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A review of the potentials, challenges and current status of microalgae biomass applications in industrial wastewater treatment

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ABSTRACT

Wastewaters from agro-industrial and industrial sources have significant organic matter contents, and some also contain oil and grease, heavy metals and toxic chemicals. Limits have been set for pollutants, especially wastewaters, entering water bodies. Conventional methods of treatment generally require large inputs of energy, large areas of land, and high operation and maintenance costs. Microalgae biomass offers an alternative treatment approach that removes nutrients and other pollutants, such as heavy metals, nitrogen compounds and harmful chemicals. Microalgae harvested after wastewater treatment can be used as value-added products because the microalgae is rich in carbohydrates, proteins and lipids. This paper presents the types of treatment processes, current application of microalgae and high-value products derived from microalgae used in wastewater treatment processes.

1. Introduction

The rapid increase in human population has led to industrial development, which represents a vital factor in the economic development of countries [1]. Gobi and Vadivelu [2] stated that the increase in wastewater in developing countries is related to population growth. Approximately 2.97 billion m^3/year of industrial and municipal wastewater is estimated to be generated by Malaysian industry. Wastewaters from various industrial sources have significant organic loading, and some also contain oil and grease, heavy metals and chemicals. A large volume of industrial wastewaters must be treated in order to prevent environmental pollution and to protect public health by ensuring that the water supplies are safe to consume.

The type of wastewater treatment required depends mainly on the effluent requirements of the wastewater. The pollutants discharged from industrial wastewaters negatively affect all aspects of the environment, such as water, air and land. Treatment of industrial effluents is generally difficult because the wastewater contains various pollutants, high organic matter contents, and poorly biodegradable components [3]. In industrial wastewater treatment, two processes are commonly used: primary treatment and secondary treatment. In primary treatment, large solids/particles are removed, while in secondary treatment, bioremediation of organic materials takes place via the action of microorganisms.

These conventional treatment methods have some drawbacks. They generally require large amounts of energy, large areas of land, and high operation and maintenance costs. Microalgae offer an alternative treatment approach in biological treatment as they are able remove nutrients and convert them into biomass [4]. Some species of microalgae have the ability to take up other pollutants, such as heavy metals [5], nitrogen compounds and harmful chemicals [6]. In Malaysia, various studies have been performed to identify and utilize microalgae, including potential uses in environmental applications [7].

The term microalgae refers to algae that are too small to be observed with the naked eye. This definition includes not only eukaryotic microalgae but also prokaryotic cyanobacteria. The major taxonomic orders of algae include *Rhodophyta* (red algae), *Chlorophyta* (green algae), *Bacillariophyta* (diatoms) and *Chrysophyta* (golden algae), as depicted in Fig. 1. Initially, *Cyanophyceae* was grouped with eukaryotic algae; however, the members' morphological properties are those of bacteria, and they were thus renamed cyanobacteria [8]. The taxonomic order might differ among authors. In addition, the members of

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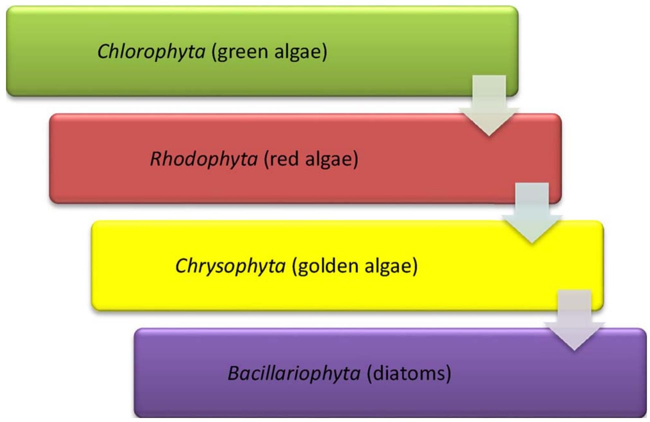

Fig. 1. Taxonomic order of algae.

microalgae differ significantly in their evolutionary background [9].

Microalgae were previously studied in the treatment of various wastewaters (domestic and industrial), including palm oil mill effluent (POME) [10,11], rubber mill wastewater [12], sago starch wastewater [13], textile wastewater [14] and wastewater containing heavy metals [5]. The robustness of microalgae enables them to thrive even in extreme conditions and has proved to be an advantage in the treatment of these wastewaters. This review considers the components available in industrial and agro-industrial wastewaters, current treatment practices, roles of microalgae and the challenges of using biomass microalgae in the treatment of agro-industrial and industrial wastewaters.

2. Treatment processes of agro-industrial and industrial wastewaters

Treatment of agro-industrial and industrial wastewaters is generally difficult because wastewater compositions vary and can include high organic matter contents and poorly biodegradable components [3]. Industrial and agro-industrial wastewater treatment involves two processes: primary treatment and secondary treatment. Generally, only municipal wastewater treatment requires tertiary treatment because disinfection is required before the water is released into water bodies. In primary treatment, also known as physical treatment, large solids/particles are removed [15]. The tools used include a bar screen, a grit and scum removal chamber, and a settling tank or clarifier for coagulation flocculation. The sludge formed during this stage is known as primary sludge. Biological treatment is known as secondary treatment, and the microbes present in the wastewater convert dissolved solids to settleable solids. In this stage, microbes utilize the organic compounds present in wastewaters as food and in turn release greenhouse gases, such as carbon dioxide, hydrogen sulphide and methane [16]. Current treatment practices for agro-industrial and industrial wastewater include microalgae, biofilms, anaerobic systems and membrane filtration. As depicted in Fig. 2, these systems can be considered secondary or tertiary treatment.

2.1. Microalgae

Microalgae are favourable for use in treating wastewaters due to their ability to take up nutrients and convert them into biomass [4]. Nutrients from the wastewater are assimilated for growth, thus reducing the amount of nutrients in the wastewater and reducing the chemical oxygen demand (COD) and the biological oxygen demand (BOD) [12]. The small size of microalgae provides a large surface area, which increases the nutrient uptake rate in the wastewater.

The application of microalgae for wastewater treatment, i.e., in which the microalgae act as remediation agents, is known as phycoremediation. Phycoremediation enables industries to address two important issues: the high use of chemicals and high energy costs associated with treating the generated wastewater. In wastewater treatment, microalgae applications include the removal of nutrients, heavy metal ions, and pathogens and the reduction of BOD via the oxygen produced photosynthetically by the microalgae [17,18] in a wide range of pollutant removal and biogas production processes. Unlike terrestrial plants, microalgae do not require a proper system for water and nutrient uptake; instead, they depend on their large surface area for the uptake of water, nutrients and carbon dioxide (CO_2) [18].

In general, the cultivation of microalgae is done in photobioreactors (PBRs) and/or raceway ponds. PBRs can be designed in horizontal or vertical columns. An example of a tubular PBR is shown in Fig. 3. The diameter is usually small to ensure that light can penetrate through the system and reach the microalgae. Air is sparged in as a source of CO_2 and to enhance mixing. The circulating air ensures that all the microalgae have enough carbon dioxide and access to light, especially near the surfaces of the columns. For PBR systems, the typical surface-to-volume ratio is 80–100 m^2/m^3 [19].

The raceway pond, also known as the high-rate algal pond (HRAP), was first developed in the 1950s to treat various types of wastewater, including industrial wastewater, urban and rural wastewaters, and agricultural wastewaters [20,21]. A model of a raceway pond is shown in Fig. 4. Raceway ponds have paddle wheels attached to the system in order to maintain constant mixing of their contents [22]. These ponds are open shallow systems with semi-circular ends [21].

Table 1 shows the applications of microalgae as bioremediation agents described by previous studies. The genus *Chlorella* has proven to be quite versatile in removing nutrients and pollutants from POME, sago starch wastewater, textile wastewater and wastewater containing heavy metal ions. Other microalgae species that have been used to treat wastewater include *Arthrospira platensis, Anabaena* sp., *Scenedesmus obliquus, Oscillatoria* sp. and *Nostoc* sp.

2.2. Biofilms

A biofilm is a carrier in which extracellular polymeric substances (EPS) are used to form thick layers of microorganism cells. The formation of a biofilm is a natural process in which no chemicals are used or added. EPS are made of polysaccharides, nucleic acids, proteins, or phospholipids. EPS help microorganism cells bind to a surface, thus protecting them from the environment by a diffusive barrier. This barrier prevents toxic substances, phagocytes and bactericides from harming the cells but can also prevent nutrients required for cell growth from reaching the cells [31].

Biofilms can be applied in many types of reactors, including moving bed biofilm reactors (MBBRs), airlift reactors (ALRs), continuously stirred tank reactors (CSTRs), packed bed reactors (PBRs), upflow anaerobic sludge blanket (UASB) reactors, fluidized bed reactors (FBRs), and expanded granular sludge bed (EGSB) reactors [31], but biofilms are commonly a part of MBBRs and fixed bed biofilm reactors. Dvořák et al. [31] reported that a MBBR successfully removed cyanide with an efficiency ranging from 75 to 99% and removed more than 85% of aniline.

The type and texture of the supporting carrier and the development and maturation of biofilms have significant effects on the success of wastewater treatment. The textures and type of carriers have comparable effects on the composition, weight and activity of biofilms [32]. Biofilms are able to withstand toxicants because they have high biomass retention, an abundance of microbial species and better process stability [33]. However, one of the major disadvantages of using biofilms is bioclogging. This process can occur when biofilms continue to grow on the solid media. Nonetheless, in biological aerated filters, biofilms play a key role in the removal of nitrogen and carbon and aid in breaking down pollutants into less toxic or nontoxic substances [34].