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Full Length Research Paper

The role of biotechnology on the treatment of wastes

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The biological processes improving fast are shown among the future technologies. In these processes which biological materials are used as degraders, raw wastes are processed to remove the contaminants in them. Biotechnological processes are used for wastewater treatment, gas treatment and disposal of solid wastes in environmental engineering. Also, these processes can be utilized for the production of biogas and hydrogen as new energy resources. For preventing environmental pollution in environmental engineering, activated sludge process, trickling filters, biotrickling filters, oxidation ponds, anaerobic treatment, composting units and biogas reactors are used extensively among the waste treatment technologies. In this review paper, the role of biotechnology on waste treatment was assessed and several treatment methods were investigated.

Key words: Biotechnology, environmental pollution, wastes, biological treatment, biological reactors.

INTRODUCTION

Among the new technologies that have appeared since the 1970s, biotechnology has attracted the most attention. It has proved capable of generating enormous wealth and influencing every significant sector of the economy. It has already substantially affected healthcare; production and processing of food; agriculture and forestry; environmental protection and production of materials and chemicals (Gavrilescu and Chisti, 2005).

In biotechnology, a biological material is used to realize a product in commercial scale. As a result of increasing interest to these biotechnological processes, many institution and work groups define biotechnology separately. Some definitions of this process will be given below (Bermek, 1989).

Biotechnology is based on many disciplines such as biochemistry, microbiology, genetic, zoology, botanic, physics, chemical engineering, food engineering, etc. According to the definition of Karl Ereky who used this term in 1919 for the first time, biotechnology is a process that raw materials are converted to new products by living organisms.

European Federation of Biotechnology presented a definition for biotechnology. In this definition, biotechnology is “the integration of natural sciences and engineering in order to achieve the application of organisms, cells, parts thereof and molecular analogues for products and services”. The multidisciplinary feature of biotechnology was emphasized in this description (EFB, 1999).

Another definition of biotechnology was given at OECD report prepared in 2005. According to this report, biotechnology is the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services. The living organisms in definition include microorganisms, enzymees, cells of animal and plant. In the description, the term “goods” expresses the products of the industries concerning food, drink, drug and biochemical substances. The term “service” mentioned above explains the treatment of environmental pollution. At the use of biotechnology for treatment of the waste materials, there is a more suitable definition for biotechnology in OECD report. Biotechnology is defined as “fermentation using bioreactors, bioprocessing, bioleaching, biopulping, biobleaching, biodesulphurisation, bioremediation, biofiltration and phytoremediation” (OECD, 2005).

Difficult and expensive methods are required for preventing environmental pollution and processing wastes. Because of that, research studies are done continuously

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on new processes. Among these research studies, microbiological processes are one of the most interesting topics. The objectives of these processes are the degradation of wastes and the occurrence of new products. The living organisms used in this method are yeasts, bacteria, fungus and algae. The products and processed waste materials obtained by these processes are very different and they exhibit diversities from one country to another (Aktan, 1983; Buyukgungor, 1983; Buyukgungor, 1992).

Biotechnology has various application fields ranging from waste treatment to medical treatment of cancer. A cleaner environment, advanced methods of diagnosis and medical treatment, better products and alternative energy resources can be considered among the benefits of biotechnology. Nowadays, environmental pollution is one of the most important problems in all world countries. Biotechnology offers many treatment methods to overcome this pollution problem. In this review, removal of wastes by biotechnological treatment is examined in depth and some examples are given to the treatment studies of wastes by biotechnological processes in environmental engineering.

BIOTECHNOLOGY IN ENVIRONMENTAL ENGINEERING

Environmental pollution occurs by deterioration of natural equilibrium of environment via various human activities. Nowadays, environmental pollution is the most important problem for all world countries. Pollution existed since the beginning of industrialization and grew by the parallel of rapidly increasing industrialization after Second World War. Precautions were taken after 1970s for preventing and reducing this pollution.

Biotechnology finds application fields in the treatment of wastewaters by biological methods and disposal of solid wastes by composting technique in environmental engineering. Biological methods are also applied to treatment of air emissions. The methods based on biotechnology in wastewater treatment are activated sludge, trickling filters, oxidation ponds, biofilters and anaerobic treatment. Furthermore, solid waste composting techniques, biotrickling filters and biosorption are the examples of biotechnology applications in environmental engineering. In all these methods, it is essential to find suitable microorganisms that will degrade organic substances and to complete the treatment process in favorable conditions.

Some biotechnological applications used in environmental engineering for waste treatment will be discussed below.

Activated sludge

An activated sludge wastewater treatment system has at least four components; an aeration tank, a settling tank (clarifier), a return sludge pump and a system of introducing oxygen into the aeration tank. Wastewater, sometimes pretreated and sometimes not, enters the aeration tank and is mixed with a suspension of microbes in the presence of oxygen. This mixture is referred to as “mixed liquor.” The microbes metabolize the organic pollutants in the wastewater. After spending, on average, an amount of time equal to the hydraulic residence time in the aeration tank, the mixed liquor flows into the clarifier, where the solids (Mixed Liquor Suspended Solids- MLSS) separate from the bulk liquid by settling to the bottom. The clarified effluent then exits the system. The settled solids are harvested from the clarifier bottom and a fraction of the settled solids is recycled to the aeration tank whilst the remainder is discarded. The result is the ability to control the average time microorganisms will remain in the reactor, called the sludge age (SRT) or mean cell retention time (MCRT). Those MLVSS (Mixed Liquor Volatile Suspended Solids) solids that are returned to the aeration tank are microbes in a starved condition, having been separated from untreated wastewater for an extended period and are thus referred to as “activated.” This process of returning microbes from the clarifier to the aeration tank enables buildup of their concentrations to high levels (1,800 to 10,000 mg/L) and that, indeed, characterizes the activated sludge process itself (Woodard, 2001).

The growth of the microorganisms in flocs is responsible for the metabolism and removal of organic matter from the liquid. Typical products of this metabolism are carbon dioxide (CO_2), nitrate (NO_3^-), sulphate (SO_4^{2-}) and phosphate (PO_4^{3-}). The nature of the floc is important as it determines the separation of sludge from the treated water and hence the efficiency of the overall process (Barbosa et al., 2007). Although the presence of a certain number of filaments is important for proper floc formation, the occurrence of large filamentous bacterial populations is detrimental for sewage treatment as it causes foam formation or settling problems of the activated sludge in the secondary clarifiers (Wagner and Loy, 2002).

In a conventional activated-sludge plant, a return of activated sludge at a rate equal to about 25% of the incoming wastewater flow is normal; however, plants operate with recirculation rates from 15 to 100%. The mixture of primary clarifier overflow and activated sludge is called “mixed liquor”. The detention time is normally 6 to 8 h in the aeration tank. In a conventional plant, the oxygen demand is greatest near the influent end of the tank and decreases along the flow path. Plants built before the process was well understood provided uniform aeration throughout the tank. A conventional plant cannot accommodate variations in hydraulic and organic loadings effectively and the final clarifier must be sized to handle a heavy solids load. Usually aeration units are implemented in parallel so that a shutdown of one unit does not totally disrupt plant operation. Modifications such as step aeration, extended aeration, contact stabilization and oxidation ditches have evolved as the activated-sludge plant has become more widely used (Liu and Liptak, 1997).

Trickling filters

Trickling filters have been used to treat wastewater since the 1890s. The name is something of a misnomer since no filtration takes place. A very active biological growth forms on the rocks and these organisms obtain their food from the waste stream dripping through the rock bed (Weiner and Matthews, 2002). It was found that if settled wastewater was passed over rock surfaces, slime grew on the rocks as mentioned above and the water became cleaner. Today this principle is still used, but in many installations plastic media is used instead of rocks. In most wastewater treatment systems, the trickling filter follows primary treatment and includes a secondary settling tank or clarifier.

Trickling filters are widely used for the treatment of domestic and industrial wastes. The process is a fixed film biological treatment method designed to remove BOD and suspended solids. A trickling filter consists of a rotating distribution arm that sprays and evenly distributes liquid wastewater over a circular bed of fist-sized rocks, other coarse materials, or synthetic media. The spaces between the media allow air to circulate easily so that aerobic conditions can be maintained. The spaces also allow wastewater to trickle down through, around and over the media. A layer of biological slime that absorbs and consumes the wastes trickling through the bed covers the media material. The organisms aerobically decompose the solids and produce more organisms and stable wastes that either become part of the slime or are discharged back into the wastewater flowing over the media. This slime consists mainly of bacteria, but it may also include algae, protozoa, worms, snails, fungi and insect larvae. The accumulating slime occasionally sloughs off (sloughings) individual media materials and is collected at the bottom of the filter, along with the treated wastewater and passed on to the secondary settling tank where it is removed (Spellman, 2003).

The overall performance of the trickling filter is dependent on hydraulic and organic loading, temperature, and recirculation. The performance of a trickle bed reactor highly relies on the uniformity of liquid distribution throughout the bed. Liquid distribution critically affects mass and heat transfer efficiency and thus the overall reactor performance. In a catalytic reactor liquid maldistribution caused non-uniform wetting of catalyst particles, which in turn reduced the contact between liquid and catalyst leading to an inefficient catalyst usage. Good liquid distribution throughout the trickle bed filter is essential for the full utilization of the bed capacity. However, because of liquid maldistribution a portion of the packing in the bed remains dry. Non-wetted zones in the bed are not colonized by the micro-organisms rendering a low efficiency of the trickle bed filter. In addition, good liquid distribution minimizes plugging and sloughing problem and liquid channeling (Doan et al., 2008).

Rotating biological contactors (RBC)

The RBC is a biological treatment system and is a variation of the attached growth idea provided by the trickling filter. Since these contactors allow obtaining high efficiencies in the removal of dissolved carbon and ammonia with less energy expense than by using activated-sludge systems, they are widely used in wastewater treatment (Di Palma and Verdone, 2009). Still relying on microorganisms that grow on the surface of a medium, the RBC is a fixed film biological treatment device; the basic biological process is similar to that occurring in the trickling filter. An RBC consists of a series of closely spaced (mounted side by side), circular, plastic (synthetic) disks that are typically about 3.5 m in diameter and attached to a rotating horizontal shaft. Approximately 40% of each disk is submersed in a tank containing the wastewater to be treated. As the RBC rotates, the attached biomass film (zoogleal slime) that grows on the surface of the disk moves into and out of the wastewater. While submerged in the wastewater, the microorganisms absorb organics; while they are rotated out of the wastewater, they are supplied with needed oxygen for aerobic decomposition. As the zoogleal slime reenters the wastewater, excess solids and waste products are stripped off the media as sloughings. These sloughings are transported with the wastewater flow to a settling tank for removal. Modular RBC units are placed in series simply because a single contactor is not sufficient to achieve the desired level of treatment; the resulting treatment achieved exceeds conventional secondary treatment. Each individual contactor is called a stage and the group is known as a train. Most RBC systems consist of 2 or more trains with 3 or more stages in each. The key advantage in using RBCs instead of trickling filters is that RBCs are easier to operate under varying load conditions, since it is easier to keep the solid medium wet at all times. The level of nitrification, which can be achieved by a RBC system, is also significant. This is especially the case when multiple stages are employed (Spellman, 2003). An RBC unit is illustrated in Figure 1. This unit has 4 media packs as seen from the picture (Mba and Bannister, 2007).

Membrane bioreactors

Membrane bioreactor technologies are, as the name suggests, those technologies that provide biological treatment with membrane separation. The term is more appropriately applied to processes in which there is a coupling of these two elements, rather than the sequential application of membrane separation downstream of classical biotreatment. Conventional treatment of munici-

Figure 1. A photo of RBC unit.

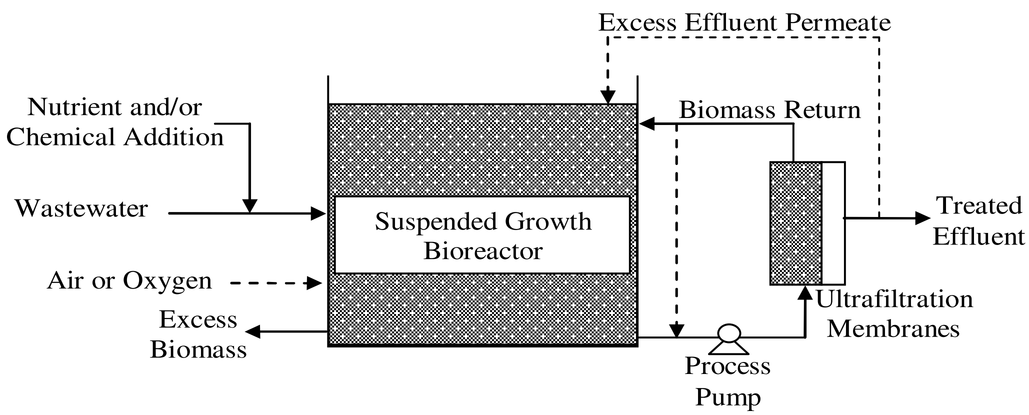

Figure 2. An external membrane configuration for membrane bioreactors (Roberts et al., 2000).

pal wastewater (sewage) usually proceeds through a three stage process: sedimentation of gross solids in the feed water followed by aerobic degradation of the organic matter and then a second sedimentation process to remove the biomass. An MBR can displace the 2 physical separation processes by filtering the biomass through a membrane. As a result the product water quality is significantly higher than that generated by conventional treatment, obviating the need for a further tertiary disinfection process (Judd, 2008). The 2 most common configurations for membrane bioreactors are submerged membranes and external membranes. These configure-tions are illustrated in Figure 2 and Figure 3 (Roberts et al., 2000; Al-Malack, 2006). Submerged type MBRs are preferred more than the external types. Several operating conditions for submerged type membrane reactors are listed in Table 1 (Melin et al., 2006).

Membrane bioreactors (MBRs) are becoming increa-singly popular due to their various advantages in waste-water treatment, e.g., flexibility of operation, ability to attain higher sludge age and consequently, less sludge production and higher nitrification and denitrification rates (Ahmed et al., 2008). Some disadvantages of this system include frequent membrane monitoring and maintenance requirements, relatively high running costs and there is a limitation as to the pressures, temperatures and pH to which the system can be exposed (Dobson and Burgess, 2007).

Besides wastewater treatment, membrane bioreactors are used for the production of amino acids, antibiotics, anti-inflammatories, anticancer drugs, vitamins, optically pure enantiomers and isomers, etc (Charcosset, 2006).

Many research studies concerning several membrane bioreactor configurations were made to improve and opti-mize this process for different purposes (Chandrasekeran et al., 2007; DeCarolis and Adham, 2007; Fan et al., 2007; Guo et al., 2008; MacAdam et al., 2007; Yuan et al., 2008).

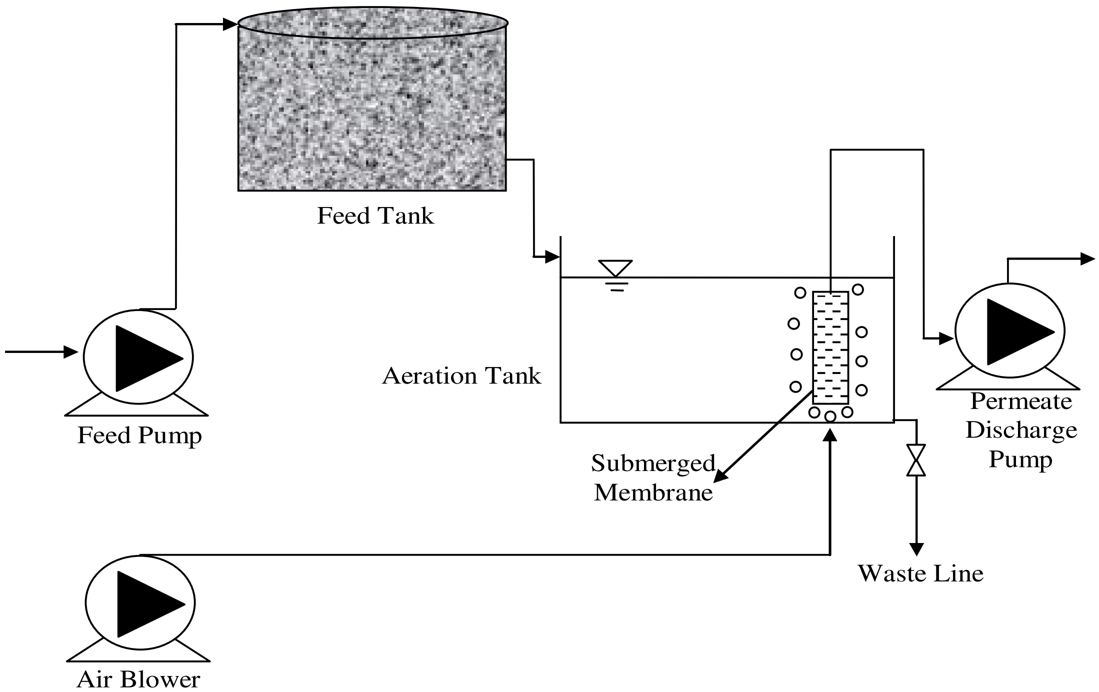

Figure 3. Submerged membrane configuration for membrane bioreactors (Al-Malack, 2006).

Table 1. Several operating conditions for submerged type membrane bioreactors.

Parameter	Value
Flux	
Instantaneous, L/(m^2h)	25 -35
Sustainable in long term operation, L/(m^2h)	15 - 30
Transmembrane Pressure, kPa	20
Biomass Concentration, g MLSS/L	5 - 25*
Solids Retention Time (SRT), d	>20
Sludge Production, kg SS/(kgCOD d)	<0.25
Hydraulic Retention Time (HRT), h	1 - 9
Food/Microorganisms Ratio (F/M), kg COD/kg MLSS d)	<0.2
Volumetric Load, kg COD/ (m^3d)	Up to 20
Air Flow Rate, Nm^3/h per module	8 - 12
Operational Temperature, °C	10 - 35
Operating pH	~7 - 7.5
Backwash Frequency, min	5 - 16
Backwash Duration, s	15 - 30
Energy Consumption for Filtration, kWh/m^3	0.20 - 0.40
for membrane aeration, %	80 - 90
pumping for permeate extraction, %	10 - 20

12 - 15 g/L is advised; higher concentrations can cause operational problems like clogging of the membrane and decreased oxygen transfer efficiency.

Anaerobic treatment

The anaerobic process comprises a series of interdependent phases. Initially complex organic compounds such as lipids, proteins and carbohydrates, if present, are hydrolyzed to simpler organics. The latter are then fermented to volatile fatty acids (VFAs) by acidogens. The most common of these fatty acids is ethanoic acid.

However, propanoic, butanoic and pentanoic acids may also be present in varying quantities depending on the stability of the process. Given the production of acids by the process, the system has to be adequately buffered to avoid pH declines which may adversely impact on the process's further progress. The acidogens include both facultative and obligate anaerobic bacteria. Up till this point in the process, the total amount of organic material persent in the wastewater would not have changed significantly although the type and complexity of organic compounds could have changed substantially. The gaseous by-product of the acidogenic reactions is carbon dioxide. Subsequent to the acidogenic phase is the methanogenic phase. The methanogens are obligate anaerobes and they convert the fatty acids from acidogenesis to methane and carbon dioxide. This results in substantial decrease in the organic content of the wastewater. The methane generated offers an avenue for energy recovery.

The anaerobic process is a complex process and there is substantial opportunity for it to become unstable and eventually fail. Among the important environmental conditions which should be present is the absence of molecular oxygen. This is particularly so for high rate processes. Such anaerobic systems should be designed with reactors which have positive pressure within the vessels so that air is excluded. An indication of impending anaerobic process failure is dropping pH. The methanogens are sensitive to pH and methanogenesis would stop if pH drops below 6.2. Bearing in mind acidogenesis precedes methanogenesis, pH control is an important consideration in the operation of anaerobic systems. The microbial consortium in an anaerobic reactor also needs an appropriate balance of macro and micro-nutrients to ensure microbial growth can occur. However, anaerobes have relatively slow growth rate and in sludge digestion this is a desirable characteristic as it meant low solids production. The methanogen cell yield is lower than the acidogen's. The low biomass yield does mean the nutrients requirement of an anaerobic process is lower than that of the aerobic process. In terms of BOD:N:P, the aerobic process would have required 100:5:1 while the anaerobic process only require 100:3.5:0.5 (Wun Jern, 2008).

The advantages of anaerobic biotechnology can be summarized as below;

i) Provision of process stability,
ii) Reduction of waste biomass disposal costs,
iii) Reduction of nitrogen and phosphorus supplementation costs,
iv) Reduction of installation space requirements,
v) Conservation of energy, ensuring ecological and economical benefits,
vi) Elimination of off-gas air pollution,
vii) Avoidance of foaming with surfactant wastewaters,
viii) Biodegradation of aerobic non-biodegradables,
ix) Reduction of chlorinated organic toxicity levels,
x) Provision of seasonal treatment.

Although the anaerobic biotechnology has these positive features mentioned above, there are also some negative conditions for this technology as follows;

i) Long startup requirement for development of biomass inventory,
ii) Insufficient inherent alkalinity generation potential in dilute or carbohydrate wastewater,
iii) Insufficient effluent quality for surface water discharge in some cases,
iv) Insufficient methane generation from dilute wastewaters to provide for heating to the 35°C optimal temperature,
v) Sulfide and odor generation from sulfate feed stocks,
vi) Nitrification not possible,
vii) Greater toxicity of chlorinated aliphatics to methanogens vs. aerobic heterotrophs,
viii) Low kinetic rates at low temperatures,
ix) High NH_4 concentrations (40 - 70 mg/L) required for maximum biomass activity.
(Speece, 1996)

Composting

The composting process is a controlled biological exothermic oxidation of organic matter, followed by a maturing phase, carried out by a dynamic and rapid succession of microbial populations. The organic matter is transformed into a final stable humus type product (compost) through its mineralization and humification (20 or 30% of the volatile solids are converted in CO_2 and H_2O). This product is a hygienic material, free of unpleasant characteristics, according to the following reaction.

Organic Microorganisms Biodegradable + O_2 → Stabilized organic residuals + Microbial biomass + CO_2+H_2O + Heat

Residual

As the decomposition of organic matter contained in the sludge is produced, the compost heats up to temperatures situated in the interval of pasteurization (50 – 70°C), which allows the destruction of pathogen organisms and no biodegradable organic compounds. Aerobic composting is carried out in static piles, in rows or in reactors. The latter 2 methods correspond, respectively, to large amounts of sludge to be treated and to the building of a reactor. The static pile, in its most simple form, needs a safe aerating system by tubes in the base of the pile, injecting or sucking air under pressure or by natural ventilation and turning over the pile regularly. The principal use of the produced material is agronomic and so allows nutrient minerals to reintegrate into the soil which otherwise would have been lost. The compost has also

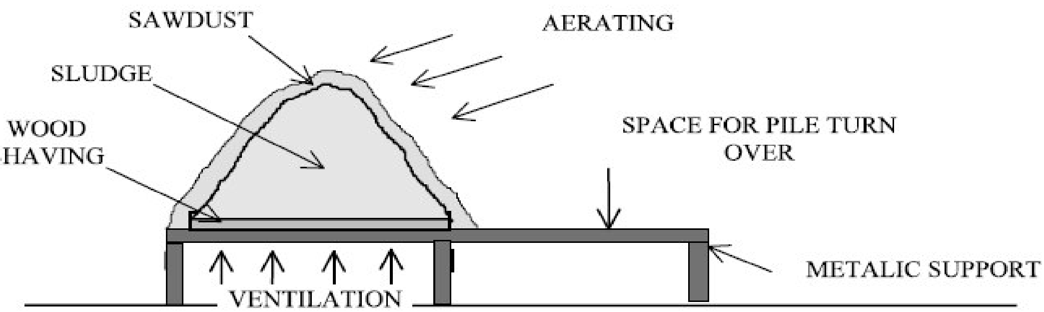

Figure 4. A pilot system diagram for composting.

been tried for other uses unrelated with agriculture.

Hoyos et al. (2002) shows a pilot system diagram (Figure 4) for composting in their study concerning waste sludge composting from gelatin-grenetine industry (Hoyos et al., 2002).

Nowadays, composting is also viewed as a cost-effective option for treating organic wastes and soils contaminated with toxic organic compounds, such as PAHs (Plaza et al., 2009).

Biosorption

The uptake of both metal and non-metal species by biomass, whether living or denatured, is commonly termed biosorption. This technique can be an alternative to conventional waste-treatment facilities (Yurtsever and Şengil, 2009).

Biosorption encompasses physico-chemical mechanisms by which metal species, radionuclides and so on, are removed from aqueous solutions by microbial biomass or products (Gadd, 2000). A variety of microbial and other biomass types has been shown to have good biosorption potential and several have been proposed as the basis for treatment of metal-bearing wastewaters. (Buyukgungor et al., 1996; Orhan et al., 2006). Compared to techniques such as precipitation and ion exchange, biosorption as a polishing or adjunct process offers the advantages of low cost, good efficiency and it does not produce sludge of high metal content (Pino et al., 2006). In biosorption, the metals are not only removeed from wastes, but also recovered to reuse for different purposes.

One of the more common questions aroused by biosorption processes involves the fate of the biosorbent after the process. Also, the fate of the concentrated solutions obtained after the elution process remains relatively unanswered. The recovery of a solute from these high concentrated solutions can be accomplished using another process, such as precipitation or electrowinning. Even if the biosorbent can be efficiently reused over several cycles, the final disposal of the material should be addressed. The common answer to the disposal of the final material is via landfill or incineration (Vijayaraghavan and Yun, 2008).

TREATMENT OF VARIOUS WASTES

Reduction of metals

Most of the heavy metals must be found at metabolic processes as trace elements, but they are also harmful components except iron and manganese. Particularly, their harmful effects increase in high concentrations. For example, mercury and cadmium have important harmful effects on individuals. They can not be degraded biologically or chemically and they accumulate in living organisms. Therefore, these types of metals must be removed from wastewaters. A process scheme for the treatment of metals by biosorption from wastewaters is given in Figure 5.

According to the literature 5 - 20% of metals are removed by sedimentation in primary treatment, 30 - 90% of metals are removed by microbiological processes from aqueous media. Some of metals recovered by anaerobic culture are Cu^{2+}, Ni^{3+}, Cr^{3+}, Zn^{2+}, Hg^{2+}. These metals can be recovered with an efficiency of 75 - 99% (Morper et al., 1984). The waste that remains from metal recovery processes can be used as fertilizer and burning material. If it is used as fertilizer, it must be pay attention to the risk of transition of harmful metals to the foods. Therefore, before the use of fertilizer, the metal concentrations in the waste must be controlled and compared with the permitted values.

Besides the treatment studies mentioned above, denatured biomasses can be used for the removal of various metals from wastewaters. There are a lot of treatment studies in the literature concerning biosorption. Pino et al. (2006) used green coconut shell powder for removing cadmium. Another treatment study was made by Bahadir et al. (2007) to treat lead ions from storage battery industry wastewaters by using biomass *Rhizopus Arrhizus*. Also Guler et al. (2007) conducted a study for removing nickel ions from wastewaters by *R. Arrhizus* immobilized on rice bran. Iqbal and Edyvean (2004)

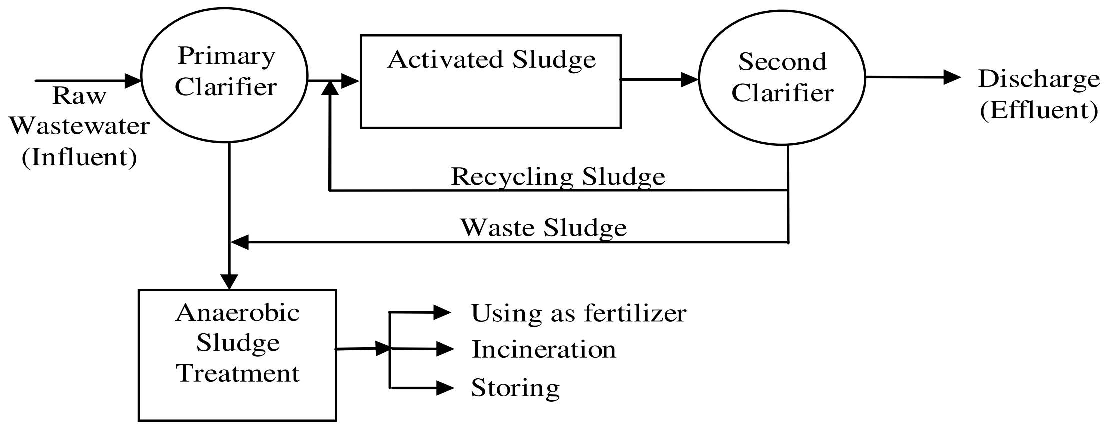

Figure 5. Removal of heavy metals from waste streams.

studied lead, copper and zinc ions biosorption by using *Phanerochaete chrysosporium* immobilized onto loofa sponge.

At all these removal studies conducted for the removal of metals by using various biomasses, removal efficiencies obtained are listed in Table 2.

Dermou and Vayenas (2007) conducted a study to reduce Cr(VI) concentration from feed solutions by using trickling filters. They studied 2 different filter media types i.e. plastic media and calcitic gravel. They achieved maximum Cr(VI) reduction rates of 4.8 and 4.7 g Cr(VI)/d for plastic material and gravel media, respectively. The feed Cr(VI) concentration they studied was about 5 mg Cr(VI)/L (Dermou and Vayenas, 2007).

Removal of phenol and its derivatives

Removal of phenol and phenol derivatives by micro-biological methods from wastewaters is an important application. Treatment of phenol which is toxic for microorganisms by this method is very interesting. Phenol makes a nutrition inhibition effect on micro-organisms, so treatment of phenol is examined according to inhibitor kinetics. A suitable treatment method for wastewaters with average phenol concentrations is activated sludge. If the wastewaters containing high phenol concentrations are delivered to the system, shock loading will occur and microorganisms will lose their activities. Multiple-stage biological reactors or biofilm reactors are more appropriate for these types of wastewaters (Molin and Nilsson, 1984). In these reactors, there is a transition from one stage to another, thereby microorganisms are acclimated to media and shock effect disappears.

In general, species of *Pseudomonas* are used in phenol removal. Mixed cultures can also be used. The other species of microorganisms are bacteria, fungus and rotifers. Species of *Pseudomonas* can be used either as free or as immobilized in phenol treatment studies (Bettmann et al., 1984; Gurel and Buyukgungor, 2004; Ustun and Buyukgungor, 2007).

There are a lot of studies made for removing phenol and its derivatives from aqueous medium in the literature (Antizar-Ladislao and Galil, 2004; Navarro et al., 2008; Thawornchaisit and Pakulanon, 2007; Wu and Ju, 2006). Aksu and Yener (1998) made a phenol removal study by using dried activated sludge and found that phenol and substituted phenols were very well removed by this biomass. The maximum loading capacity of dried activated sludge was found as 86.1, 102.4 and 116.3 mg/g for phenol, *o*-chlorophenol and p-chlorophenol respectively at an initial pollutant concentration of 100 mg/L (Aksu and Yener, 1998). Guler and Buyukgungor (2008) conducted a study for removing phenols and substituted phenols by using live *Aspergillus niger* from aqueous solution. The removal efficiencies were 99.5% for phenol, 69.28% for *o*-chlorophenol and 36.98% for p-chlorophenol. The concentrations of phenol and substituted phenol were 50 mg/L and the biomass quantity for the treatment studies was 1.0 g (Guler and Buyukgungor, 2008).

Moussavi and Mohseni (2008) performed a study to remove phenol vapors from waste gas streams by using biotrickling filter, packed with polyurethane foam cubes and enriched with phenol degrading mixed culture. In their study, phenol was removed with an efficiency of 99% (Moussavi and Mohseni, 2008).

Removal of organics and nutrients

Krishna et al. (2009) used anaerobic baffled reactor for the treatment of wastewater which has an approximately 500 mg/L COD (Chemical Oxygen Demand). In this study, when the hydraulic retention time was chosen as 8 and 10 h, COD and BOD (Biological Oxygen Demand) removal efficiencies were observed as 90% (Krishna et al., 2009). Gannoun et al. (2008) studied the treatment of

Table 2. Various treatment studies of biosorption.

Biomass	Metal	Efficiency	Reference
Green Coconut Shell Powder	Cd	98%	Pino et al. (2006)
R. Arrhizus	Pb	94%	Bahadir et al. (2007)
P. Chrysosporium immobilized onto Loofa Sponge	Pb	88%	Iqbal and Edyvean (2004)
	Cu	69%	
	Zn	40%	
Raw Rice Bran	Cr(III)	≈62%	Oliveira et al. (2005)
	Cr(VI)	≈26%	
	Ni(II)	≈27%	

cheese whey by using upflow anaerobic bioreactor. Before this treatment they applied a pretreatment to cheese whey for solving the inhibition problems during anaerobic treatment. After pretreatment, COD of the wastewater was decreased with an efficiency of 50%. Then pretreated cheese whey was fed to the upflow anaerobic bioreactor. For a COD concentration of 5 g COD/L and at hydraulic retention time varying from 4 to 2 days, COD removal rates were found as 90% and 77%, respectively (Gannoun et al., 2008).

Nakhla et al. (2006) conducted a work with submerged vacuum ultrafiltration membrane to remove organics from food-processing wastewater. In their study, BOD and COD were removed with efficiencies of 95 - 96.5% and 96 - 99%, respectively (Nakhla et al., 2006). Another study was made by Ünlü et al. (2005). They used an ultrafiltration-hollow fiber membrane submerged into bioreactor for removing inert COD, orthophosphate, ammonium and nitrate ions from strong wastewater. Orthophosphate, ammonium and nitrate ions were removed on the levels of 30%, less than 10 and 28% on average, respectively. Inert COD was not retained by ultrafiltration membrane module with a pore size of 0.03 µm (Ünlü et al., 2005).

Chavan and Mukherji (2008) operated the rotating biological contactors for the treatment of hydrocarbon-rich wastewater. They used oil degrading bacteria and phototrophic microorganisms in the bioreactor. At N:P ratio of 19:1, 28.5:1, 38:1 and 47.4:1, the total petroleum hydrocarbon removal efficiencies were found to be 98.6, 99.4, 99.4 and 99.3% respectively and total COD removal efficiencies were found to be 84.6, 97.8, 97.0 and 95.6% respectively (Chavan and Mukherji, (2008).

CONCLUSIONS

The application of biotechnology on various fields such as industry, agriculture, waste treatment is very important in view of economic and environmental benefits. In this technology, processing of products is less expensive and product quality is enhanced. It is possible to evaluate various wastes around us by microbiological processes. Today, numerous microbiological waste processing projects can be conducted at high scale. For example, solid and liquid wastes containing high organic substances are used for obtaining methane. Consequently, a new energy resource arises. In the treatment of industrial and municipal wastewaters, various microbiological methods such as activated sludge, trickling filters, oxidation ponds, membrane bioreactors are used successfully. One of the important points of waste processing is to think all direct and indirect expenses and to calculate profitability ratio. Wastes belonging to municipality and industries (liquid, solid and gaseous) that constitute environmental pollution and threaten public health must be treated. In the removal of these types of contaminants, cost of the project will be less important.

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