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Biological and Chemical Strategies for the Treatment of Sugar Industry Effluents

Hina Ambreen[1], Shabbir Hussain[1]*, Naureen Naeem[2], Asrar Ahmad[3], Muhammad Riaz[4], Aisha Saddiqa[5]

[1]Department of Chemistry, [2]Department of Biology,Lahore Garrison University, Lahore, Pakistan
[3]Department of Chemistry, University of Education Township, Lahore, Pakistan
[4]Department of Chemistry, University of Sargodha, Pakistan
[5]Department of Chemistry, Government College University, Lahore, Pakistan

*Email:dr.shabbirhussain@lgu.edu.pk

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Abstract: The waste effluents from sugar industries create lot of pollution problems in the adjacent areas. Sugar industries discharge huge quantities of residual water causing damage to the biotic as well as abiotic environment due to its pungent smell, higher BOD and COD values and the exceeded concentration of chlorides, sulphates, heavy metals, carbohydrates, nutrients, oil and grease. Current studies were performed to evaluate the available strategies used to minimize the pollution load created by sugar industries. Attempts have been made to overview various available procedures such as construction of microbial fuel cell, hydrolytic pre-treatment, valorization of sugar industry waste, synthesis of silver nanoparticles, symbiotic process, chemical and electrical oxidation processes, which are used for the treatment of sugar industry effluents.

Keywords: Sugar industries, effluents, treatment, biological, chemical, process.

Introduction

Sugar is extensively utilized in everyday human life as a basic source of sweeteners, preservatives and energy (Asadi, 2006). The sugar industry plays an important role in the economic growth; however, its effluents contain the hazardous chemicals which destroy the biotic and abiotic ecosystem very badly. The presence of metallic and non-metallic particles can be beneficial agriculturally for the seed germination and plant growth whereas higher concentration of these elements can cause adverse effects on the environment and its inhabitants. Sugar mills play a central role in water, land and air pollution (Aghbashlo et al., 2018). The production of sugar from sugar cane brings about alarming environmental changes due to extraordinary water usage and greater chances of eutrophication (Franco et al., 2013). The effluent discharged from the sugar industry badly disturbs flora and fauna of aquatic bodies which receive such a kind of polluted waste water. These pollutants also affect the human health especially in the rural and semi-urban inhabitants, who use the stream, lakes and river water for agriculture and domestic purposes. The paddy crops are severely damaged when polluted water from sugar industries is used in the agricultural areas (Rajaeifar et al., 2017). The inadequately treated waste water from sugar industry produces foul smell in the environment. When the farmers use such a kind of contaminated water for irrigation purposes, it results in the decrease of plant growth and the crop yield (Hosenuzzaman et al., 2015). Increasing numbers of deaths of domestic animals have also been reported due to this polluted water (Hosseinzadeh-Bandbafha et al., 2018). Currently, various treatment procedures are available for successful removal of pollutants from the waste water of industries (Ambreen et al., 2018; Iqbal et al., 2019; Rehman et al., 2019) depending upon the nature of effluents.

Keeping in view the highly contaminated nature of waste water discharged from sugar industries and its consequent toxic effects on human health, domestic animals and agricultural crops, current studies were performed to overview the strategies used for the treatment of waste water of sugar industries.

Materials and Methods

The nature of waste contaminants from sugar industries and their treatment strategies (biological and chemical) are reviewed in the current studies. The sugarcane and the sugar beet are the major commercial sources of sugar production in the world (Cheesman, 2004). Sugar industries release a variety of contaminants which are toxic for the environment (Ahmad et al., 1982; Samuel et al., 2011; Tanksali, 2013). Relevant literature (Aguilara et al., 2018; Gopinath et al., 2018; Jayabalan et al., 2019; Maitia et al., 2018; Prasad et al., 2015; Sahu, 2019; Tiwari et al., 2017) for the treatment of sugar industry effluents by chemical and biological methods has been consulted. The treatment procedures by the construction of microbial fuel cell, microbial electrolytic cell (Jayabalan et al., 2019), electro-chemical oxidation (Sahu, 2019), valorization (Gopinath et al., 2018), biological synthesis of silver nanoparticles (Aguilara et al., 2018), electro-oxidation collective technique (Tiwari et al., 2017) and hydrolytic pretreatment for the manufacture of enriched biobutanol (Maitia et al., 2018) were also reviewed.

Results and Discussion

Effluents from Sugar Industry

In the sugar industry major energy resource is combustion, the use of low quality fossil fuels (like bagasse) produces high sulphur contents (Samuel et al., 2011). During sugar manufacturing, the water is mostly utilized in cane juice clarification, cane washing, boiler purging, evaporator cleaning, in heaters and in cooling systems. This water when finally discharged from the sugar industry contains many contaminants which cause environmental problems. It also shows high level of total dissolved solids, biological oxygen demand (BOD) and chemical oxygen demand (COD). This water has also the high levels of carbohydrates, nutrients, oil, grease, chlorides, sulphates and heavy metals. The rapid depletion of oxygen in waste water is due to high levels of BOD/COD. It also causes foul smell and water becomes unfit for domestic and drinking purpose which is also dangerous for the aquatic life. By making it mandatory by the law, industrialists are trying to maintain a low-cost solution, for the essential reduction of polluted contents in water. The filtration and sedimentation are common processes used in the sugar industry (Ahmad et al., 1982).

The second option of water treatment is biological method which contains processes like fluidized bed reactor (FBR), lagoons, aerated ponds, up flow anaerobic sludge blanket (UASB) and expanded granular sludge blanket. Occasionally, both anaerobic and aerobic treatment methods are used for sugar industry wastewater treatment.

Numerous chemicals are utilized in sugar industries mostly for the purpose of impurities coagulation and products refining. For clarifying purpose and to increase the pH of the juices, $Ca(OH)_2$ is added. Very small amount of H_3PO_4 is added earlier to increase the clarification (Tanksali, 2013). CO_2 gas is released in the form of bubbles through the defecated juice,which may cause the lowering of pH level and it results in the enhancement of impurities precipitation. Polymer-based chemicals, like polyelectrolytes are used for coagulating and gelling of impurities during the process of defection and carbonation. From defecated raw sugar, SO_2 is bubbled out to remove the unwanted color from sugar. For periodic cleaning, NaOH or Na_2CO_3 is added. This process is followed by neutralizing process, with the addition of dilute HCl. Lead subacetate is used as a clarifying agent in pol (polarization) analysis of cane juice. All these chemicals, one-way or another, cause an increase in organic strength, dissolved solids and suspended matter in the final residual water (Tanksali, 2013). Currently great efforts are being made to investigate the influence of industrial effluents discharged into rivers or streams (Prasad et al., 2015).

Quality Assessment of Effluents

It is merely 3% fresh water accessible on the face of earth. This accessible fresh water is getting polluted significantly due to increase in industrialization and damaging the biotic and abiotic environment. In these circumstances the preservation approaches play a significant role in conservation of fresh water bodies and water quality. Enormous amount of fresh water is utilized for manufacturing processes which are performed in industries. Meanwhile the quantity of ingesting fresh water is almost equal to the quantity of wastewater discharged as effluent (Hosenuzzaman et al., 2015). Thus, it is necessary to estimate the concentration of waste water effluents in order to formulate a suitable treatment system which can also be improved by the use of latest technologies. As central pollution control board (CPCB) directed way, all industries should approve Zero Liquid Discharge (ZLD) in industrial premises so that the discharge of effluent without treatment can be avoided. By implementing biological and chemical treatment processes affiliated with Activated Sludge Process (SAP), the efficiency of treatment plants had shown improved results. The expected limitations of cured effluents should be prescribed by CPCB so that discharged wastewater can be utilized for the domestic uses and for agricultural purposes (Hosenuzzaman et al., 2015).

Microbial Fuel Cell for Treatment of Sugar Industry Effluents

It is a cheap process for cleaning polluted waste water. MFC (Microbial fuel cell) have dual chambered structure. Its simple set up has been shown in Figure 1. The cell can simply be constructed by using air tight plastic bottles of one-liter volume. The cell contains anode and cathode chambers and each bottle is connected through its middle with a PVC pipe. Agar (2gms) was mixed with 2gms NaCl (sodium chloride) and mixture was heated, in water bath. The molten agar was then cooled down and poured into the PVC pipe; a cello-tape was used to seal its one end. The agar was allowed to solidify; the PVC pipe comprising of the salt-agar mixture was fixed between two bottles by the use of epoxy material. This mixture acts like a salt bridge, carbon rods can be used as electrodes. The Microbial Fuel Cell is far cheaper as well as effective technique for waste water treatment (Prasad et al., 2015).

This set up can effectively eliminate the BOD, TDS, TSS, chlorides, and sulphates. The oil and grease pollutant can also be removed very effectively. This type of aerobic biological treatment plant can be built for waste water management mainly in sugar industry. These hydraulic retentions take time, which is about 12 days. After every 72 hours the sample of treated water can be checked and tested for sulphates and chlorides, oil and grease, pH, TSS, TDS, COD and BOD to assess the proficiency of plan. By using this method, the waste degradation in water has been examined; the results obtained are quite appreciable as it decreases COD up to 94.5% and a small amount of electricity 110mV has also been formed (Fig. 2) (Prasad et al., 2015).

Fig. 1 Microbial Fuel cell for the purpose of water treatment (Prasad et al., 2015).

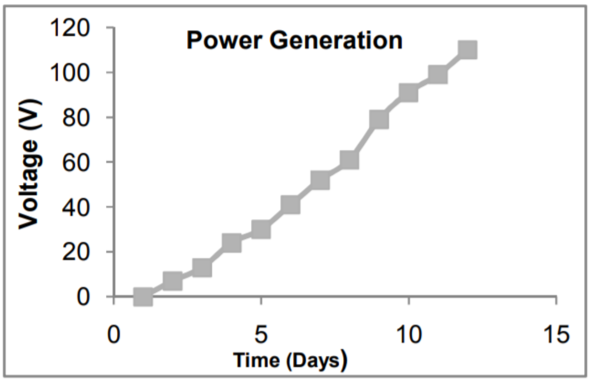

Fig. 2 Voltage of MFC with sugar industry waste water (Prasad et al., 2015)

Bio-hydrogen Production by Microbial Electrolytic Cell

Bio-hydrogen can be produced from the effluents of sugar industry, by microbial electrolysis cell (MEC) with dual chamber. The MEC reactors can be operated through different effluents (used as substrate) which include the chemicals excreted from cane sugar as well as raw sugar reprocessing constituents of the sugar industry (Jayabalan et al., 2019).

By using cathode metals like nickel plate, stainless steel mesh or nickel foam, bio-hydrogen can be produced. The efficiency of MEC is verified by the production of hydrogen gas and columbic productivity. The recovery of hydrogen and COD elimination capacity are also performance indicators of MEC. It was discovered that the use of sugar effluents in Microbial Electrolytic Cell (MEC) is very effective for the production of hydrogen gas. By applying the voltage of 1.0 V, the Ni foam presented maximum production of hydrogen; about 1.59 mmol/L/D hydrogen was produced by cane sugar and 1.43 m mol/L/D was produced by raw sugar effluents. With reference to this research, one of the potential candidates is Ni-foam due to its low cost. Ni electrodes are used to refine hydrogen synthesis with the help of MEC technology (Jayabalan et al., 2019).

Electro-Chemical Oxidation

Attempts were made to shield the surrounding environment by treating the waste water especially released from the sugar industry with the help of coagulation processes and electro-coagulation. It was demonstrated that 85% chemical oxygen demand (COD) can be reduced by electrocoagulation and 89% color reduction was noted at initial pH of sample 6.5. The experiments were performed with a distance of 20mm between the electrodes and current density 156 Am^{-2} was applied. NaCl electrolyte was used having 0.5M concentration. By adding ferric salt which works as chemical coagulant, 98% reduction in COD and 99.7% color removal were noted (Sahu, 2019).

Valorization

In this process, the sugar industry effluents are being utilized by other industries in making paver blocks, bricks, activated blenders, cements and other products used in construction. This process solves the disposal problems of sugar industry wastes and generates additional revenue. Energy can also be produced by the sugar industry by products. For this process a symbiotic frame work is established which contains the by-products of sugar industry and works as source of energy manufacture and sustainable building material (Gopinath et al., 2018).

Biological synthesis of silver nanoparticles

Nanotechnology finds an extreme interest in today‘s science (Abbas et al., 2016). The silver nanoparticles (AgNPs) are the biologically synthetic products which are excessively studied. Generally, during the formation of AgNPs, there is an unwanted production of silver chloride (AgCl) as a by-product which is not easy to be removed (Aguilara et al., 2018).

However, a new process has been formulated for AgNPs preparation, in which waste water from sugar industry and sugar cane bagasse, are used as capping agents, by soxhlet extraction system (Fig 3). It was observed that by fluctuating the pH of reaction medium, the undesirable production of AgCl can be avoided and also the uniform particle size of AgNPs is observed (Aguilara et al., 2018).

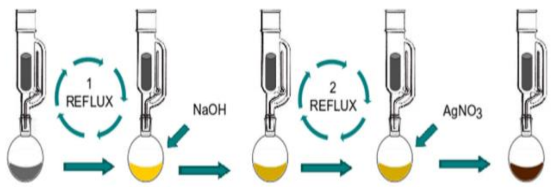

Fig. 3 Production of silver nano-particles by Soxhlet apparatus (Aguilara et al., 2018)

The analytical techniques like FTIR, DLS, DRX, TEM, SEM and UV–Vis absorption are applied to characterize these nanoparticles. The synthesized nanoparticles have shown good antimicrobial activity against Gram negative bacteria (e.g., Pseudomonas aeruginosa and Escherichia coli) and Gram-positive bacteria (e.g., *Staphylococcus aureus*). However, comparative better results were obtained with Gram negative bacteria (Aguilara et al., 2018).

Treatment By Electro-Oxidation Collective Technique

It is an electro and chemical oxidation treatment system, studied by batch mode. In this method the dischargable limit is not reached by a single treatment. Hence, an attempt has been made for the treatment of wastewater from sugar industries with the help of electrochemical as well as chemical processes *via* applying copper metal as electrode (Tiwari et al., 2017).

At pH 6, 84% color can be reduced and 81% of COD by electrochemical process. The distance between two electrodes was kept 20 mm and current density remained approximately 178 A m^{-2}. The action time was 120 min during this treatment. This combined treatment at pH 6 and 8mm mass loading with copper sulphate, demonstrated 98% COD (chemical oxygen demand) reduction and 99.5% color removal (Tiwari et al., 2017).

Hydrolytic pre-treatment procedures for manufacturing of enriched biobutanol

In this technique, argo-industrial wastes like brewery industry liquid waste (BLW), apple pomace solid wastes (APS), brewery spent grain (BSG), starch industry wastewater (SIW) and apple pomace ultrafiltration sludge (APUS) are used as reactant substrates for the synthesis of biobutanol. The process conditions and the nature of agro-industrial wastes are the two major factors which govern the efficiency of hydrolysis techniques. For example, total reducing sugar yield of 0.433g/g as well as 0.468g/ is obtained by acid-catalyzed hydrolysis process of BSG and BLW, respectively. On the other hand, the reducing sugar yield from microwave assisted hydro-thermal technique reaches about 0.404g/g from apple pomace solid wastes (APS). This yield is increased to 0.631g/g from apple pomace ultrafiltration sludge (APUS) and decreased to 0.359g/g from starch industry wastewater (SIW). The reaction parameters (concentration of substrate, pH and time) were optimized by using central composite model technique for acid-catalysed BLW hydrolysis. This optimization resulted in generation of inhibitors including acetone-butanol-ethanol (10.62 g/L), total phenolic compounds (0.567 g/kg), levulinic acid (9.3 g/kg), furfural (1.6 g/kg), 5-hydroxymethyl furfural (20 g/kg) (Maitia et al., 2018).

Conclusion

The waste water discharged from sugar industries is foul smelled and contains high level of total dissolved solids, biological oxygen demand (BOD) and chemical oxygen demand (COD), chlorides, sulphates, heavy metals, carbohydrates, nutrients, oil and grease. Biological processes such as fluidized bed reactor (FBR), lagoons, aerated ponds, up anaerobic sludge blanket (UASB) can be used for treatment of such water. Microbial fuel cell (MFC) can be constructed between two plastic bottles with a PVC connector (containing salt-agar mixture)for cleaning of polluted waste water. Various electrochemical as well as chemical processes are also applied for successful treatment of sugar industry effluents. Valorization is another process by which the sugar industry effluents are being utilized by other industries for making paver blocks, bricks, activated blenders, cements and other products used in construction industry. This water can be utilized for preparation of silver nanoparticles. Hydrolytic pre-treatment procedure can be applied for manufacturing enriched biobutanol.

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