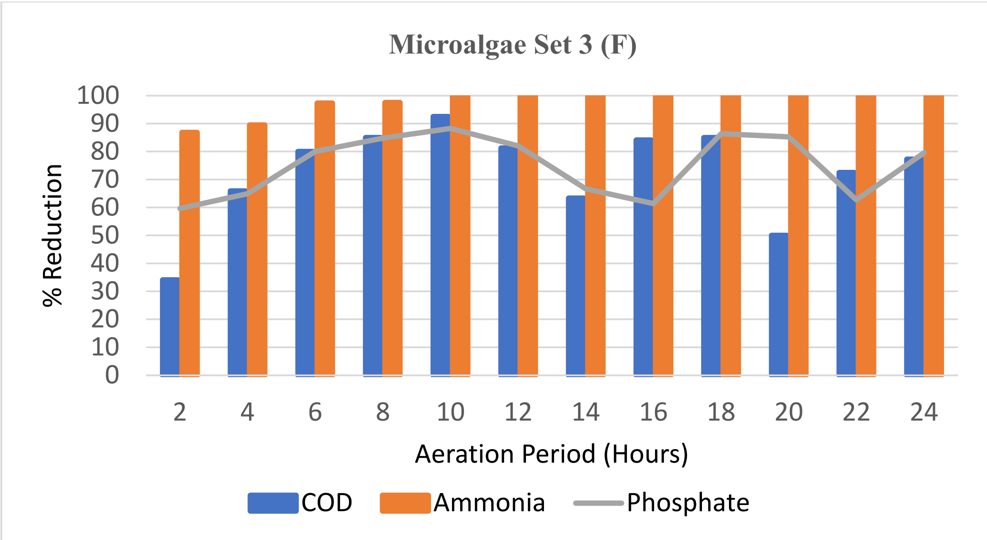


(a)



(b)

Fig. 3. Reduction in COD, ammonia and phosphate at different aeration times for filtered effluents when treated with microalgae (a) Set 1 (b) Set 2 (c) Set 3



(c)

Continiued Fig. 3. Reduction in COD, ammonia and phosphate at different aeration times for filtered effluents when treated with microalgae (a) Set 1 (b) Set 2 (c) Set 3

the detention period of 3 hours. In contrast, the maximum reduction, i.e., 100% (concentration of ammonia in filtered effluent was below detectable limit), was firstly found at 11 hours of detention time. However, a reduction in phosphate concentration varied between 42.11% to 93.18%. The amount of phosphate concentration found in filtered effluent at optimum detention time (11 hours) was 0.22 mg/L, as shown in Figure 3.

However, reductions in solids (TS, TDS and TSS) and EC were also studied. The maximum reduction observed was 27.27%, 41.36%, 29.35% and 24.87%, respectively, for TDS, TSS, TS and EC for filtered effluents. In addition to this, pH and DO were also analyzed in the effluents. Both pH and DO were increased in the effluent at all the detention times. DO and pH concentration reached 6.90 mg/L and 8.92, respectively, at 11 hours.

Concerning optimum detention time for microalgae, *Chlorella Vulgaris* alone functioned admirably to expel the NH_3-N and phosphate. In light, the NH_3-N removal was rapid compared to the dark (Kshirsagar, 2013), affecting the COD removal under similar conditions. However, COD reductions were lesser than nutrients as nitrate formation affects the COD removal (Moondra et al., 2020a). The photosynthesis process enhances with expanding light intensity until the light saturation point (Park et al., 2011). Light conveyance has been concentrated as a significant working component in algal culture. Light is also essential for NADPH and ATP synthesis that generates carbon skeletons (Sousa et al., 2013) and affects nitrifiers' performance. Uniform dissipation of light and proper penetration likewise helps to maintain a strategic distance from the self-shading effect.

Light acts as the quickening agent during the nutrient uptake in a mixotrophic condition (Aslan and Kapdan, 2006). Likewise, nitrogen and phosphorus expulsion efficiencies depend upon the media structure and ecological conditions, for example, the underlying nutrient concentration, the light intensity, the nitrogen/phosphorus proportion, the light/dark cycle or microalgal species. The dark-light cycle is crucial for microalgae-based wastewater treatment (Lee et al., 2015). The present study also observed that increasing the detention time does not increase the removal efficiency of the system. Dark periods between short flashes of light can enhance photosynthesis efficiency, especially under high light intensity (Park and Lee, 2001). However, continuous illumination inhibited the denitrification process (Jia and Yuan, 2016), increasing oxygen concentration.

The pH variation impacted algal cell physiology and affected the form of nutrients by increasing alkalinity (Kube et al., 2018). An increase in the pH of the effluents was due to photosynthesis (Schumacher and Sekoulov, 2003). At high pH, auto-flocculation is observed, which contributes to removing the suspended algae from the effluent and lessening the phosphorus concentration via interaction between cations and phosphates to precipitate as an algal–mineral complex (Moondra et al., 2021a). Microalgal treatment also leads to the disinfection of pathogens (Goncalves et al., 2017).

Microalgae comprise 40-50% of carbon, nitrogen (1% - 10%) and phosphorus about 1.3% with a typical formula $C_{106}H_{181}O_{45}N_{16}P$. The order of utilizing nitrogen sources by *Chlorella Vulgaris* follows the NH_4>NO_3>N_2 rule and does not utilize other nitrogen sources until ammonia is depleted (Moondra et al., 2020a). Biomass assimilation, volatilization and nitrification were the principal contributors to nitrogen expulsion. Nitrogen is also absorbed and fused into biomass through cell blends during the development of heterotrophs and autotrophs to a lesser degree (Foladori et al., 2018).

$$NO_3 + CO_2 + \text{microalgae} + \text{sunlight} \rightarrow \text{protein}$$

$$NH_3 + CO_2 + \text{microalgae} + \text{sunlight} \rightarrow \text{protein}$$

In the present study, phosphorus evacuation was because of adsorption onto the cells' surface, trailed by digestion by the biomass (Su et al., 2011) for a part of the phosphate ions. Phosphorus is taken into the cell membrane through energized transport and assimilated into nucleotides for RNA and ATP formation (Li et al., 2011). It is stored in organic compounds such as nucleic acids, phospholipids, and proteins. Microalgal cells use phosphate for energy transfer, photosynthesis, DNA and RNA and are stored in excess far beyond the requirement in the form of polyphosphate within algal biomass (Hwang et al., 2016). An increase in the dissolved oxygen concentration during the experiment; resulted from algal growth, indicating a prevalence of photosynthetic activity over heterotrophic carbon-oxidation and nitrification (Delgadillo-mirquez et al., 2016); it was also due to external aeration.

COD decrease initially was low because of acclimation of life forms in new conditions, and besides, the carbon might be some colloidal, gradually biodegradable material (Su et al., 2011). The removal of COD was attributed to the attached growth of micro-organisms and biomass. The removal of COD resulted due to the development of micro-organisms and biomass. In the meantime, they could utilize oxygen provided by the photosynthesis of algal to disintegrate the organic matter in raw wastewater (He and Xue, 2010).

Reduction in solids was observed with time in the microalgal treatment system. However, the decrease in TDS was the least compared to TS and TSS. An increase in TDS might be the presence of filamentous microalgae in suspension during the initial phase. But with time, the settling of microalgae was predominant during the middle and last stage of the study leading to a decrease in TDS concentration. Variation in EC was similar to TDS.

CONCLUSIONS

The present study results depicted domestic wastewater treatment with *Chlorella Vulgaris* as a biotechnological approach. The treatment was quite efficient in much lower detention time (11 hours), unlike mentioned by several researchers in the last few decades. The maximum reduction observed for COD, phosphate and ammonia in non-filtered effluents at the optimum detention time was 87.5%, 85.0% and 100%, respectively. The reduction further increased to 92.5%, 93.18% and 100%, respectively, for COD, phosphate and ammonia in case of the filtered effluent when treated with microalgae. Therefore, it was clear that the proposed treatment approach offers an eco-friendly, low-cost and efficient technology for domestic wastewater treatment without tertiary treatment.

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The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

REFERENCES

Abdel-Raouf, N., Al-Homaidan, A. A. and Ibraheem, I. B. M. (2012). Microalgae and wastewater treatment. Saudi J. Biol. Sci., 19(3); 257–275.

Arbib, Z., Ruiz, J., Alvarez-Díaz, P., Garrido-Perez, C. and Perales, J. A. (2014). Capability of different microalgae species for phytoremediation processes: wastewater tertiary treatment, CO_2 bio-fixation and low cost biofuels production. Water Res., 49; 465–474.

Aslan, S. and Kapdan, I. K. (2006). Batch kinetics of nitrogen and phosphorus removal from synthetic wastewater by algae. Ecol. Eng., 28(1); 64–70.

Boretti, A. and Rosa, L. (2019). Reassessing the projections of the world water development report. NPJ Clean Water., 2; 15-20.

Brenner, K., You, L. and Arnold F.H. (2008). Engineering microbial consortia : A new frontier in synthetic biology. Trend Biootechnol., 26(9); 483–489.

Cabanelas, I. T. D., Ruiz, J., Arbib, Z., Chinalia, F. A., Garrido-Perez, C., Rogalla, F., Nascimento, I. A. and Perales, J. A. (2013). Comparing the use of different domestic wastewaters for coupling microalgal production and nutrient removal. Bioresour. Technol., 131; 429–436.

Cuellar-Bermudez, S. P., Aleman-Nava, G. S., Chandra, R., Garcia-Perez, J. S., Contreras-Angulo, J. R., Markou, G., Muylaert, K., Rittmann, B. E. and Parra-Saldivar, R. (2017). Nutrients utilization and contaminants removal: A review of two approaches of algae and cyanobacteria in wastewater. Algal Res., 24; 438–449.

Delgadillo-mirquez, L., Lopes, F., Taidi, B., and Pareau, D. (2016). Nitrogen and phosphate removal from wastewater with a mixed microalgae and bacteria culture. Biotechnol. Rep., 11; 18–26.

Delrue, F., Alvarez-Díaz, P. D., Fon-Sing, S., Fleury, G., and Sassi, J. F. (2016). The environmental biorefinery: Using microalgae to remediate wastewater, a win-win paradigm. Energies., 9(3); 132-151.

Denny, P. (1997). Implementation of constructed wetlands in developing countries. Water Sci. Technol., 35(5); 27–34.

Feng, Y., Li, C., and Zhang, D. (2011). Lipid production of Chlorella vulgaris cultured in artificial wastewater medium. Bioresour. Technol., 102(1); 101–105.

Foladori, P., Petrini, S., Nessenzia, M. and Andreottola, G. (2018). Enhanced nitrogen removal and energy saving in a microalgal-bacterial consortium treating real municipal wastewater. Water Sci. Technol., 78(1); 174–182.

Goncalves, A. L., Pires, J. C. M. and Simoes, M. (2017). A review on the use of microalgal consortia for wastewater treatment. Algal Res., 24; 403–415.

He, S. and Xue, G. (2010). Algal-based immobilization process to treat the effluent from a secondary wastewater treatment plant (WWTP). J. Hazard. Mater., 178; 895–899.

Hwang, J. H., Church, J., Lee, S. J., Park, J. and Lee, W. H. (2016). Use of microalgae for advanced wastewater treatment and sustainable bioenergy generation. Environ. Eng. Sci., 33(11); 882–897.

Jia, H. and Yuan, Q. (2016). Removal of nitrogen from wastewater using microalgae and microalgae-bacteria consortia. Cogent Environ. Sci., 2(1); 1275089-1275103.

Kshirsagar, A. D. (2013). Bioremediation of wastewater By using microalgae: An experimental study. Int. J. LifeSc. Bt & Pharm. Res., 2(3); 2250–3137.

Kube, M., Jefferson, B., Fan, L. and Roddick, F. (2018). The impact of wastewater characteristics, algal species selection and immobilisation on simultaneous nitrogen and phosphorus removal. Algal Res., 31; 478–488.

Lee, C. S., Lee, S. A., Ko, S. R., Oh, H. M. and Ahn, C. Y. (2015). Effects of photoperiod on nutrient removal, biomass production, and algal-bacterial population dynamics in lab-scale photobioreactors treating municipal wastewater. Water Res., 68; 680–691.

Li, Y., Chen, Y., Chen, P., Min, M., Zhou, W., Martinez, B., Zhu, J. and Ruan, R. (2011). Characterization of a microalga Chlorella sp. well adapted to highly concentrated municipal wastewater for nutrient removal and biodiesel production. Bioresour. Technol., 102(8); 5138–5144.

Lu, Q., He, Z. L., Graetz, D. A., Stoffella, P. J. and Yang, X. (2010). Phytoremediation to remove nutrients and improve eutrophic stormwaters using water lettuce (Pistia stratiotes L.). Environ. Sci. Pollut. Res., 17(1); 84–96.

Lv, J., Feng, J., Liu, Q. and Xie, S. (2017). Microalgal cultivation in secondary effluent : Recent developments and future work. Internat. J. Mol. Sci., 18(1); 79-95.

Moondra, N., Jariwala, N. D. and Christian, R. A. (2020a). Microalgal-bacterial consortia : An alluring and novel approach for domestic wastewater treatment. WCM., 4(1); 51–56.

Moondra, N., Jariwala, N. D., and Christian, R. A. (2020b). Sustainable treatment of domestic wastewater through microalgae. Int J Phytoremediation., 22(14); 1480-1486.

Moondra, N., Jariwala, N. D., and Christian, R. A. (2021a). Integrated approach of phycoremediation in wastewater treatment: an insight. WCM., 5(1); 8–12.

Moondra, N., Jariwala, N. D., and Christian, R. A. (2021b). Microalgae based wastewater treatment: a shifting paradigm for the developing nations. Int J Phytoremediation., 23(7); 765-771.

Olguin, E. J., Mendoza, A., Gonzalez-Portela, R. E. and Novelo, E. (2013). Population dynamics in mixed cultures of Neochloris oleoabundans and native microalgae from water of a polluted river and isolation of a diatom consortium for the production of lipid rich biomass. New Biotechnol., 30(6); 705–715.

Park, J. B. K., Craggs, R. J. and Shilton, A. N. (2011). Wastewater treatment high rate algal ponds for biofuel production. Bioresour. Technol., 102(1); 35–42.

Park, K. H. and Lee, C. G. (2001). Effectiveness of flashing light for increasing photosynthetic efficiency of microalgal cultures over a critical cell density. Biotechnol Bioprocess Eng., 6(3); 189–193.

Renuka, N., Sood, A. and Ratha, S. K. (2013). Evaluation of microalgal consortia for treatment of primary treated sewage effluent and biomass production. J. Appl. Phycol., 25(5); 1529–1537.

Schumacher, G. and Sekoulov, I. (2003). Improving the effluent of small wastewater treatment plants by bacteria reduction and nutrient removal with an algal biofilm. Water Sci. Technol., 48(2); 373–380.

Sousa, C., Compadre, A., Vermue, M.H. and Wijffels, R.H. (2013). Effect of oxygen at low and high light intensities on the growth of Neochloris oleoabundans. Algal Res., 2(2); 122–126.

Su, Y., Mennerich, A. and Urban, B. (2011). Municipal wastewater treatment and biomass accumulation with a wastewater-born and settleable algal-bacterial culture. Water Res., 45(11); 3351–3358.

Sukacova, K., Trtílek, M. and Rataj, T. (2015). Phosphorus removal using a microalgal biofilm in a new biofilm photobioreactor for tertiary wastewater treatment. Water Res., 71; 55–63.

Sydney, E. B., Silva, T. E., Tokarski, A., Novak, A. C., Carvalho, J. C. D, Woiciecohwski, A. L., Larroche,

C. and Soccol, C. R. (2011). Screening of microalgae with potential for biodiesel production and nutrient removal from treated domestic sewage. Appl.Ener., 88(10); 3291–3294.
Xu, M., Li, P., Tang, T. and Hu, Z. (2015). Roles of SRT and HRT of an algal membrane bioreactor system with a tanks-in-series configuration for secondary wastewater effluent polishing. Ecol. Eng., 85; 257–264.