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Fungi: An approach to treat wastewater

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Abstract
Current global environmental issues raise unavoidable challenges for the use of natural resource. Environmental pollution is turning into global issue in which water pollution is a serious concern, since water is used for different purposes. Now-a-days, supplying the human population with clean water is becoming a problem. Several industrial processes causing the production of large amount of toxic and stable pollutants and releases as wastewater. The disposal of these contaminated effluents into receiving waters can cause environmental damages. Therefore tanneries/ other allied industries are constrained to treat their effluents in order to minimize the negative impact on environment. The main reason for treating wastewater is to prevent the spread of diseases and safeguarding water sources against pollution. The development of efficient wastewater treatment technologies and circular economic approaches is thus become increasingly important. Treatment of wastewater is one of the strategies for the management of water quality. Due to some drawbacks over the years concerning chemical treatment, biological treatment is now employed to avoid the unpleasant conditions in natural water resources. Treating the wastewater using microbes and discharge into natural water bodies is the best idea to maintain the environment safely. Fungal microorganisms are used in the remediation process due to its low cost, fast growth, easy cultivation and eco-friendly properties. The immobilization of the fungus could allow the use of the system repeatedly, with obvious advantages from a further application point of view. Self-assembled fungal pellets have great potential in wastewater treatment because they are easily separated from dye-containing wastewater, and exhibit good decolonization properties and strong acid/base tolerances during the culturing and adsorption processes.

Keywords: Wastewater, treatment, fungi, decolonization

Introduction

Nowadays due to urbanization and industrialization, several pollutants and its derivatives are discharged into water bodies and it is estimated that every year 1.8 million people die due to suffering from waterborne diseases. A large part of these deaths can be indirectly attributed to improper sanitation. In order to prevent the spread of such diseases waste water treatment plant is adapted to get safe drinking water and better living conditions to nourish the steadily increasing world's population. If wastewater is not properly treated, then the environment and human health can be negatively affected. These impacts can include harm to fish and wildlife populations, oxygen depletion, beach closures and other restrictions on recreational water use, restrictions on fish and shellfish harvesting and contamination of drinking water. Wastewater treatment is an important initiative which has to be taken more seriously for the betterment of the society and our future. Wastewater treatment is a process, wherein the contaminants are removed from wastewater by different processes.

Wastewater, especially that containing textile dyes, discharged into river systems can cause serious pollution to the environment and threaten the lives of microorganisms in the water. More than 100,000 types of commercial dyes are produced annually and over 1000 tons of dyes are annually discharged into water systems from the textile industry alone. Dyes are organic chemical reagents that are widely used in plastics, paper, textiles, leather tanning and printing processes. This causes significant environmental challenges [1]. Many materials (such as organic and inorganic film, cloth, copper mesh, aerogels) have been applied in wastewater treatment but the dye effluent is difficult to degraded by conventional waste water treatment.

Conventional wastewater treatment includes physical, chemical and biological treatments. Follow a line of investigation to find such low-cost, low-tech, user friendly methods, which on one hand avoid threatening our substantial wastewater dependent livelihoods and on the other hand protect degradation of our valuable natural resources. Biological treatments refers to removes pollutants using micro-organisms might be attractive topic, with an aim to develop effective and environment friendly wastewater treatment technology.

Fungi have also been reported to increase the degradability, settleability and dewaterability of wastewater sludge and contribute to the sludge management strategy. Fungal mediated bioremediation generally uses extracellular enzymes to breakdown the pollutants and reduce or remove the toxic waste from the environment [2]. Fungi mycelium can also works as a filter network used in buffer zones around streams to filter the run-off from farms, highways and suburban zones [3]. In other words it is a form of bioremediation, the process of using fungi to degrade or sequester contaminants in the environment. Stimulating microbial and enzyme activity, mycelium reduces toxins in-situ.

In order to develop efficient and cost effective treatment, fungal immobilization for dye decolorization and adsorption techniques are involved. The absorbents are typically applied to absorb harmful organic compounds and reduce the concentration of dyes in the wastewater.

Fungi-Prologue

Fungi are broadly classified as macrofungi and microfungi according to the size of their fruiting bodies. Macrofungi form fruiting bodies readily visible to the naked eye, with a diameter of at least 1 mm (mushrooms), and as much as 30 cm in puff balls. Microfungi, on the other hand, are microscopic, having minute fruiting bodies that cannot be seen by the naked eye (e.g., *Penicillium*). Their mode of reproduction is through spore formation. Most fungal spores range from 2 to 20 μm in size and are of different shapes and colors [4]. Fungi are basically classified by their mode of reproduction (both sexual and asexual) and the nature of their multinucleate or multicellular hyphal filaments.

Fungal Composition

Fungi, being eukaryotes, have a cellular chemistry similar to that of other eukaryotic organisms. The DNA base ratio (percentage guanine + cytosine) of eukaryotic cells is reported to be 38–63%, although the DNA content of fungi has been found to be as low as 0.15–0.30 percent. Most fungal carbohydrates are polysaccharides, such as chitin, chitosan, mannan, glucan, starch, and glycogen. Chitin, a principal cell wall component in Dikaryomycota (group of fungi characterized by hyphae with perforated septa, which usually occur in the dikaryotic phase), is a polymer of β- 1, 4 *N*-acetylglucosamine. Although glycogen is the main storage polymer, disaccharides such as trehalose and sugar alcohols such as mannitol are also used. Lipids include long-chain fatty acids (such as palmitic, oleic, and linoleic acids), phospholipids, and sphingolipids [5].

Growth Requirements of Fungi

Fungi are free-living heterotrophic osmotrophs in which assimilation of digested food material takes place through the cell wall [6]. Fungi absorb nutrients from the substrates on which they grow. They absorb simple, easily soluble nutrients, such as sugars through their cell walls *via* active and passive transport. They excrete digestive enzymes to break down complex nutrients into simpler forms that they can absorb. Fungi derive their energy and intermediates for synthesis from oxidation of compounds through respiration and fermentation. Fungi produce large quantities of organic compounds, including acids such as itaconic acids, oxalic acids, lactic acid, pigments (e.g., β-carotene, astaxanthin) and aromatic alcohols (e.g., resorcinol and phenol) [7].

Fungi in Wastewater Treatment

Fungus, an unicellular organism having potential and promising role in wastewater treatment. Fungi are also part of the microorganisms found in wastewater treatment systems. A number of filamentous fungi are found naturally in wastewater treatment systems as spores or vegetative cells, although they can also metabolize organic substances.

Fungi are shown to be most capable candidate to remove azo dyes compounds during wastewater treatment process. Fungal biomass can absorb dyes from wastewater regardless of whether the fungus is dry or wet. Fungi are the rich source of degrading enzymes and possess the ability to withstand extremely harsh conditions such as low pH, fluctuating pollution load and low nutrient concentrations.

Fungi also have a greater resistance to inhibitory compounds than do bacterial species. The hyphal growth of fungi provides a greater protection for their sensitive organelles. The cell walls of fungi, a layer of extra-polysaccharide matrix, protect them from inhibitory compounds through adsorption. Moreover, fungi are eukaryotes, having considerably more genes than bacteria, which make them more versatile in tolerating inhibitory compounds [8] .The higher number of genes in fungi imparts greater reproductive selectivity, which might result in better adaptations to the environment [9].

The white rot fungi typically secrete one or more of the three principal ligninolytic enzymes, *i.e*. lignin peroxidase (LiP), manganese peroxidase (MnP) and laccase (Lac). These enzymes are highly non-specific with regard to their substrate, which gives them the capability to degrade a wide range of highly recalcitrant organopollutants with molecular structure similar to lignin, such as humic [10]

The unique capacity of fungi is to produce specific and non-specific enzymes make them very attractive for the degradation of complex organic pollutants: synthetic dyestuffs, phenols and pharmaceutical compounds [11]

A number of fungi species, such as *Aspergillus*, *Penicillium, Fusarium*, *Absidia* and a host of others have been implicated in the removal of carbon and nutrient sources in wastewater. Most of the fungi are also reported to have the ability to breakdown organic matter present in the wastewater. Additionally, some fungi use their fungal hyphae for trapping and adsorbing suspended solids to accomplish their energy and nutrient requirements. Several filamentous fungi have been reported to secrete enzymes which help in the degradation of substrates during wastewater treatment.

A new approach to facilitate the application of white rot fungi (WRF) under non-sterile conditions, by introducing grain sorghum as carrier and sole carbon and nutrient source for fungi. For example, *Trametes versicolor* was immobilized on sorghum, and its ability to remove humic acid (HA) from industrial wastewater under sterile and non-sterile conditions. Sorghum used as a carrier material for immobilization of fungi as a sole source of carbon.

Different Forms of Fungus

There are three forms of fungal morphologies that can be used for wastewater treatments;

- Suspended mycelia (freely dispersed filaments, nanosized),
- Clumps (aggregated but still dispersed) and

- Pellets (denser, spherical aggregations).

Fungal pellets are spherical, ellipsoidal or oval masses consisting of intertwined hyphae with sizes ranging from several hundred micrometers to several millimetres. Fungal pellets can offer a series of operational advantages compared to dispersed mycelia because of the ease of separating fungal biomass from complex dye solutions. Interestingly, fungal biomass can absorb dyes from wastewater regardless of whether the fungus is dry or wet. Moreover, there is no effect during the growth process of pellets if the media is mixed with organic dyes under extreme conditions. Dye decolorization with microorganisms is a cost effective and environmentally friendly method, which can be used.

Mechanisms Involved
Biosorption
Biosorption is a physiochemical process that occurs naturally in certain biomass which allows it to passively concentrate and bind contaminants onto its cellular structure. Biosorption as an alternative or adjunct biotechnology has often been proposed in the context yet, ironically, has probably had the least success in exploitation [12].
The biosorption mechanisms of the fungus pellets to acid anionic dyes are very complex and mainly involve biodegradation and biosorption [13]. Complexation and electrostatic interactions are the two main mechanisms behind the biosorption. The biosorption mechanisms of the dyes are dependent upon their various chemical structures. The different functional groups of the biosorbent play different roles in the biosorption of dyes.
The fungal cell walls are composed of polysaccharides (chitin and chitosan) proteins, lipids and melanin with various functional groups such as amines, carboxyl and phosphate groups, which are capable of binding dye molecules [14]

Electrostatic Interactions
The biosorption of acid dyes involves electrostatic interactions, which could be a major factor behind dye decoloration. For some water-soluble acid dyes, they can be ionized into sodium cations and colored sulfonate anions. Therefore, the positively-charged functional groups on the fungus can attract sulfonate anions and remove them from an aqueous solution. After adjusting the pH values of the dyes with hydrochloric acid, the amino groups in the fungal biomass are protonated, and such protonated amino groups make the biosorption process of dyed sulfonate anions more easy and efficient.

Enzymes
In addition to the electrostatic interactions, other mechanisms may be involved in the biosorption of the dyes. Fungi possess the ability to produce non-specific oxidative enzymes, which allow degradation of pollutions with highly complex structures [11].
Fungal biosorption can be classified into two parts:
1. A passive reaction, which is non-metabolism dependent, and
2. An active uptake, which is metabolism dependent and comprises an energy driven process.

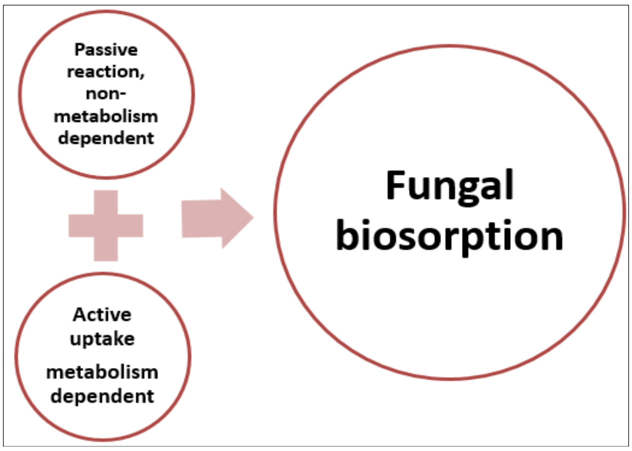

Fig 1: Show the fungal biosorption

Table 1: The wastewater Enzymes degradation and producing fungi

Type of wastewater	Enzymes used for degradation	Enzymes producing fungi [16]
Phenolic-laden wastewater	Lignin peroxidase, chloroperoxidase, manganese peroxidase, laccase	Phanerochaete chrysosporium, Caldariomyces fumago, Rhizoctonia praticola
Cyanide-rich wastewater	Cyanide hydratase	Gloeocercospora sorghi, Stemphylium loti
Food-processing wastewater	L-galactonolactone oxidase, Chitinase	Candida norvegensis, Serratia marcescens

Advantages of Fungi in Wastewater Treatment
A traditional biological wastewater treatment system generates large quantities of sludge (mainly bacterial biomass), which is of low value and expensive to treat before disposal. Meanwhile, fungi are often cultivated in industry as a source of a variety of valuable biochemical. Integrating wastewater remediation with recovery of valuable resources may possibly lead to an economically viable solution for sustainable waste management. From these perspectives, the fungal wastewater treatment process can be an attractive alternative that utilizes a low-cost organic substrate as a feed to generate high value fungal byproducts with concomitant wastewater remediation. The fungal wastewater treatment process offers several inherent merits, including (a) higher degradation rates of complex organic compounds present in wastewater due to the presence of specific fungal enzymes, (b) efficient solid separation of the fungal biomass from the mixed liquor, and (c) the possibility to recover valuable fungal byproducts.

Conclusion

Fungal biotechnology for wastewater treatment has recently been of great interest in the environment decontamination of organic and inorganic pollutants. Self-assembled fungal pellets have great potential in wastewater treatment because they are easily separated from dye-containing wastewater, and exhibit good decoloration properties and strong acid/base tolerances during the culturing and adsorption processes. The adsorption mechanism indicated that the fungus pellets possess efficient decoloration abilities with a high adsorption rate of 98%. Several analysis showed the excellent decoloration performance relies on the active groups on the fungus pellets and electrostatic interactions, including enzymes involved in cell wall degradation. Using low cost materials such as fungi, adds advantage include a low capital investment, relatively simple operation, low operating cost and lack of degradation by products. Thus, an inventory based on economics and regulatory requirements needs to be developed to arrive at a viable solution for constructing a full-scale fungal wastewater treatment process for resource recovery.

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