Microalgae for Simultaneous Removal of Organic and Nitrogenous Compounds from Wastewater

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Abstract. The increasing population growth and rapid urbanization, particularly in the developing countries, have significantly contributed to the amount and the quality of domestic wastewater. Although in certain cities, centralized wastewater treatment facility is available, it mainly aims at removing organic substances as the system uses the conventional one. Even after the treatment, the effluent is still rich with nutrients pollutants, particularly nitrogenous compounds originated from bathrooms and kitchens. Consequently, excessive nitrogenous matter in the effluent will end up in the water bodies which can lead to eutrophication, stimulating algal bloom, changing the balance of organism and degrading the water quality. As the conventional wastewater treatment system is expensive to invest and operate, an alternative cheaper and reliable method for wastewater treatment should be available, meeting the need of the developing countries. In recent years many researches have shown that microalgae have capability of simultaneously reducing organic and nitrogenous substances in the wastewater for further developed as sources for producing medicines, healthy foods, ingredients, chemicals, biofuels, electricity, animal feeds, and many more. In this paper, we will review and discuss the potential application of microalgae in wastewater treatment, with attention to simultaneously removal of organics and nitrogenous substances in wastewater.

1. Introduction
The increasing population growth and rapid urbanization, particularly in the developing countries, have significantly contributed to the change in the landscape of human settlement and impacts on ecological environment [1]. In the last ten years, the urban population in Africa, Asia and Latin America has increased by two-fold, causing more than 50% of world’s population to live in cities and their vicinity [2]. Although urban inhabitants may get some benefits from better sanitation, well infrastructure and improved access to clean water, the number of people living in cities with inadequate clean water and sanitation has steadily multiplied due to inability of infrastructure improvements to keep up with the urbanization rate. In the case of Indonesia, the situation is quite similar to those of other developing countries, the population grows at a rate of 2.3% per year on average, and the rate is even higher in urban areas, around 5.4 % per year [3]. Almost half of its 250
million people live in urban areas, requiring more supply of clean and potable water and generating domestic wastewater.

With the increasing development in Indonesia, medium and big cities in the country become more densely populated, as it attracts more people from villages to come to cities expecting a better life. Unfortunately, urban development has not yet been followed by the improvement of domestic wastewater treatment. Up to 2017, there are only 12 high populated big cities in the country which have centralized wastewater treatment plants, accommodating merely 5 per cent of the country’s population to connect to these treatment facilities [4]. When considered from the domestic wastewater generated, those centralized treatment facilities only serve one per cent of the country’s urban liquid waste. In fact, in addition to industrial liquid effluent, household wastewater is also categorized as a significant contributor for organics and nutrients pollutants. Although many households use septic tank system to treat their wastewater, housing in urban areas with limited space of land usually discharge the wastewater directly into a sewer network without any treatment, which eventually it will lead to water bodies. These untreated wastewaters are not only still rich with organics but also with nutrients pollutants, particularly nitrogenous substances originated from bathrooms and kitchens. Although nutrients such as nitrogen and phosphor are essential for the food chain of aquatic life, excessive input of nutrients from continuous wastewater entering the water bodies can lead to eutrophication, stimulating algal bloom, changing the balance of organism and degrading the water quality. Bouwman et al. [5] stated that primary sources of nutrients causing eutrophication in the freshwater system came from agriculture effluent and wastewater discharge from households and industry.

The implementation of conventional domestic wastewater treatment usually only treats organic pollutants considered as biological oxygen demand (BOD), without treating the excessive nutrients in the wastewater. As a result, the treated effluent still contains high nutrients, particularly nitrogen compounds [6]. Additional units of treatment, such as nitrification and denitrification steps, could be added to the conventional treatment system to lower the nitrogenous compounds in the wastewater, with a consequence of increasing the capital and operational costs. This is the reason why excess nutrients are not processed. Therefore, an alternative method is needed that is better and cheaper, which can reduce organic compounds and nitrogen compounds simultaneously.

In recent years, microalgae have received greater attention worldwide as they pose potential applications in renewable energy, pharmaceutical industry, food products, cosmetics, wastewater treatment, and many more. With regards to the interest in environmental protection, many studies have shown that utilization of microalgae is an effective method of removing excessive nutrients in the wastewater, enabling to reduce the nitrogenous compounds up to 95% [7], [8]. One of the most attractive features of utilizing microalgae in the wastewater treatment is their capability to take up organic and inorganic nutrients from wastewater to produce biomass which can be used as feedstocks for biofuel generation. In this paper, we will review and discuss the potential application of microalgae in wastewater treatment, with attention to simultaneously removal of organics and nitrogenous substances in wastewater.

2. Current Treatment Removal System Organics and Nitrogen from Wastewater

A conventional wastewater treatment method is still the most used for the removal of organic and nitrogenous compounds in domestic and industrial wastewaters. The process comprises of three to four stages, starting from preliminary treatment, primary treatment up to secondary treatment, and sometimes furnished with tertiary treatment. With the purpose to save the usage of energy, most of the treatment facilities are performed up to second step only. A process diagram of conventional wastewater treatment is presented in Fig. 1, covering all three stages [9].

The pretreatment stage aims at removing any large objects from sewage or raw wastewater so they will not damage plant equipment/parts and will not clog the pumps or pipelines. As the first stage of treatment, it is equipped with screen and grit to enable the removal of separable large suspended solids
such as rags, bottles, cups, cans, etc. or any other materials such oil. The effluent of this stage will go to the primary treatment for further process.

**Figure 1.** A schematic diagram of a conventional wastewater treatment system [9].

Primary treatment is a stage of processing which needs to be done before the wastewater enters the secondary treatment. Pre-treated sewage flows to a primary clarifier or sedimentation tank which utilizes flocculants and coagulant to speed up the settling of suspended solids to the bottom of the tank. At the immediate treatment stage, about 60-65% of suspended solids from the incoming wastewater is removed. The settled solids, called primary sludge, will be discharged from the sedimentation tank and transfer to another unit for further process. The remaining liquid will be transported to the next level to undergo biological treatment. At this stage of treatment, it involves aerobic biological means called “activated sludge process”, the most common process employed to remove organic substances from the wastewater. The incoming sewage from the primary sedimentation tank will enter activated sludge tank to which air is supplied to promote the growth of microorganisms like bacteria to degrade the organic substances in the wastewater. The processed wastewater, including microorganisms, is introduced into a secondary sedimentation tank to allow heavier solids to settle to the bottom of the tank. This sludge, called as secondary sludge will be recycled back to the aeration tank to maintain the amount of sludge or microorganisms in the tank and the remaining sludge will be processed in the sludge digestion unit together with the primary sludge. At the stage of secondary treatment, it is expected that 80-85% of organic pollutant is removed.

In particular cases, specific contaminants such as toxins, nitrogen, phosphorous, or microorganisms must meet the standard set up by local authorities prior to releasing to the environment. Therefore, the tertiary treatment will be required to remove the contaminants in the effluent until it is safe to dispose into the water bodies. It has been well known that conventional wastewater treatment is especially effective for the removal of organic substances, but not for the nutrient compounds, such as nitrogen and phosphor. Therefore, even after the secondary treatment, the treated effluent still contains high nutrient substances, particularly nitrogenous compounds, which eventually will promote eutrophication when discharged to the water bodies. Other issues with the implementation of the conventional wastewater treatment system include high energy consumption for the supply of air and high capital cost requirement if the treated wastewater has to meet the stringent regulation standard.
Increased operating cost due to energy consumption [11] would be a burden for the underdeveloped and developing countries to adopt the conventional treatment system for treating their domestic and industrial wastewaters. Therefore, an alternative, cheaper and reliable method for wastewater treatment should be available that fits for the need of the developing countries.

3. Microalgae Wastewater Treatment Approach

Although the characteristics of domestic wastewater are slightly different from one city to another, in general, it contains organic, nitrogenous and phosphorus compounds. As in many cases, conventional wastewater treatment has been accepted to treat the domestic wastewater despite the fact it only removes mostly organic compounds and consumes a lot of energy for supplying air into the activated sludge tank. In the case the wastewater containing a high level of nitrogen, additional units such as nitrification and denitrification have to be added to the activated sludge system, leading to an increase of investment and operational costs. Arias et al. [12] proposed to integrate the algal system into the conventional system with the aim at removing nitrogen compounds in the effluent after processed by activated sludge unit since the algae have been well known for their capability of removing nutrients in wastewaters. However, there has been a lot of research performed to investigate the capability of microalgae in the removal of not only nitrogenous and phosphorus compounds but also organic and heavy metals in wastewaters. Many species microalgae have been tested to treat wastewaters originated from domestic effluent [13], dairy industry [14], pulp and paper mill [15], agro-based industry [16], brewery industry [17], refinery and various industries.

The algal bloom phenomena due to the excess of nutrient in the water indicate that microalgae can utilize the nutrients for their growth. Consequently, microalgae are suitable to treat wastewater containing excess nutrient, particularly nitrogen. Delgadillo-Mirquez et al. [18] utilized microbial consortium consisting of microalgae and bacteria to treat domestic wastewater containing high ammonium concentration. They found out that when the batch experiment was operated at the temperature of 25 °C, the consortium was able to remove total nitrogen and phosphor up to 83% and 100%, respectively. Although bacteria in this study was able to remove the organic compound in wastewater, no such information is provided in the paper. Do et al. [13] found more promising nutrients removal efficiency in domestic wastewater with the use of Desmodesmus sp. Operated under batch condition for 12 days, this microalgae species was able to remove 99.10% of ammonia nitrogen, 91.31% of total nitrogen, and 95.67% of total phosphate [13]. Similar encouraging nutrient removal efficiency in domestic wastewater was also reported with the utilization of Chlorella variabilis [19]. Wastewater resulted from the fertilizer industry has been known to have rich nutrient, which is suitable when treated with microalgae. Microalgae Scenedesmus sp. was investigated to treat wastewater from the fertilizer industry under batch mode receiving 12-hour light for ten days [20]. The microalgae species was able to remove ammonium (NH4+), total phosphorus (TP), COD, and \( \text{BOD}_5 \) with efficiency up to 93%, 96%, 93%, and 84%, respectively. Various studies have reported favourable results of the use of different microalgae in treating domestic wastewater containing excessive nutrient compounds. Similar success of the simultaneous removal of organic carbon and nitrogen from wastewater was also reported by Yunardi et al. [21].

Unlike the conventional wastewater treatment system which requires different units to treat carbonaceous and nutrient substances, the present research results have shown that microagal wastewater treatment system is capable of removing the organic and nitrogenous compounds simultaneously in a single unit. Shurair et al. [22] studied simultaneous removal of organic and nitrogen from domestic wastewater utilizing mixed indigenous microalgae (MIMA) in the reactor operated under batch mode without any \( \text{CO}_2 \) supplied. They observed that that MIMA was able to remove nitrogen up to 71.7% from domestic wastewater. At the same time, the system also removed the organic compounds, measured as COD by 70.3%. Interesting results of microalgae studies were presented by Usha et al. [15] who treated pulp and paper mill effluent in an outdoor open pond. Two microalgae Scenedesmus species were cultivated in the wastewater and able to eliminate, a maximum of 82% and 75% of BOD and COD, respectively. At the end of the 28-day cultivation period, 65%
removal of NO3-N and 71.29% removal of PO4-P was observed. It was found that dairy wastewater is suitable for the cultivation of microalgae, particularly *Acutodesmus dimorphus* as reported by Chokshi et al. [14]. These microalgae not only grow their biomass very fast, which could reach 840 mg dried biomass/L after 4 days of cultivation, but also eliminate 90% of COD and 100% of ammoniacal nitrogen, respectively. Since the algae biomass contained about 25% lipid and 30% carbohydrate, it was suggested that the biomass could be converted into biodiesel and bioethanol, respectively. The microalgal system is not only appropriate to simultaneously removal organic and nitrogen substances from domestic [21], [23], [24], pulp and paper [15], and dairy wastewaters [14], it also shows the reliable performance when treated wastewaters from fertilizer industry [25], slaughterhouse [26] and mixed industrial wastewaters. Considering from energy usage and biomass production point of views, the microalgal system for wastewater treatment is envisaged to replace the commonly used conventional wastewater treatment system.

4. **Prospect Applications of Algal Biomass**

Wastewater has been almost always considered as an unwanted matter that needs be removed. However, it is not the case for the algal wastewater treatment system, microalgal biomass produced from an algal wastewater treatment system poses a number of commercial applications. Therefore, the wastewater is considered as raw material to produce biomass. Interestingly, wastewater is a freely available and appropriate medium for the growth of various microalgae species because it consists of macro- and micro-nutrients required by the algae for their growth. This is distinctly different from the conventional wastewater treatment system where excess sludge resulted from the secondary stage is considered as a waste, requiring additional units and cost to treat such unwanted solid waste. Algal biomass or its extracts have significant potential applications to produce renewable energy, such as biodiesel, bioethanol, methane or biogas; healthcare products, cosmetics and personal care products; and human and animal nutrition. Figure 2 shows a schematic diagram of the dual utilization of microalgae biomass as wastewater treatment and raw materials to produce new products [27].

![Diagram showing the dual utilization of microalgal biomass](image)

**Figure 2.** A diagram illustrating various materials produced from algal biomass [29].

In recent years, microalgae have become the subject of investigation to produce different biofuels. Microalgal biomass has been known to store around 30–80% of lipids, mainly consisting of triglycerides—the source to produce biodiesel. Since microalgae can produce biomass very quickly, cultivating microalgae in wastewater would be a cost-effective means and at the same time eliminate pollutants from the wastewater. A number of algal strains have been studied for the production of
biodiesel. Microalgae strain *Chlorella* is considered to be suitable for the production of biodiesel since their fatty acid has similar characteristics to diesel oil originated from fossil fuel. However, many researchers claimed that majority of microalgae species are suitable to produce biomass as feed stock for biodiesel manufacture because of high lipid content, even in some case the *B. braunii*, their biomass could accumulate lipids up to 80% [28]-[30]. In addition to biodiesel, more recently there have been numerous researches to convert microalgae carbohydrate into bioethanol [31], [32]. Biofuels are the only possibility for the utilization of microalgae biomass, since the use of algae as a food source has been practiced for a long time. Chlorophylls contained in the algae is not only suitable for human and animal nutrition, but also for cosmetics [33]. Another important future application of microalgae is in the area of pharmaceutical industry. Recent studies have shown that microalgae possess antioxidant, antibacterial, antiviral, anti-inflammatory and anticancer properties [34]. On top of the above-mentioned applications, microalgae also appear to have potential as raw materials for other applications, such as biofertilizers and biopesticides [35], biopolymers including bioplastics, polyurethane, polyesters [36] and many other applications.

5. Conclusions
Although microalgae are more known for their capability to reduce nutrients in wastewaters, different studies have shown that they are able to remove organic carbon and nitrogen from wastewater simultaneously. Such system will provide a more cost effective in terms of investment and operation, since the treatment requires only one unit to treat organics and nutrients and needs less air supply compared to its counterpart the conventional wastewater treatment system. Therefore, in the near future the microalgal wastewater treatment system is envisaged to replace the conventional one. The use of microalgae to treat wastewater will provide additional advantages, since the algae biomass can be converted into valuable materials. Although at the present time, microalgae biomass is still under investigation and exploitation for the biobased energy, due to their rapid growth, it possesses great potentials to replace fossil fuels in the future. Apart from biofuels, algae biomass was found to have potential to convert to other valuable products, including food, biopolymers, cosmetics among others.

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