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Review

Application of photosynthetic bacteria for removal of heavy metals, macro-pollutants and dye from wastewater: A review

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ABSTRACT

Photosynthetic bacteria not only can be applied for wastewater treatment, but also are used to generate quality added products such as biodiesel and hydrogen. Although many articles have been published on the utilization of photosynthetic bacteria to treat wastewater, there is no comprehensive literature review on this field. Therefore, the aims of this study are (1) to review the ability of photosynthetic bacteria for removal of different pollutants such as heavy metals, nutrients and dye from wastewater and (2) to review effective parameters such as light intensity and temperature on the growth rate of photosynthetic bacteria. Photosynthetic bacteria have a high ability to remove heavy metals, dyes and macro-pollutants from wastewater. Production of photosynthetic bacterial biomass depends on temperature, light intensity and amount of nutrients in the environment. The yellow light is able to enhance the removal of chemical oxygen demand by photosynthetic bacteria. Also, photosynthetic bacterial biofilms can be deteriorated if insufficient amount of nutrients are accessible. Using photosynthetic bacteria is a promising technology to treat different types of wastewater effectively and economically.

1. Introduction

Fresh water is contaminated with different types of pollutant due to the human activities worldwide. For instance, the application of fertilizer can increase the amount of nitrate concentration in the water which is harmful for the living organisms [1]. Therefore, it is important to develop new, efficient and economic methods to treat water. Nowadays, biological methods have been widely applied in several fields [2–4]. A potential group of microorganisms used in wastewater treatment is the photosynthetic bacteria [5]. Kobayashi and Tchan [6], reported that photosynthetic bacteria can remove pollutants from water. Since, photosynthetic bacteria are able to utilize carbon dioxide, using this type of microorganisms can reduce the environmental impacts [7]. It is while that biodegradation using chemotrophic microorganisms produces a huge amount of bacterial biomass which sometimes is more dangerous than the original contaminants. Photosynthetic bacteria have been utilized for treatment of different wastewaters from sugar industries, food processing, chicken abattoirs, dairy and fermented starch [8–11]. This type of bacteria are resistant against salty environments therefore, they have a good potential for treating different high-organics-load wastewaters [12]. The photosynthetic bacteria are particular strain of bacteria that have light absorbing pigments. This strain can convert light energy into chemical energy. Photosynthetic bacteria have bacteriochlorophyll to produce their energy. Although, chlorophyll and bacteriochlorophyll are very similar to each other, bacteriochlorophyll is able to adsorb longer wavelength of light compared with chlorophyll. There are 7 types of bacteriochlorophyll specifically *a*, *b*, *c*, *d*, *e*, *f* and *g*. Among of all these types, the type of *a* is the most common type of bacteriochlorophyll in the photosynthetic bacteria. The photosynthetic bacteria that have bacteriochlorophyll do not use water as an electron donor as they do not produce oxygen; therefore, photosynthesis with bacteriochlorophyll is named as anoxygenic photosynthesis.

Photosynthetic bacteria are able to survive under light-anaerobic or dark-aerobic conditions. The photosynthetic bacteria offer a numerous advantages for the bioremediation process due to its capacity to utilize various types of organic compounds. The classification of photosynthetic bacteria is shown in Fig. 1.

Most of purple sulfur bacteria are anaerobe or microaerophile. This strain of bacteria uses hydrogen sulfide as an electron donor, which is oxidized to produce granules of elemental sulfur instead of oxygen. Green sulfur bacteria are obligate anaerobe and use sulfide ions, hydrogen or ferrous iron as an electron donor. There are many advantages using photosynthetic bacteria for wastewater treatment like: 1)

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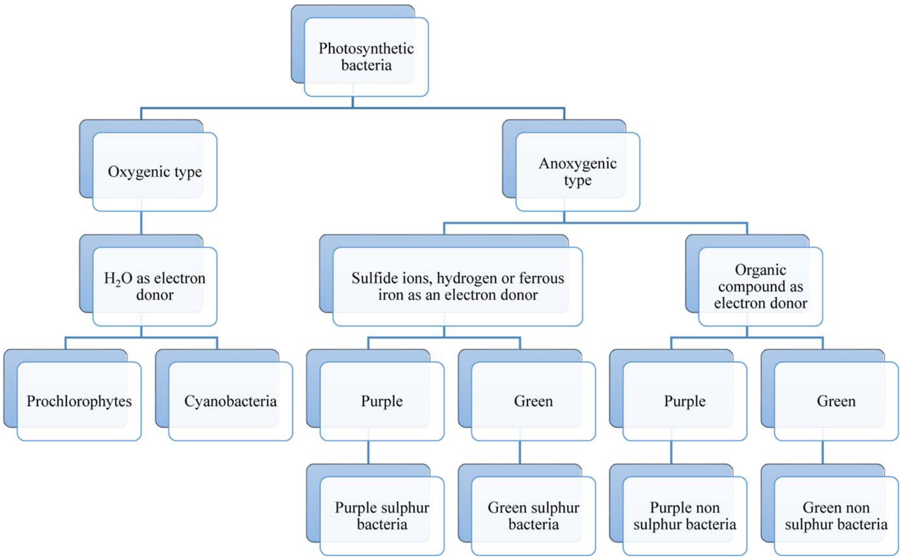

Fig. 1. Photosynthetic bacteria classification.

utilization of carbon dioxide to reduce the greenhouse effect [13], 2) generation of value-added products like hydrogen, vitamins, carotenoids and biopolymers during wastewater treatment [14]; [15], 3) minimum nutrients requirement as they are able to utilize solar energy which is available in nature [16], 4) able to utilize inorganic electron donor therefore, the operation cost is reduced as no need to add carbon source during wastewater treatment [17]; [18], 5) they have a vast metabolism activities that makes them to able degrade recalcitrant compounds [19], 6) having two pathways for metabolism of energy including dark-aerobic and light-anaerobic conditions in several species [20], 7) able to produce precious substances such as aminolevulinic acid which diagnosed for the treatment of cancer [21], 8) since, some photosynthetic bacteria are able to utilize sulfide as their sole electron donor, therefore can reduce malodorous emissions from wastewater treatment facilities [22,23], 9) able to produce single cell protein that can be used as protein supplement [24,25], 10) high amount of biomass production as animal feedstuff and 11) non harmful to other organisms as they can be easily separated [16].

Photosynthetic bacteria have the capability of contamination degradation with a high yield in a reasonable time. The majority of photosynthetic bacteria can be utilized as food for vegetarian animals. Photosynthetic bacteria produce biomass rich in carotenoids, vitamin, protein that can be utilized as animal food [26,27]. The main quality added products when photosynthetic bacteria are cultivated for wastewater treatment are hydrogen, single cell protein, carotenoid, 5-aminolevulinic acid, vitamin B_{12}, poly-ß-hydroxy, butyric acid, biodiesel and poly-b-hydroxybutrate [28]. Some groups of photosynthetic bacteria are able to secrete hydrogenase enzyme; therefore, they have good potential for bio-hydrogen production [29].

Beside several advantages of photosynthetic bacteria, they have some disadvantages such as 1) slow growth rate of some species like *Rhodobacter marinus* and *Rhodobacter adriaticusn* compared to non-photosynthetic bacteria [30]; 2) many purple sulfur bacteria and purple non-sulfur bacteria are extremely sensitive to oxygen that could repress photosynthetic pigments and photosynthetic apparatus. This leads to prevention of using these bacteria in aerobic condition for bioremediation [31]. Although, many articles have been published on the utilization of photosynthetic bacteria for wastewater treatment, there is no comprehensive literature review on the removal of color, micro-pollutants such as chemical oxygen demand (COD), phosphorous, nitrogen and heavy metals from wastewater. Therefore, the aims of this study are (1) to review the ability of photosynthetic bacteria for the removal of different pollutants such as organic compounds, heavy metals, macro-pollutants and dye from wastewater and (2) to review the effective parameters on the growth rate of photosynthetic bacteria such as light intensity, temperature and nutrients availability.

2. Removal of dye

Dyes comprise of numerous substances that are very dangerous to the oceanic living beings [32]. Several types of dyes are being utilized in textile industries and are released into the environment by colored textile wastewater. For instance, releasing highly colored textile wastewater into the environments can affect photosynthetic function in the aquatic plants. In contaminated water with dye, light has a low penetration which can have an impact on aquatic life [33,34]. The ability of conventional systems is not good enough to remove dye in compliance with the textile wastewater discharge standards [35]. The *cyanobacterium oscillatoria formosa NTDM 02* was discovered to be exceptionally successful in dye removal from the textile effluent [35]. There are three noteworthy systems for dye degradation by photosynthetic bacteria including adsorption process, chemical dye oxidation and biodegradation process. Biodegradation process is slower than adsorption and chemical oxidation for dye removal [36]. In addition, advanced oxidation methods should be applied to convert dyes to biodegradable compounds before using biological methods to reach to the wastewater discharge standards.

Wastewater contaminated with azo color is considered as a most stable type of polluted waters that contains color, COD and toxics due to the extensive amount of hazardous compounds [37]. In color removal, it is essential to explore the microorganisms that have the *azoreductase* protein by addition of a handy bioprocess for decolorization of azo color. The *azoreductase* is the vital compound for catalyzing the reductive cleavage of azo bond that makes it less toxic. As found by Liu et al. [38], *Rhodopseudomonas palustris (AS1.2352)* contains the *azoreductase* compound which has ability of decolorization of azo color. They discovered that in anaerobic condition the ideal temperature and pH for decolorization were 30–35 °C and 8, respectively. Meanwhile, an alternative strain *R. palustris 51 ATA* successfully mineralized and removed red dye (RR195) under anaerobic condition [39].

Tran et al. [40] reported that the degradation of azo color by *R. blasticus, R. adriaticus, Rhodo pseudomonas capsulatus, R. palustris and Rhodovulum strictrum* showed the domination of azo-reductase compound available in these microorganisms. The reductase protein is the normal catalyst which is responsible of dye-decolorization, while oxidase chemical has a same ability [41]. Goszczynski et al. [42] and Molina-Guijarro et al. [43] reported the effect of oxidase in the degradation of dye. Laccases are copper-containing oxidase enzymes