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Microbial Diversity of Industrial Wastewater: A Review

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Abstract: Water pollution is one of the major ecological challenge for all forms of life. The major cause of water pollution is rapid industrialization. Industries use water for various activities and during these activities; they generate an enormous volume of wastewater. The wastewater can be collected either in a local sewer system, treated by wastewater treatment plants, or directly released into the environment. In case of direct discharge of wastewater into the different water bodies, it adversely affects the life which is dependent on this for their water needs. Industrial wastewater contains various microorganisms, organic (chlorides, sulphates, oil and grease, hydrocarbons, pesticides, herbicides, phenol, aliphatic compounds), and chemical compounds (heavy metals, detergents, pesticides, nitrogen, and phosphorus) which are harmful to the environment as well as to humans. Bacteria are the most common microorganisms which are present in industrial wastewater, some of these are helpful in the treatment of wastewater and some are pathogenic which is responsible for various types of waterborne diseases. Thus, this study reviews various types of Bacteria present in industrial wastewater in terms of their roles within the wastewater treatment process.

Keywords: Coliforms, Cyanobacteria, Denitrifying bacteria, Filamentous bacteria, Methane-forming bacteria, Pathogenic bacteria

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Introduction

Water is essential for the survival of human life and it plays a vital role in sanitation for our rural and urban communities. It is also used for various purposes like agriculture, industries, community, recreation, etc. (Merrett, 1997; Kay *et al.*, 1997), and also provide a wide range of ecosystem and environmental services (Frederick, 1993). Water is a limited resource and the earth is covered by 70% of water but only 0.5% of water is useful for humans. This water is available in aquifers, Lakes, Reservoirs, Rivers, Streams,

and rainfall. 2.5% of the water is available in the form of glaciers and stored as groundwater. The rest 97% of water is saltwater and not so useful for humans (Baker *et al.*, 2016).

India is a growing country and during last few decades the water demand is increased due to the rise of the human population and industrialization. Industries use water for various purposes like manufacturing various products, Washing, cleaning, cooling, and during these activities they generate the wastewater on a large

scale without treatment or by a mismanaged treatment system. The nature of industrial wastewater depends on the activities of a particular industry from which it is originated (Surti, 2016). It is characterized by two basic components like organic components (chlorides, sulphates, oil and grease, hydrocarbons, pesticides, herbicides, phenol, aliphatic compounds) (Zheng *et al.*, 2013), chemical compounds (heavy metals, detergents, and pesticides, nitrogen and phosphorus) which are toxic to the various life forms of the ecosystem and also cause harmful effect to the environment (Rajasulochana and Preethy, 2016).

The wastewater generated from various industries is directly discharged into open sources or sewer systems, further, the wastewater is treated by Sewerage treatment plants or wastewater treatment plants but insufficient or mismanaged industrial wastewater treatment may cause eutrophication in the open water bodies or can create a beneficial form for the water borne pathogens (Ilyas *et al.*, 2019). These include *Salmonella* sp., *Escherichia* sp., *Shigella* sp., *Yersinia* sp., *Klebsiella* sp., *Vibrio cholera*, *Mycobacterium* sp., and *Pseudomonas* sp. These pathogens are transmitted to humans through the water while bathing, washing, or drinking water and causes various types of waterborne diseases like pneumonia, foodborne illness, typhoid fever, diphtheria and cause a major threat to humans (El- Lathey *et al.*, 2009; Cai and Zhang, 2013).

The monitoring of these microorganisms can be used as the parameter of industrial wastewater pollution and as a sign of the health status of the community which lives around the treatment plants or near disposal sites. Effective treatment of industrial wastewater is essentially required for the monitoring of various waterborne diseases and other environmental and health risks.

Microbial diversity found in industrial wastewater:

Industrial wastewater contains various types of microorganisms and among these some are having pathogenic properties which cause various types

of diseases in humans and animals. These microorganisms also play a crucial role in the wastewater treatment process and can degrade various types of inorganic and organic compounds. Generally, these microorganisms originate from industrial processes, treatment processes, fecal waste, etc.

Bacteria: Bacteria are the most common microorganism found in industrial wastewater. A wide range of bacterial communities are found in industrial wastewater (Table 1), including members of different taxonomic, biochemical (e.g., N₂-fixation, nitrification, denitrification, sulfur oxidation), and physiological groups (e.g., anaerobic, aerobic, phototrophic, heterotrophic). Some of these give utilitarian benefits to water cleaning, like nutrient removal and make it less harmful to the environment. These bacterial communities uniquely help in the treatment process to ensure there is little to no impact on the surrounding environment. These bacterial communities also contain many microbes from humans and animals, which could interact with the bacterial communities of normal water (e.g., waterways and lakes) unpredictably (Numberger *et al.*, 2019).

Bacteria are classified as follow according to their role in industrial wastewater:

Coliforms: Many researchers observed the presence of coliforms bacteria in industrial wastewater. The presence of these bacteria indicates the occurrence of pathogenic microbes (Clark, 1995). These are mainly gram-negative bacteria, most of these present in human fecal and animal manure, soil and wastewater of pulp and paper, and textile industrial wastewater (Parveen *et al.*, 1997; Gauthier and Archibald, 2001). These types of bacteria are frequently used as an indicator of water quality and *Escherichia coli* is most commonly used as an indicator organism to monitor water quality and bacteriological quality of wastewater (Rompre *et al.*, 2002). Most common Coliforms present in industrial wastewater belong to the *Enterobacteriaceae* family including *Klebsiella* sp., *Enterobacter* sp.,

Table 1: Common Bacterial species present in industrial wastewater

S. No.	Bacterial Family	Bacteria	References
1.	Enterobacteriaceae	<i>Enterobacter aerogenes</i>	Ginige <i>et al.</i> , 1998
		<i>Aerobacter aerogenes</i>	Kumar <i>et al.</i> , 2016
		<i>Enterococcus hirae</i>	Raed, <i>et al.</i> , 2017
		<i>Escherichia coli</i>	Ogunnus and Dahunsi, 2014
		<i>Enterobacter sp.</i>	Okezie <i>et al.</i> , 2020
		<i>Proteus sp.</i>	Ogunnus and Dahunsi, 2014
		<i>Klebsiella sp.</i>	Ogbomida <i>et al.</i> , 2016
		<i>Salmonella sp.</i>	Ogbomida <i>et al.</i> , 2016
		<i>Klebsiella pneumonia</i>	Manir <i>et al.</i> , 2020
		<i>Shigella sp.</i>	Manir <i>et al.</i> , 2020
		<i>Serratia marcescens</i>	Affandi <i>et al.</i> , 2014
2.	Bacillaceae	<i>Bacillus circulans</i>	Ginige <i>et al.</i> , 1998
		<i>Bacillus macerans</i>	Ginige <i>et al.</i> , 1998
		<i>Bacillus cerus</i>	Kumar <i>et al.</i> , 2016
		<i>Bacillus megaterium</i>	Hussain <i>et al.</i> , 2018
		<i>Bacillus subtilis</i>	Raed <i>et al.</i> , 2017
		<i>Bacillus alvi</i>	Ginige <i>et al.</i> , 1998
		<i>Bacillus aryabhatai</i>	Zainth <i>et al.</i> , 2019
		<i>Bacillus polymyxa</i>	Kumar <i>et al.</i> , 2016
		<i>Exiguobacterium sp.</i>	Tahrani <i>et al.</i> , 2015
3	Staphylococcaceae	<i>Staphylococcus aureus</i>	Kumar <i>et al.</i> , 2016
		<i>Staphylococcus sp.</i>	Ogbomida <i>et al.</i> , 2016
4	Pseudomonadaceae	<i>Pseudomonas putida</i>	Ginige <i>et al.</i> , 1998
		<i>Pseudomonas aeruginosa</i>	Raed <i>et al.</i> , 2017
		<i>Pseudomonas pseudoalcaligenes</i>	Rozitis and Strade, 2015
5	Microbacteriaceae	<i>Corynebacterium rathay</i>	Kumar <i>et al.</i> , 2016
		<i>Microbacterium sediminis</i>	Balion- Salas <i>et al.</i> , 2018
6	Lactobacillaceae	<i>Lactobacillus delbrueckii</i>	Raed <i>et al.</i> , 2017
		<i>Lactobacillus sp.</i>	Prakashveni and Jagadeesan, 2008
7	Streptococcaceae	<i>Streptococcus sp.</i>	Ogbomida <i>et al.</i> , 2016
		<i>Streptomyces sp.</i>	Fakorede <i>et al.</i> , 2013
8	Corynebacteriaceae	<i>Corynebacterium sp.</i>	Fakorede <i>et al.</i> , 2013
9	Morganellaceae	<i>Proteus vulgaris</i>	Manir <i>et al.</i> , 2020
		<i>S. proteus</i>	Okezie <i>et al.</i> , 2020
10	Aeromonadaceae	<i>Aeromonas hydrophilla</i>	Affandi <i>et al.</i> , 2014
		<i>Aeromonas sp.</i>	Oljira <i>et al.</i> , 2018
		<i>Aeromonascaviae</i>	Rozitis and Strade, 2015
11	Alcaligenaceae	<i>Bordetella sp.</i>	Okezie <i>et al.</i> , 2020
		<i>Alcaligenes faecalis</i>	Prakashveni and Jagadeesan, 2008
12	Leuconostocaceae	<i>Leuconostoc lactis</i>	Prakashveni and Jagadeesan, 2008
13	Listeriaceae	<i>Listeria sp.</i>	Fakorede <i>et al.</i> , 2013
14	Tsukamurellaceae	<i>Tsukamurella inchoensis</i>	Rozitis and Strade, 2015
15	Sphingobacteriaceae	<i>Sphingobacterium thalpophilum</i>	Rozitis and Strade, 2015
16	Rhodobacteraceae	<i>Paracoccus versutus</i>	Rozitis and Strade, 2015
17	Falvobacteriaceae	<i>Falvobacterium johnsoniae</i>	Rozitis and Strade, 2015
18	Commamonadaceae	<i>Acidovorax deflafieldii</i>	Rozitis and Strade, 2015
19	Desulfobulbaceae	<i>Desulfobulbs</i>	Jabari <i>et al.</i> , 2016
		<i>Desulfomicrobium</i>	
20	Zymomonadaceae	<i>Zymonas sp.</i>	Kumar <i>et al.</i> , 2016
21	Paenibacillaceae	<i>Paenibacillus sp.</i>	Raj <i>et al.</i> , 2007
		<i>Aneurinibacillus aneurinilyticus</i>	

Escherichia coli, *Pasteurella* sp. and *Proteus* sp. (Bohra *et al.*, 2012).

Cyanobacteria: This is also known as blue-green algae which is a remarkable group of organisms. These are considered algae because of their microscopic morphology, pigmentation, and oxygen advancing photosynthesis. These are the largest group of photosynthetic prokaryotes because of their widespread occurrence and frequent morphological variety (Vijayakumar, 2012). Various species of cyanobacteria such as *Anabaena beckii*, *Anabaena fertilissima*, *Nostoc calcicola*, and *Westiellopsis prolifica* are present in dye effluent and *Anabaena fertilissima* in paper mill, and *Anabaena beckii* and *Nostoc calcicola* are present in sugar mill effluent (Vijayakumar *et al.*, 2007).

Denitrifying bacteria: Denitrifying bacteria are helpful in biological denitrification. The denitrification enables the change of oxidized nitrogen compounds by a wide range of bacteria into harmless nitrogen gas with the carbon evacuation. The cycle uses nitrate as terminal electron acceptors, changing them over to nitrogen, nitric oxide, and nitrous oxide gases. Denitrifying bacteria are present in various environments such as deep sea, wastewater treatment plants etc. Many researchers isolated and identified denitrifying bacteria in industrial wastewater which includes *Achromobacter*, *Alcaligenes*, *Aquaspirillum*, *Azoarcus*, *Bacillus*, *Brachymonas*, *Paracoccus*, *Pseudomonas*, *Rhodocyclus*, *Thauera*. *Pseudomonas* species are commonly recognized as the primary microorganisms to achieve the denitrification (Janda *et al.*, 1998; Kniemeyer *et al.*, 1999; Sakano *et al.*, 2002; Leta *et al.*, 2004; Yoshie *et al.*, 2004; Reh fuss and Urban, 2005; Thomsen *et al.* 2007; Wang and Lee, 2007).

Sulfur Reducing Bacteria: Sulfur Reducing Bacteria (SRB) is a different heterogeneous group of anaerobic microorganisms living in different ecological conditions. These also participate in

nutritional cycles or the environment and help in the degradation of various organic matters through the process of dissimilatory sulfate reduction (Dash *et al.*, 2012). Sulfur reducing bacteria present in industrial wastewater are *Desulfovibrio*, *Clostridium*, *Bacteroides*, *Desulfobulbus*, *Desulfomicrobium*, and *Desulfotomaculum* etc. (Boopathy and Daniels, 1991; Jabari *et al.*, 2016).

Filamentous Bacteria: Filamentous bacteria are present in activated sludge of wastewater treatment plants and cause various problems during the treatment process. The extensive growth of these bacteria causes bulking and can prevent sufficient flocculation and settling biomass in the secondary clarifier which can carry the solids into the final treated effluent (Nielsen *et al.*, 2009).

Filamentous bacteria might be considered to hinder wastewater treatment when they grow extensively, but these also play an important role in the development of activated sludge flocs with sufficient settling and clarification properties (Gerardi *et al.*, 1990). The various species of Filamentous bacteria are present in activated sludge of a wastewater treatment plant which includes *Candidatus'Microthrix parvicella'*, *Thiothrix* sp., a few *Mycolata* (formerly referred to as *Nocardia* or *Nocardioforms*), *Alphaproteobacteria* ('Nostocoida'- like), the Gammaproteobacteria (*Thiothrix* and type 021N), the Actinobacteria (*Candidatus'Microthrix'*, *Mycolata*), Chloroflexi (types 1851, 0041 and 0092) *Sphaerotilus natans* (type 1863, type 0092) and *Haliscomenobacter hydrophila* (Soddell and Seviour, 1990; Ramothokang *et al.*, 2003; Nielsen *et al.*, 2009).

Methane forming bacteria: These play a vital role in the anaerobic process where they obtain stable and auto-managed fermentation through digestion and decomposition of the organic compounds present in waste and wastewater into biogas. In this process, the organic compounds degrade to

Table 2: Common pathogenic bacteria present in different industrial wastewater

Bacteria	Industry	References
<i>E. coli</i>	Food and Beverage industry	Farasat <i>et al.</i> , 2012
<i>Salmonella</i> sp.	Meat industry	Stocis <i>et al.</i> , 2016
<i>Yersinia</i> sp.	Pharmaceutical industry	Ali and Naseem, 2012
<i>Klebsiella pneumonia</i>		
<i>Shigella</i> sp.	Modern Abattoir	Manir <i>et al.</i> , 2020
<i>Proteus vulgaris</i>		
<i>Staphylococcus aureus</i>	Textile industry	Kumar <i>et al.</i> , 2016
<i>Listeria</i> sp.	Brewery industry	Fakorede <i>et al.</i> , 2013

the basic constituents to acquire methane gas in the absence of an electron acceptor like oxygen (Khanal, 2008). The most common methane forming bacteria community present in industrial wastewater belongs to *Acetoclastic methanogens*, *Methanosarcina* sp., *Methanotrix* sp., *Hydrogenotrophic*, *Methanoculleus* sp., *Methanobacterium* sp., *Methanospirillum* sp., *Bacillus methylotrophicus*, *Ralstoniapickettii*, *Providenciarettgeri*, and *Myroidesodoratimimus* etc. (Murunga *et al.*, 2016; Vitezova *et al.*, 2020).

Pathogenic bacteria: Industrial wastewater contains various types of pathogenic bacteria which cause many harmful effects on human health and responsible for many types of waterborne diseases (El-Lathey *et al.*, 2009; Cai and Zhang, 2013). These pathogenic bacteria are transmitted to humans through the water while bathing, washing, drinking water, or by eating food exposed to contaminated water and by industrial wastewater treatment plants (WWTPs), through excreted dung in raw sewage from infected people, or in drinking water (Osunmakinde *et al.*, 2019). These bacteria colonize the human digestive tract and are shed in excrement. A significant number of these microbes are commensal and advantageous to their hosts (Varela and Manaia, 2013). Table 2 illustrates common pathogenic bacteria present in different industrial wastewater.

Conclusion

Industrial wastewater leads eutrophication, algal growth, health risk to humans as well as the contamination of environment. The wastewater

treatment plants are not able to treat the water efficiently and cause various health risks to humans and are also responsible for various waterborne diseases. Thus there is a need to reduce and treat the industrial wastewater effluents which are released into water bodies.

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