The Overview of Sustainable Technologies for the Treatment of Industrial Wastewater and its Potential for Reuse

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ABSTRACT:

Industrial wastewater has been discharged into the environment as a result of industrial operations, which comprises organic/inorganic/toxic compounds that have been present in the form of dissolved/suspended matter. The amount and quality of industrial effluent vary greatly based on the type of industry that produces it. Depending on wastewater composition, it could be highly biodegradable/non-biodegradable, or include chemicals that are resistant to treatment. The growing prevalence and diversity of synthetic chemicals is a major problem with industrial wastewater. During wastewater treatment, highly complex, putrescible organic particles are partially removed and partially decomposed into mineral or fairly stable organic substances. Conventional treatment methods often need significant energy inputs, extensive land expanses, and high operating and maintenance expenses. Recently, improved wastewater treatment techniques such as membrane technology, electrochemical processes, and oxidation processes have been developed and the treated water from these systems may be reused in a variety of applications, including irrigation and landscaping. In this study, a variety of industrial wastewater sources, treatment methods, and reuse techniques are explored.

Keywords:

Industrial wastewater, Nano technology, Biochemical Oxidation, Activated sludge process

INTRODUCTION:

The Disparate behavior of industrial effluent treatment is used to adjust the pH in the treated Water, removal of oily nature substances like grease particles, removal of metals, biodegradable pollutants and other hazardous substances. The various industries like chemical, pharmaceutical, textile, mining, fertilizer manufacturing, pulp and paper industry, distillery, food processing industries are still suffering the wastewater treatment process because of removal of organic, inorganic compounds present in the effluent needs separate methodologies to dispose it after treatment. Most of the growth of industries is failed in the water treatment process and adversely affects the ecosystem.to identify new growing innovative techniques to treat the complex industry water effectively.

Multifarious studies have studied about various oxidation of different organic pollutants, including aromatic and phenolic compounds, pesticides, herbicides, and organic dyes (Bigda, 1996;Karci et al., 2012; Kusic et al., 2006; Ma et al., 2005; Martinez et al., 2003; Sun et al., 2007; Xue et al., 2009).

Some of prescribed methods already discussed in various occasions.

S.No	**Processes**	**Material**	**Advantages**	**Disadvantages**
1	Chemical precipitation	Lime, Alkali, Acid, Base, Surfactants, Sulphide /flocculants, Stirring, Mixing and fluid handling	1. Low metal concentration 2. To handle large quantities of wastewater. 3.Simple to use	1. High chemical requirement, 2. pH maintenance at optimum level 3.Precipitant concentration etc.to be monitored is quite difficult
2	Ion exchange	Ion exchange resins either natural or synthetic	1.High treatment capability 2.Higher rate of metal removal	1. Cannot be employed on a large scale 2. Costly synthetic resins
3	Membrane filtration	Membranes, surfactants enhance and support the process	1. Reuse of wastewater 2. Recovery of valuable material 3.prevention of environmental damages	1.Membrane fouling 2.Capital cost 3.Maintenance and operational cost 4.Less efficient
4	Coagulation/flocculation	Salts of aluminum, iron	1.Applicable to large scale wastewater treatment	1.Production of sludge in large quantities 2.Sludge disposal

				issues
5	Electrolytic recovery	Electrical energy	1. Lesser chemical consumption 2.Recovery of pure metal, 3.Effective removal	1. Energy costs 2. High capital cost of designing and implementing 3.Reduced efficiency at dilute concentration. 4.Cannot be applied to higher quantity of wastewaters
6	Adsorption	Fluid handling unit/regenerating media, pumps for a constant and uniform flow	1.Highly effective for removing heavy metals to permissible limits	1.Chemical regeneration requirement 2.Disposal of exhausted adsorbents 3.High cost 4.Loss of adsorption capacity
7	Reverse osmosis	Resins supported with membranes	1.Effective removal of metals from wastewater	1.High costs of chemicals 2.Fouling of membranes
8	Ion exchange	Resins supported by membranes	1.Selective heavy metal removal	1.High capital cost equipment and instrument 2.High operational and resin regeneration cost.

1.1 Treatment Options:

The physico chemical techniques of treating wastewater are identified as sedimentation, adsorption, steam stripping, wet-air oxidation (WAO), coagulation precipitation, techniques. The recent option included in this is biological treatment.in general these techniques are used to remove suspended solids, colloidal particles, floating matters, colors, and toxic compounds.

i. **Sedimentation:**

The presence of dissolved solid particles, oily and greasy nature of an effluent is leads for the formation of suspended matter in the wastewater. Total suspended solids (TSS) are removed by using sedimentation tanks. If the sedimentation process is not done proper the resultant is black coloured effluent discharge. Treatment of effluent with the addition of chemicals is effectively to reach the points effectively.

ii. **Adsorption:**

Mostly Adsorption using different adsorbents (activated carbon being the dominant one) may be used to remove the hazardous components from wastewater.

In batch adsorption and column adsorption methods are active methods in the treatment of wastewater. Replacement/regeneration of adsorption-bed material in adsorption process often makes cost-prohibitive.

iii. **Steam Stripping:**

Mostly steam stripping process is applicable in treating ammonia in the presence of coke wastewater. Not only treating ammonia but also have a difficulty to remove the pollutant in the presence of coke wastewater. Adjusting pH is one of major problem in this method. Another important complication is capital investment.

iv. **Wet-Air Oxidation:**

This method is place an important to remove organic contaminants such as chemical oxygen demand (COD). Salt precipitation leads to causes serious reactor plugging. Construction of salt separator in a correct position can avoid this problem.

v. **Coagulation and Flocculation:**

Flocculation is a physical process used to dissolve the organic particles as sediments to remove from effluents. This process always takes place as an intermediate process. It effectively removes the organic pollutants, total dissolved solids & dissolved particles.

The Coagulation is a chemical process using coagulants to collide the pollutants as a solid deposit in the wastewater processing.

In recent days effective management of wastewater treatment process follows advanced oxidation process. This oxidation process includes chemical oxidation followed by Fenton reagent, membrane techniques and ozonation methods. The main features of advanced oxidation treatment are discussed in the following section.

i. **Ozonation:**

Ozone has a high oxidation value. This capacity is used in the colour removing process, removal of COD, BOD, TDS vales in industries. The release of oxygen free radicals strike the organic compounds in industrial water and remove it. It also assaults the presence of microorganisms. But this process needs expensive chemicals like potassium iodide .so it is not preferable by most of the industries.

ii. **Chemical Oxidation:**

In the chemical oxidation process, the hydroxyl ions play a vital role for the removal of dissolved particles in wastewater treatment. Maintaining pH is important in this process. In most of the cases Fenton's reagent (H2O2 and FeSO4.7H2O) is prefers due to its reactivity. The organic wastes in the effluent can be busted by this Fenton reagent.

iii. **Electrochemical Oxidation:**

Comparatively Electrochemical oxidation is an ecofriendly and favourable technology in the industrial water treatment process. Most of the refractory treatment process is done by this electrochemical oxidizing method for the removal of phenolic compounds. Nowadays graphite, platinum, anode and Boron-doped diamond (BDD) cathodes are preferable to remove particularly ammonical compounds. The most effective provocation is energy consumption.

iv. **Electro-Fenton Advanced Oxidation :**

In the chemical oxidation process using Fenton's reagent causes lower oxidation rate and the amount of sludge produced is very high. For this obstacle Electro-Fenton is a process is specifically formulated. The electro-Fenton conquers the oxidation by electrochemically by converting the iron (III) compounds into iron (II) compounds. The oxidation process is again continued by the formed ferrous salt.

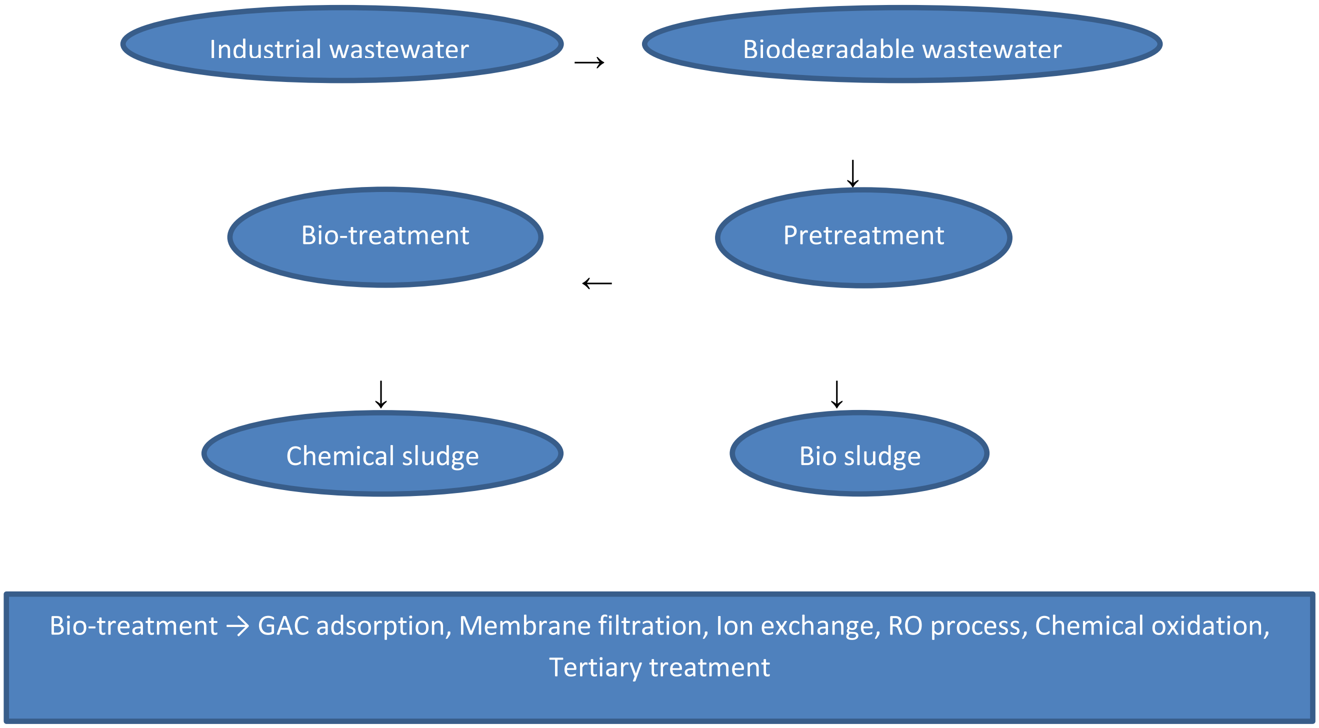
v. **Membrane Technology:**

Membrane-based technologies are the materialize techniques used in the industrial water treatment process. There are number choices to place number of membranes. All types of membranes can be planned to place this type of filtration process like Nano filtration (NF), microfiltration (MF), ultrafiltration (UF) and RO membranes, etc., Among the huge membrane choices, NF membrane prefers to be the most important due to its low operating pressure, high flux, high retention of multivalent anion salts and organic matter, and relatively low operational costs. The productivity of separation depends on the three important parameters namely pore radius, thickness-porosity ratio and charge density of the membranes.

vi. **Photo catalytic Oxidation:**

In the wastewater treatment process, Photo catalytic or photochemical degradation processes are emerging trends due to its complete mineralization at low temperature. The release of photons are not depending the catalyst present in the solution. The free radical mechanism initiated the reaction with sufficient energy of the molecule. UV radiation produces free radicals by simple photochemical degradation of oxidizers. Free radicals are produced by another way i.e through photo catalytic mechanism of semiconductor materials. (Bhatkhande et al., 2002; Mazzarino and Piccinini, 1999).Natural sunlight or UV light can be used for this method to reduce cost and also for large scale operations. (Han et al., 2012; Konstantinou and Albanis, 2004).Oxides such as TiO2, ZnO, ZrO2, and CeO2, or sulfides such as CdS and ZnS have been used as photo catalysts (Bhatkhande et al., 2002).the overall degradation is depend on the surface area and the number of active sites present in the catalyst ((Xu et al., 1999). The bandgap in semiconductors causes charge separation in Photo catalytic reactions (Daneshvar et al., 2003).

The schematic representation of Wastewater treatment methodology is shown below



1.2 Classification of Biological Treatment Processes:

The cultivation of microbial population is deals by its two of the important mechanisms. They are suspended growth mechanism and the attached growth mechanism.

a. Suspended growth mechanism:

Activated sludge process (ASP) is an efficient biological treatment process in which microbes within the aeration tank or bioreactor grow while remaining suspended in the aqueous medium.in the sedimentation tank deposited sludges are continuously treated. The treated sludges with microbes are again and again activated by passing fresh oxygen in the aeration tank. Among the deposits organic deposits are easily decomposed. Some of the chemicals do not completely removed by this ASP. These disadvantages are rectified by using single-step ASP.

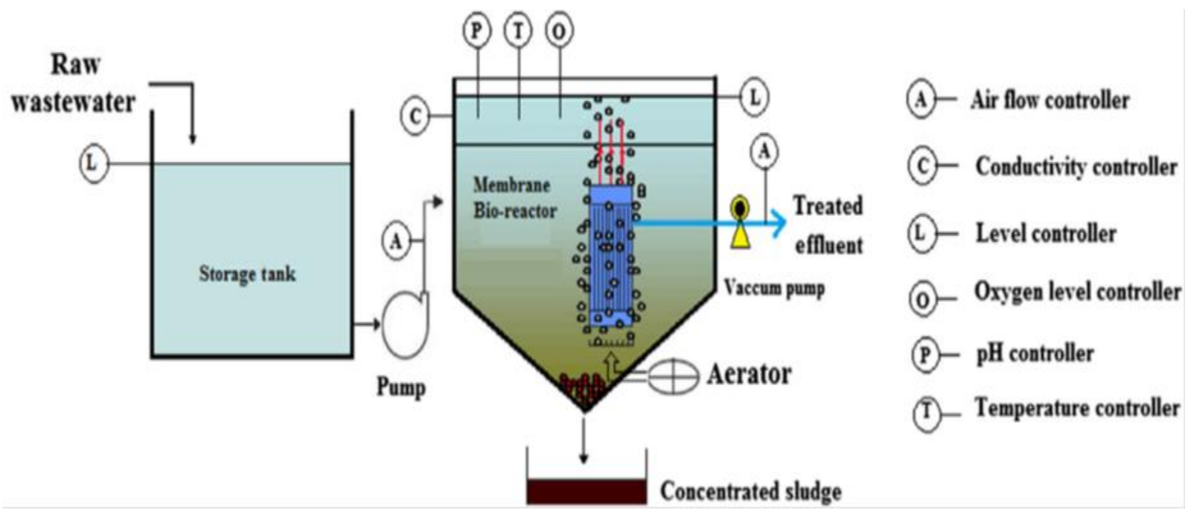
b. Single-step treatment:

The activated sludge unit is constructed by main aerated column accompanied by downstream sedimentation tank. There are several steps takes place in the ASP is Removal of organic matter by adsorption and agglomeration followed by microbial flocculation, subsequent assimilation and finally mineralization by complete oxidation. Mostly the importance consequence in this process is (HRT) High hydraulic residence time and lengthy solid-retention time. Multistep treatment focuses denitrification reaction also.

i. **Biofilm system (BF):**

Biofilm system is the next higher level process to meet over the negligence of ASP. It has higher coherence of removing COD. A biofilm is designed by combining [(anaerobic (A) - oxygen1 (O1)- oxygen 2(O2)] i.e. A-O1-O2 with a cubical structure with micro and macro pores. This type of system will have high water content capacity and porosity and can remove more than 90% COD. Biological aerated filters the active film grows over a support medium completely submerged in wastewater where oxygen is supplied by diffusers at the base of the reactor. High specific surface area of the medium promotes microbial growth of film with substantial thickness. These microbial films act as bioreactor as well as bio filters making the process quite efficient.

Schematic of membrane bioreactor(Luong TV,et.al., CIRP, 2016;40:419_24.)



ii. **Bio augmented activated sludge process:**

An activated sludge system based on bioaugmentation with specialized microorganisms can be a powerful tool to enhance the efficiency of a wastewater-treatment process through improved flocculation and settling of activated sludge.

The future growth of industries will be decided by the development of novel reactors, reactor configurations, and devices that operate with improved efficiency and reduced cost (capital and operating). This development is indicated by new terminologies such as anaerobic membrane bioreactor (AnMBR), enhanced membrane bio reactor (EMBR), anaerobic migrating blanket reactor (AMBR), membrane biofilm reactor, and sequencing batch bio filter granular reactor (SBBGR).

i. **Nanotechnology:**

In Industrial wastewater treatment Nanotechnology is having a significant role. Nano-materials are also expected to play an important role in the modification of existing adsorbents and catalysts used in wastewater treatment processes. The fabrication of metal nanoparticles have been developed by diverse technique such as thermal decomposition hydrothermal method ,solvothermal method , thermal process , microwave irradiation method , precipitation method , magnetron sputtering , combustion solution method using glycine , laser-induced deposition , sonochemical synthesis , sol–gel synthesis , combustion synthesis, thermal reduction , urea-assisted homogeneous precipitation and precursor calcinations . Chromium (Cr_2O_3) possess specific applied applications such as liquid crystal displays in high-temperature resistant materials , coating materials , corrosion resistant materials , green pigment , solar absorbers , heterogeneous catalysts , ceramics, coatings, printing and paint industry. In contrast with the conventional method, bio synthesis is friendlier to environment because it utilizes plants extract as the chemicals substitute. In industry reusing treated wastewater getting attention in an economical importance.

ii. **Carbonaceous Nano materials:**

The carbon based nano materials like carbon nano-tubes, graphene, and graphene derivatives are named as Carbonaceous Nano materials. They possessed by high surface area, highly tunable carbon backbone, and hydrophobicity. This property establishes these materials acceptable for the adsorptive removal of cyanobacteria toxins, heavy metals, natural organic matter (NOMs), and dyes. Numerous applications of carbonaceous materials is due to their high surface area, antifouling property, high selectivity, permeability, high flux, porous structure, and antimicrobacterial property.

CONCLUSION:

The importance of industrial growth leads to many societal activates of nation. Therefore care must be taken in the wastewater treatment process and disposal. The ecosystem should be preserved by avoiding to pass the industrial wastewater without treating. There were tremendous methods in the wastewater treatment process are discussed. Different types of conventional, advanced and specialized forms of industrial wastewater treatment methods with its specification are focused in industrial case studies and applications. Present day industrial wastewater treatment emphasizes the drastic reduction of pollutant levels, and each pollutant class often has its own discharge limits specified by the respective government or pollution control agencies, with an eye towards minimizing the cost of treatment. Interestingly, most of the present day operations do not specifically intend to recycle or reuse wastewater unless faced with severe constraints. The likelihood of water scarcity in many regions in the near future, combined with the escalating cost of water, is driving many industries to adopt industrial wastewater treatment, recycling, and reuse. The discussion of various treatment technologies in the previous chapters can be used to identify present day wastewater treatment needs, as well as treatment guidelines for the future. For a quick analysis, these needs and guidelines can be summarized as follow so amount of technology can solve the problems of water pollution unless there are regulations on water use and compliance of said regulations. While compliance of regulations can be enforced to some extent by government, total compliance requires adherence to ethics. Ethics is a source of guidance beyond enforceable law and is not always philosophical. In matters of water use, we have to also consider ethics. Discharging heavily polluted wastewater into river bodies without proper treatment is an unethical decision on the part of the management. Where windows have to be kept closed to prevent entry of particulate pollutants and hazardous gases from coal-fired thermal power plants, all the involved business houses, policy planners, sanctioning authorities and above all the government are naturally to be blamed for a very unethical decision of running such a plant.

REFERENCES:

1. Adler, S., Beaver, E., Bryan, P., Robinson, S., Watson, J., Separations Roadmap. Center for Waste Reduction Technologies of the American Institute of Chemical Engineers, New York, pp. 10016–5991. 2000. Vision 2020: 2000
2. Flynn, D., 2009. The Nalco Water Handbook. McGraw-Hill, New York.
3. Foulger, J.H., 1931. The use of the Molisch (a-naphthol) reactions in the study of sugars in biological fluids. J. Biol. Chem. 92 (1931), 345–353.
4. Dakwala, M., Mohanty, B., Bhargava, R., 2011. Waste water minimization of starch industry using water pinch technology. In: Cleaner Production Initiatives and Challenges for a Sustainable World – 3rd International Workshop, Advances in Cleaner Production, Sao Paulo, Brazil, 18–20 May, 2011.
5. Deng, C., Feng, X., 2009. Optimal water network with zero wastewater discharge in an alumina plant. WSEAS Transactions on Environment and Development 5 (2), 146–156.
6. Khezri, S.M., Lotfi, F., Tabibian, S., Erfani, Z., 2010. Application of water pinch technology for water and waste water minimization in alumina anodizing industries. Int. J. Environ. Sci. Tech. 7 (2), 281–290. M
7. Hugot, E., 1986. Handbook of Cane Sugar Engineering. Elsevier, New York.
8. Shivaraman N, Kumaran P, Pandey RT, Chatterjee SK, Chowdhury KR, Parhad NM. Microbial degradation of SCN2 Phenol and CN2 in a completely mixed aeration system. Environ Pollut 1985;39:141_50 (Series A).
9. Pandey RA, Parhad NM, Kumaran P. Biological treatment of low temperature carbonization wastewater by activated sludge process—a case study. Water Res 1991;25:1555_64
10. Luong TV, Schmidt S, Deowan SA, Hoinkis J, Figoli A, Galiano F. Membrane bioreactorand promising application for textile industry in Vietnam. Procedia CIRP 2016;40:419_24.
11. Thakura R, Chakrabortty S, Pal P. Treating complex industrial wastewater in a new membrane-integrated closed loop system for recovery and reuse. Clean Technol Environ Policy Springer 2015;17(8):2299_310.
12. Pal P. Groundwater Arsenic Remediation. Waltham, MA, USA: Elsevier Inc.; 2015. Membrane-integrated Hybrid Treatment System for Arsenic Removal by Parimal Pal, Indian Patent No. 275244

13. Kumar R, Pal P. Turning hazardous waste into value-added products: production and characterization of struvite from ammoniacal waste with new approaches. J CleanProd 2013;43:59_70.
14. Pal P, Dey P. Process Intensification in lactic acid production by three stage membrane-integrated hybrid reactor system. Chem Eng Process Process Intensif 2013;64:1_9.
15. Roy M, Chakrabortty S. Developing a sustainable water resource management strategy for a fluoride-affected area: a contingent valuation approach. J Clean Techno Environ Policy Springer 2013;16(2):341_9 2014
16. Pei Z., Chen, H. and Gao, L., 'Hydrothermal synthesis of large sized Cr_2O_3 polyhedrons under free surfactant', *Materials Letters*, 159(1), (**2015),** pp. 357–361.
17. Rajagopal, S., Bharaneswari, M., and Nataraj, D, 'Crystal structure and electronic properties of facile synthesized Cr_2O_3 nanoparticles', *Materials Research Express*, 3(1), (**2016),** pp.1-10.
18. Pardo, P., Calatayud, J. M., and Alarcón, J, 'Chromium oxide nanoparticles with controlled size prepared from hydrothermal chromium oxyhydroxide precursors', *Ceramics International*, 43(2), (**2017),** pp.2756-2764.
19. Roy, M., Ghosh, S., and Kanti naskar, M, 'Solvothermal synthesis of Cr_2O_3 nanocubes via template- free route', *Materials Chemistry and Physics*, 159(1), (**2015),** pp. 101-106.
20. Chen, Z., Dun, Y., and Li, Z, 'Synthesis of black pigments containing chromium from leather sludge', *Ceramics International*, 41(8), (**2015),** pp. 9455-9460.
21. Ibarra-galván, V. and Villavelazquez-Mendoza, C, 'Synthesis of Eskolaite (α-Cr_2O_3)Nanostructures by Thermal Processing of Cr_2O_3-Loaded Activated Carbon', *Particulate Science and Technology: An International Journal*, 32(5), (**2014),** pp. 451-455
22. Han li, B., Han yu, T., and Yu weng, C, 'Thermal and plasma synthesis of metal oxide nanoparticles from MOFs with SERS characterization', *Vibrational Spectroscopy*, 84(1), (**2016),** pp.146–152,
23. Vaidya AK. Globalization: International blocs organizations, Other issues, ABCCLIO, 2006.
24. Babu BR, Parande AK, Raghu S, Kumar TP. Cotton textile processing: waste generation and effluent treatment. J Cotton Sci 2000;11:14153.
25. US Environmental Protection Agency, Profile of Textile Industry. Washington, USA, 1997.

26. AI-Degs YS, Khraishen MAM, Allen SJ, Ahmad MN. Effect of carbon surface chemistry on the removal of reactive dyes from textile effluent. Water Res 2000;34:92735.
27. Handa BK. Treatment and recycle of wastewater in industry. National Environmental Engineering Re-search Institute, Nagpur, 1991.
28. Garg A, Bhat KL, Bock CW. Mutagenicity of aminoazobenzene dyes and related structures: a QSAR/QPAR investigation. Dyes Pigm 2002;55:35052
29. Mittal A, Mittal J, Kurup L. Adsorption isotherms, kinetics and column operations for the removal of hazardous dye, Tartrazine from aqueous solutions using waste materials-Bottom.
30. Tsuboy MS, Anjeli JPF, Mantovani MS, Knasmiiller S, Umbuzeiro GA, Ribeiro LR. Genotoxic, mutagenic and cytotoxic effects of the commercial dye CI Disperse Blue 291 in the human hepatic cell line HepG2. Toxicol In vitro 2007;21:1650
31. Stammati A, Nebbia C, Angelis ID, Albo AG, Carletti M, Rebecchi C, et al. Effects of malachite green (MG) and its major metabolite, leucomalachite green (LMG), in two human cell lines. Toxicol In Vitro 2005;19:8538. Figure 6.7.10 Schematic of membrane bioreactor
32. Rehn L. Bladder tumours in fuchsin workers. Arch Klin Chir 1895;50:588600.
33. Juang Y, Nurhayati E, Huang C, Pan JR, Huang S. A hybrid electrochemical advanced oxidation/microfiltration system using BDD/Ti anode for acid yellow 36 dye.
34. Jonstrup M, Kumar N, Murto M, Mattiasson B. Sequential anaerobic-aerobic treatment of azo dyes: decolorisation and amine degradability. Desalination 2011;280(13): 33946.
35. Savin II, Butnaru R. Wastewater characteristics in textile finishing mills. Environ Eng Manage J 2008;7(6):85964 wastewater treatment. Sep. Purif. Technol., 2013;120:289295
36. Patel S, Rajor A, Jain BP, Patel P. Performance evaluation of effluent treatment plant of textile wet processing industry: a case study of narol textile cluster, Ahmedabad, Gujarat. Int J Eng Sci Innovative Technol (IJESIT) 2013;2:4.
37. Barredo-Damas S, Alcaina-Miranda MI, Iborra-Clar MI, Mendoza-Roca JA. Application of tubular ceramic ultrafiltration membranes for the treatment of integrated textile wastewaters. Chem Eng J 2012;192:21118.
38. Feng F, Xu Z, Li X, You W, Zhen Y. Advanced treatment of dyeing wastewater toward reuse by the combined Fenton oxidation and membrane bioreactor process. J Environ Sci 2010;22(11):165765.

39. Luong TV, Schmidt S, Deowan SA, Hoinkis J, Figoli A, Galiano F. Membrane bioreactor and promising application for textile industry in Vietnam. Procedia CIRP 2016;40:41924.
40. MoUD 2013. Manual on sewerage system and sewage treatment, CPHEEO, New Delhi, Government of India
41. Van Zyl, P.J., Wentzel, M.C., Ekama, G.A., Riedel, K.J., 2008. Design and start-up of a high rate anaerobic membrane bioreactor for the treatment of a low pH, high strength, dissolved organic wastewater. Water Sci. Technol. 57 (2), 291–295.
42. Technologies for Energy Recovery from Industrial Wastewater- A Study in Indian Context. TERI Information Monitor on Environmental Science, New Delhi, 3(2): 67- 75.
43. Vigneswaran, S., Davis, C., Kandasamy, J., Chanan, A., 2011. Water and wastewater treatment technologies, Vol. 1. Urban Wastewater Treatment: Past, Present and Future. Encyclopedia of Life Support Systems (EOLSS) (viewed on 20 February, 2014, www.eolss.net/Sample-Chapters/C07/E6-144.pdf).
44. Wen, C., Huang, X., Qian, Y., 1999. Domestic wastewater treatment using an anaerobic bioreactor coupled with membrane filtration. Process Biochem. 35 (3–4), 335–340.
45. Wijekoon, K.C., Visvanathan, C., Abeynayaka, A., 2011. Effect of organic loading rate on VFA production, organic matter removal and microbial activity of a two-stage thermophilic anaerobic membrane bioreactor. Bioresour. Technol. 102 (9), 5353–5360.
46. Yuan, L.-M., Xi, D.-L., Zhang, Y.Q., Zhang, C.-Y., Yi, D., Gao, Y.-L., 2007. Biological nutrient removal using an alternating of anoxic and anaerobic membrane bioreactor (AAAM) process. In: Proceedings of the 10th International Conferen on Environmental Science and Technology, Kos island, Greece, 5–7 September 2007.
47. Yang L, Hu W, Chang Z, Liu T, Fang D, Shao P, Shi H, Luo X (2021) Electrochemical recovery and high value-added reutilization of heavy metal ions from wastewater: Recent advances and future trends. Environment International, 152. https://doi.org/10.1016/j.envint.2021.106512
48. Ye Y, Ngo HH, Guo W (2020) Bioresource Technology Reports Nutrient recovery from wastewater: From technology to economy. Bioresource Technology Reports 11(April):100425. https://doi.org/10.1016/j.biteb.2020.100425

49. Yildiz Sizirici B (2012) Water and wastewater treatment: Biological processes. In F. Zeman (Ed.), Metropolitan Sustainability: Understanding and Improving the Urban Environment (1st ed., pp. 406– 428). Woodhead Publishing. https://doi.org/10.1533/9780857096463.3.406

50. Yoldi M, Fuentes-Ordoñez EG, Korili SA, Gil A (2019) Zeolite synthesis from industrial wastes. Microporous Mesoporous Mater 287(June):183–191. https://doi.org/10.1016/j.micromeso.2019.06.009

51. Yorkor B, Momoh Y (2019) A Review of Anoxic Wastewater Treatment: An Overlooked Aspect in A Review of Anoxic Wastewater Treatment: An Overlooked Aspect in Wastewater Treatment in Nigeria. https://doi.org/10.12691/ajwr-7-4-2. January

52. Yoshimura M, Byrappa K (2008) Hydrothermal Processing of Materials: Past, Present and Future. J Mater Sci 43(April):2085–2103. https://doi.org/10.1007/s10853-007-1853-x

53. Yoshino H, Hori T, Hosomi M, Terada A (2020) Identifying prokaryotes and eukaryotes disintegrated by a high-pressure jet device for excess activated sludge reduction. Biochem Eng J 157(January):107495. https://doi.org/10.1016/j.bej.2020.107495 Page 24/116

54. Zaharioiu AM, Bucura F, Ionete RE, Marin F, Constantinescu M, Oancea S (2021) Opportunities regarding the use of technologies of energy recovery from sewage sludge. SN Applied Sciences 3(9)