Biotechnological
Communication

Biosci. Biotech. Res. Comm. 12(1): 140-146 (2019)

BBRC
Bioscience Biotechnology
Research Communications

Biotechnological management of water quality: A mini review

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ABSTRACT

Since eighteenth century onwards, with the advent of industrial revolution, petrochemical and chemical industries have seen tremendous growth. Wastewater is an essential raw material as well as a by-product of modern day industries and the magnitude of wastewater generation depends upon the level of technological progress of the particular industry of a particular country. It has been observed that least developed and developing countries generate a huge volume of wastewater as compared to the developed ones. This paper discusses the chemistry of water and wastewater, parameters of water for application in drinking water, wildlife and fisheries, irrigation and industrial cooling purpose. Various methods based on physical, chemical and biological treatment available for treatment of wastewater to make it reusable and less harmful to the environment on discharge. Several biological methods of waste treatment and treatment process including trickling filter, activated sludge, aerated lagoon, and waste stabilisation ponds to reduce or degrade some pollutants have been presented in this study. New approaches incorporate natural processes instead of conventional chemical treatment. The role of various microbes has been also discussed to treat various organic pollutants present in wastewater. Applications of genetic engineered microbes as well as certain metabolic engineering mediated interventions have shown significant degradation and reduction of pollutants concentration. Research on wastewater treatment suggests treatment of wastewater must be designed specifically for the particular type of effluent produced. Nevertheless, strategies can be developed for multipollutant targets using biotechnological approaches.

KEY WORDS: BIOLOGICAL TREATMENT, DDT, METABOLIC ENGINEERING, ORGANOCHLORINE, WASTEWATER

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Received 23/02/2019 Accepted after revision 2/03/2019
Published: 30th March 2019 Pp-140-146

Available at: https://bbrc.in/
Article DOI: http://dx.doi.org/10.21786/bbrc/12.1/18

INTRODUCTION

Waste is defined as the unwanted or the discarded material which has no further known application and can be divided into three categories-solid, liquid and gaseous. When any undesired agent mixes with water it makes it impure and unacceptable for further use. Wastewater has been defined as water which has some impurities. Generally, it is pure water and various polluting agents in different proportion. Chemistry of pure water elaborating the physical and chemical properties of water and how its peculiar structure makes it a universal solvent has been discussed in detail later section. Wastewater is an essential a by-product of modern day industries (Buljan & Kral 2011, Shi Hanchang 2011, Miksch et al., 2015, González-Camejo et al., 2017).

From agriculture to domestic to anindustrial level, water is extensively used as a raw material. Agriculture and public health practices add many pesticides to the water making it unfit for use. From oil, food, dairy& beverages to textile & leather to pharmaceutical & chemical to paper & pulp to metal and power generating industries, each and every industry needs ahuge amount of water for its operation and is a major contributor of wastewater production. Nuclear, mining and quarries also produce agreat volume of wastewater as a by-product. For example, agricultural nitrate is one of the major reasons for groundwater pollution, (Shukla et al. 2013) (Miksch et al., 2015) (González-Camejo et al., 2017). After use of water, it is discharged as wastewater. Composition of wastewater varies to reference to its production site. Major characteristics include total organic content, solid content present in it, pH, temperature, colour, presence of heavy metals and their concentration, presence of microbes and their population etc. For reuse of this water, government agencies and various international bodies dealing with water and health have graded water into different categories. In India, Central Pollution Control Board has classified water into five classes depending upon their end use and passing the standards set by it. It is very important to know the standard parameters of water quality before its application towards human and animal consumption and for watering plants. Scientific progress in each sector contributed to exhaustion of water resources and waste generation. The amount of wastewater generation depends on the level of technological process development to the particular industry in a particular country and it will be reduced with the improvement of industrial technology. (Hammer 2001, Gogate and Pandit, 2004, Rastogi, 2010 Shi, Hanchang 2011 Rawat et al., 2011, Veerakumari, 2015, Ansari et al., 2017).

It has been observed that least developed and developing countries generate a huge volume of wastewater as compared to the developed ones. In the present review, a detailed account of water chemistry, wastewater characteristics, and wastewater treatment methods has been summarized. Also, the role of various biological methods in the treatment of a range of organic pollutants has been discussed.

Chemistry of water

Water is composed of one oxygen atom and two hydrogen atoms that form covalent bonds with the unpaired electrons of oxygen. The hydrogen atoms are placed at 0.958Å from oxygen. The angle between the two hydrogen (bond angle) is 104.5^o making it a bent molecule with partial positive charges on each hydrogen and a partial negative charge on the oxygen atom. Thus, it is a polar molecule. This helps water molecules to form hydrogen bonds with other molecules, including water, (Némethy et al., 1962, Devangee Shukla, et al 2013, Veerakumari, 2015, Emiliano et al. 2017).

It is termed as a universal solvent for the ability to effect many chemical reactions and facilitating the hydrolysis, breaking the bigger molecules into their simpler forms. It possesses certain peculiar and unique physiochemical properties vital for the maintenance of life activities. It solubilises a large number of organic and inorganic compounds. Therefore, it might have been the primary resource for the origin of life. Almost all living organisms possess >70% of their mass comprising water. It is important for many biochemical reactions. It has a high affinity for salts. Physical properties of water are as follows: heat capacity 1 cal/g, heat of vaporization 540 cal/g at 0°C, latent heat of fusion 97.7 cal/g at 0°C, surface tension 76 erg/cm^2, dielectric constant 79, melting point 0°C, boiling point 100°C and viscosity 1.14 x 10^{-3} g/cm-s (Rastogi Smita, 2010 Devangee Shukla, et al 2013, Veerakumari 2015).

Parameters of water for various uses

Central Pollution Control Board (CPCB) of India has proposed various classes of water as 'A to E' about their end use. Drinking Water Source without conventional treatment but after disinfection has been categorised under Class "A" of water and possess the following characteristics: i) Total Coliforms Organisms MPN/100mL shall be 50 or less ii) pH between 6.5 and 8.5 iii) Dissolved Oxygen 6mg/L or more and iv) Biochemical Oxygen Demand (BOD_5^{20}) of 5 days at 20°C 2mg/L or less. Bureau of Indian Standards has defined Indian Standard Specifications for Drinking Water, under IS: 10500, 1992. This report provides information on the permissible and desirable limits of various parameters in drinking water. Rahmanian et al. (2015) have discussed the determination of parameters for drinking water. Class B water is designated best for organised outdoor bathing. The coliforms MPN/100 mL in this class is ≤500 and pH 6.5-8.5. The dissolved oxygen and the BOD_5^{20} levels are set at ≥5 ppm and ≤3 ppm respectively. Class C water is a drinking water source that is available after conventional treatment and disinfection process. The MPN for coliforms is set at ≤5000 per mL with pH 6-9 and dissolved oxygen level of ≥ 4 ppm while the BOD_5^{20} is recommended at ≤ 5 ppm. Class D water is useful for wildlife and fisheries. Its free ammonia -N is ≤ 1.2 ppm. The pH ranges between 6.5-8.5 while the dissolved oxygen is ≥ 4 ppm. Water for Irrigation, Industrial Cooling, Controlled Waste disposal comes under class "E" of water and it shall have the pH between 6 and 8.5. Additionally, the boron content shall not be more than 2mg/L and maximum Electrical Conductivity at 25°C (mhos/cm) is capped on 2250 (Ansari et al., 2009) for the purpose of proper treatment and dilution of effluent before discharge in water stream or on land. Physico-chemical characteristics of distillery effluent samples such as colour, odour, Total Solids, Total dissolved solids, Total Suspended Solids, pH, Electrical Conductivity, Total hardness, Calcium, Magnesium, Alkalinity, Chloride, Dissolved Oxygen, Biological Oxygen Demand, Chemical Oxygen Demand, Ammonical Nitrogen, Total Phosphorus, and Total Potassium were analysed and it was observed that the characteristics of spent wash and PTDE (primary treated distillery effluent.

The composition of wastewater

Wastewater is simply that part of the water supply to the community or to the industry which has been used for different purposes and has been mixed with solids, either suspended or dissolved. Wastewater is 99.9% water and 0.1% solids. The main task of treating the wastewater is to remove most or all of this 0.1% of solids (Spellman, 2013) toxic chemical products formed as secondary metabolites by a few fungal species that readily colonise crops and contaminate them with toxins in the field or after harvest. Ochratoxins and Aflatoxins are mycotoxins of major significance and hence there has been significant research on broad range of analytical and detection techniques that could be useful and practical. Due to the variety of structures of these toxins, it is impossible to use one standard technique for analysis and/or detection. Practical requirements for high-sensitivity analysis and the need for a specialist laboratory setting create challenges for routine analysis. Several existing analytical techniques, which offer flexible and broad-based methods of analysis and in some cases detection, have been discussed in this manuscript. There are a number of methods used, of which many are lab-based, but to our knowledge there seems to be no single technique that stands out above the rest, although analytical liquid chromatography, commonly linked with mass spectroscopy is likely to be popular. This review manuscript discusses (a.The composition of wastewater varies according to the primary use of water. It gives a reflection of the lifestyle and technologies enjoyed by this progressive world. Two major constituents are organic and inorganic compounds, (Rastogi, 2010, Ansari et al., 2017).

Carbohydrate, protein, fats, amino acids and volatile acids etc. come under the organic compounds while sodium, calcium, chlorine, potassium, sulphur, magnesium, bicarbonate ammonium salts and heavy metals etc. are listed as inorganic compounds by various researchers (Abdel-Raouf et al., 2012). Hydrocarbons, fats, oils, waxes and high molecular weight fatty acids are collectively referred to as oil and grease come under organic substances (Hammer 2001). Biological components constitute bacteria, fungi, virus and algae etc. Eutrophication is a common phenomenon worldwide due to the discharge of industrial wastes into open water resources which includes vast amounts of nitrogen and-phosphorous (Rawat et al., 2011, González-Camejo et al., 2017). Characteristics of wastewater from various industries

Characteristics and compositions of wastewater vary from industry to industry. Wastewater characterisation depends upon changes in colour, odour, total dissolved solids (TDS), total suspended solids (TSS), pH, conductivity, temperature, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and volatile organic compounds (VOCs)etc. The physical characteristics of distillery effluent samples and observed spent wash colour to be dark brown, odour unpleasant, total solids 42400.2 ± 6.4 (CPCB: 90000-120000), total dissolve solids 38200.2 ± 4.8, total suspended solids 4200.0 ± 0.0, pH 4.2 ± 1.2 (CPCB: 3.7-4.5), electrical conductivity (μmho/cm) 16450.8 ± 8.2, total hardness 2432.4 ± 5.4 calcium 2070.0 ± 2.6 (CPCB: 2000-3500), magnesium 2260.5 ± 6.7, alkalinity 2864.5 ± 8.0, chloride 8530.2 ± 8.3(CPCB: 5000-6000), dissolve oxygen Nil, biochemical oxygen demand 32300.8 ± 10.8 (CPCB: 45000-50000), chemical oxygen demand 57164.6 ± 12.9 (CPCB: 80000-100000), ammonical nitrogen 1254.4 ± 2.4 (CPCB: 1000-2000), total phosphorus 44.4 ± 5.6 (CPCB: 200-300), total potassium 7440.2 ± 3.8 (CPCB: 8000-12000). All values given here are in mg/litre(Central Pollution Control Board, 2008) (Ansari et al., 2009)for the purpose of proper treatment and dilution of effluent before discharge in water stream or on land. Physico-chemical characteristics of distillery effluent samples such as colour, odour, Total Solids, Total dissolved solids, Total Suspended Solids, pH, Electrical Conductivity, Total hardness, Calcium, Magnesium, Alkalinity, Chloride, Dissolved Oxygen, Biological Oxygen Demand, Chemical Oxygen Demand, Ammonical Nitrogen, Total Phosphorus, and Total Potassium were analysed and it was

Table 1. Various methods of biological treatment. (Cheremisinoff, 1996) (Hoffmann, 1998) (Tchobanoglous et al., 2003) (Von Sperling, 2007) (Mara, 2009) (Butler et al., 2017)			
S. No.	Process	Treatment Agents	Waste treated
1	Trickling filters (attached growth)	Packed bed covered by the microbial film	Acetaldehyde, benzene, chlorinated hydrocarbons, nylon, rocket fuel
2	Activated sludge (suspended growth)	Aerobic microorganisms suspended in wastewater	Refinery, petrochemical and biodegradable organic wastewaters
3	Aerated lagoon	Surface impoundment plus mechanical agitation	Biodegradable organic chemicals
4	Waste stabilization ponds	Shallow surface impoundments plus aeration to promote the growth of algae and bacteria and algae symbiosis	Biodegradable organic chemicals

observed that the characteristics of spent wash and PTDE (primary treated distillery effluent (Devangee Shukla, et al. 2013).

Wastewater treatment

Wastewater treatment refers to the application of various treatment methods on wastewater to make it reusable or less harmful to the environment when discharged. Methods of treatment used for removal of contaminants using physical, chemical and biological reactions are known as unit operations, and they are categorized as primary, secondary and tertiary treatment methods. Primary treatments involve physical operations such as screening and sedimentation for removal of floating and settle able solids found in wastewater. Secondary treatments involve chemical and biological processes to remove most of the organic and inorganic matters present in the wastewater. Then comes the tertiary treatment methods or advanced techniques. Treatment of wastewater must be designed specifically for the specific effluent produced (Gogate and Pandit, 2004, a review of oxidation processes operating at ambient conditions was presented. It has been observed that none of the methods can be used individually in wastewater treatment applications with good economics and high degree of energy efficiency. Moreover, the knowledge required for the large-scale design and application is perhaps lacking. In the present work, an overview of hybrid methods (the majority are a combination of advanced oxidation processes Central Pollution Control Board, 2008, Shi, Hanchang 2011).

Biological treatments of wastewater

Biological treatments of wastewater facilitate the removal of all the settleable colloidal solids and degrade or reduce the present organic as well as inorganic matters (Rawat et al., 2011). Microorganisms utilize the organic/inorganic sources present in the wastewater as a nutrient or food for growth. The process of nutrient utilisation significantly reduces the organic and inorganic loads of the wastewater. Several microorganisms including bacteria, fungus and algae (Table-2) or symposium of algae and bacteria or fungal and bacterial have been explored for wastewater remediation across the globe, (Cheremisinoff, 1996, Butler et al., 2017). Various methods have been devised to date for remediation of wastewater and they include aerobic, anaerobic and the combination of both. They are further subdivided as per their growth system into attached or suspended growth systems. Some of them are listed in Table 1 & 2.

Metabolic engineering to treat wastewater

Metabolic engineering stands for a branch of molecular biology where alternation in the genome of an organism is carried out to achieve a specific purpose of bringing specific genotypic or phenotypic changes in the concerned microorganism. Metabolic engineering is exercised to achieve many objectives such as to reduce or stop the production of by-products to optimise the yield, to increase the rate of thebiochemical process, reduce the energy consumption and ultimately to develop a strain with resistance to biotic as well abiotic stress (Yang & Liu, 2007) (Kumar and Prasad, 2011). The purpose of metabolic engineering is to obtain a robust strain of microorganism to gain optimum productivity, in the case of wastewater remediation, optimum nutrient removal to decrease the organic and inorganic loads. Mutant bacteria have also been introduced for wastewater treatment (Ostergaard et al., 2000) (Siejen & Macro 2008) (Naidoo & Adimola 2014).

Although for metabolic overproduction, very often the strains of the microorganisms are subjected to mutation and selection for yield improvement, the prospect to introduce heterologous genes and regulatory elements makes metabolic engineering, a promising area of research (Soda et al., 1999). The use of a floc-forming bacterium as the host for a recombinant plasmid was proposed. The floc-forming and phenol-degrading GEM Sphingomonas paucimobilis 551 (pS10-45. Bioaugmentation engineered bacteria have a unique position

Table 2. Microbial degradation of various organic pollutants. (Bush et al., 1961) (McCLURE et al., 1991) (Rochkind et al., 1986) (Cheremisinoff, 1996) (Smidt et al., 2000) (Wang et al., 2000) (Tchobanoglous et al., 2003) (Bidlan R, Manonmani H. K., 2007) (Seo et al., 2009) (Mandal and Mallick, 2011) (Renuka et al., 2013) (Saxena et al., 2016) (Gong et al., 2017) (Kumar et al., 2017) (Singh et al., 2017)		
S. No.	**Organic Pollutant**	**Microbes involved**
1	Petroleum hydrocarbons,	*Acinetobacter, Arthrobacter, Mycobacteria, Actinomycetes, Pseudomonas etcamongbacteria; Scolecobasidium and Cladosporium among yeasts.*
2	Pesticides,herbicides, like Aldrin, Dieldrin and organophosphates like Parathion and Malathion	*Zylerionxylestrix (fungus)*
3	2, 4-D, 1,2,3-trichloropropane (TCP)	*Pseudomonas, Arthrobacter*
4	Diichlorodiphenyltrichloro ethane(DDT)	*Penicillium (fungus), Serratia marcescens (Bacteria)*
5	Kepone, piperonylic acid, Lignocellulosic wastes, Pentachlorophenol	*Pseudomonas*
6	Ethyl benzene	*Nocardiatartaricans (Bacteria)*
	Wastewater	*Calothrix sp., Lyngbya sp., Ulothrix sp, and Chlorella sp. Chlamydomonasrenhardtii, Parachlorellakessleri-I, Nannochloropsisgaditana Scenedesmussp.(Algae)*
7	Heavy metals like cadmium	*Genetically modified E. coli*
8	Chlorinated aromatic compounds	*Desulfomonile tiedjei (bacteria)*
9	Lignins from Paper mills	*Aspergillustrichosporon (Yeast), arthrobacter, Chromobacter, Pseudomonas, Xanthomonas (Bacteria)*

in the treatment of effluent from printing and dyeing industries because of its various advantages, including powerful treatment capability, good decolourisation effect, and modest impact on the surrounding of the original processing system and so on (Xie et al., 2014). McClure *et al.* discussed the role of genetic engineering in improving wastewater treatment with a focus on the degradation of recalcitrant compounds especially chlorinated aromatic compounds. They also investigated the survival and function of natural and genetically modified bacteria when inoculated into laboratory-scale activated sludge units, (McClure et al., 1991). Research on wastewater treatment suggests treatment of wastewater must be explicitly designed for the particular type of effluent produced. Banerjee *et al.* studied various aspects to increase the lipid accumulation in microalgae *Chlamydomonas reinhardtii* and stressed on metabolic engineering associated with other factors to get the desired result (Banerjee et al., 2016).

Trained microorganisms to treat wastewater

Raju *et al.* investigated the role of a consortium of microorganisms to degrade or reduce the concentration of lindane and DDT present in pesticide water. They reported enhanced green gram seed germination upon reduction of Lindane and DDT concentration when the microbial consortium was used (Raju et al., 2017). The strain of *Serratia marcescens* was found to have profound DDT degrading potential Organochlorine which was considered recalcitrant compounds were shown to degrade at enhanced rates in the presence of non-ionic surfactants such as tweens and specificdead-end metabolites of Dichlorodiphenyltrichloroethane (DDT) like Dichlorodiphenyldichloroethylene (DDE) and Dichlorodiphenyldichloroethane (DDD) have also been shown to get metabolised by indeed trained microbes (Bidlan 2007a) (Bidlan 2007b) (Bidlan 2009) (Bharadvaja et al., 2016).

CONCLUSION

Wastewater is generated from various activities in the community and also through natural processes. There are various strategies developed to reduce the levels of various contaminants in the wastewater. Most of the treatment plants use microbial remediation from the microbes already exixtinng in the sludge. Latest trend is to shift from the conventional chemical treatments to the biological treatments as these are more ecofriendly. Research is being carried out around the globe by various groups and a lot of funds are being pushed into this by many countries so that the best possible treatment methods can be implemented for facilitating clean and healthy water for a better, green and robust environment.

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