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A Mini-Review of The Typical Wastewater Treatment Technologies

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Abstract: Many studies have been carried out in recent years to increase the efficacy of wastewater treatment methods. High population expansion, on the other hand, has resulted in increased consumerism, pollution, and resource demands. As a result, it appears that evaluating typical wastewater treatment procedures in order to choose the most efficient one is required. Several technologies, including precipitation, membrane technology, and adsorption approaches, have been employed to meet the required discharge standards. During the adsorption process, electrostatic attraction and repulsion between molecules drive the interaction between the adsorbate and adsorbent. As a result, the adsorption method may be employed in a variety of wastewater treatment applications to remove contaminants via a binding interaction between molecules. In this work, the most applied technologies for treating wastewater around the world have been reviewed.

Keywords: Wastewater Treatment, Pollution, Membrane Technology, Adsorption

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1. Introduction

On the earth, over 70% of the area is covered with water. However, 97% of the world's water is saltwater which is undrinkable and leaves only 3% of the water that is fresh. Among the 3% of fresh water, 68.7% is locked in icecaps and glaciers, 30.1% is in fresh groundwater, remaining only a very small portion, 1.3% of fresh water on the surface for human consumption [1, 2]. With the increase in human population, the freshwater resources are getting more insufficient and do not get replenished to accommodate for the human water daily usage. This condition of lacking access to enough water resources can be seen across the world, especially in Africa, Asia, and Latin America, where around 2.1 billion people live without safe drinking water at home[3]. Therefore, it is important to secure any freshwater sources to accommodate the daily usage of human beings.

In recent decades, the rapid increase of the human population around the world and the revolutionary of industrial activities had led to a new threat, which is the rapid increase in wastewater. Wastewater is also known as sewage, which originates from household wastes, human and animal wastes, industrial wastewaters, storm runoff, and underground infiltration [4]. Wastewater can bring a lot of harm to public health and the environment, such as the pollution of clean water, contamination of the wildlife and natural habitat, degradation of soil, causing diseases, and many more [5, 6]. This can be seen from the news where toxic foam covers the banks of Yamuna at Kalindi Kunj, Hindi due to the discharging of untreated wastewater from factories into the Haryana and Uttar Pradesh [7]. Besides, in the US, the Bradenton city's treatment plant is also being sued due to the discharging of more than 160 million gallons of raw and partially treated sewage, including human waste, solvents, pesticides, paint, and other chemical substances into the Manatee River which exposed the public towards sewage-borne pathogens and various toxic pollutants [8].

To deal with the harmful impact of wastewater, efficient wastewater treatment is the most obvious way to deal with the water scarcity, which can supplement the freshwater resources and allow potable water to be accessible to all. Throughout the years, there have been many efforts being made to introduce various wastewater treatment technologies such as conventional filtration, coagulation-flocculation, and biological treatment systems. Obotey Ezugbe [3]With the advancement of technology in the current world, combinational treatment technologies had also been widely researched which can achieve a very high percentage of removal of contamination in wastewater. In this paper, Three of the most widely used and efficient wastewater treatment technologies will be discussed, which are precipitation/encapsulation, membrane technologies, and adsorption.

2. Classification of Water Pollutant

Water pollution is one of the major issues faced worldwide in this generation. The sources of water pollution included wastewater, industrial wastewater, agricultural runoff, and stormwater runoff. Water pollutants can be classified into seven categories, which are organic pollutants, inorganic pollutants, pathogens, suspended solids, nutrients and agriculture pollutants, thermal, radioactive, and other pollutants [9]. **Table 1** summarizes the sources and effects of the pollutants based on different classifications of the water pollutants.

Table 1: Sources and Effect of Different Water Pollutants [10]

Types of Water Pollutants		Sources	Effect
Organic	Oxygen Demanding Wastes	-Domestic and municipal sewage, wastewater from food processing industries, etc.	-Depletion of the DO (Dissolved Oxygen) due to consumption by aerobic oxidation of organic matter present in wastewater. -Affect aquatic life if the DO falls below 4.0 mg/L (DO for healthy water should be above 6.5-8 mg/L)

Synthetic Organic Compounds	-Manmade production, such as synthetic pesticides, synthetic detergents, food additives, paints, plastics, solvents, etc. -Spillage of these compounds during transportation	-Toxic and bio refractory (Resistant to microbial degradation) -Make water unfit for different uses -Detergents can form foams -Volatile substances may cause an explosion in sewers
Oil	-Oil spills, leak from oil pipes, wastewater from production and refineries	-Can spread over the surface of water due to lighter mass, which separates the contact of water with air, causing the reduction of DO. -Endanger water birds and coastal plants due to coating of oils -Reduction of light transmission through surface waters, thereby reducing the photosynthetic activity of aquatic plants
Pathogens	-Sewage discharge and wastewater from industries like slaughterhouses	-Cause water-borne diseases from viruses and bacteria, E.g.: cholera, typhoid, dysentery, polio, infectious hepatitis
Nutrients	-Agriculture run-off, wastewater from the fertilizer industry, and sewage containing a substantial concentration of nutrients like nitrogen and phosphorous	-Stimulate the growth of algae and other aquatic weeds, which causes: 1. Degrade value of water body 2. Reduction of DO 3. Skin and eye irritation, gastroenteritis, and vomiting if contact with people
Suspended Solids and Sediments	-Surface runoff of silt, sand, and minerals eroded from land during the rainy season and through municipal sewers	-Siltation occur, which reduces the storage capacities of reservoirs -Suspended solids can block sunlight penetration in water -Affect diversity of aquatic ecosystem
Inorganic	-Discharge in water bodies through sewage and industrial wastes, including mineral acids, inorganic salts, trace elements, metals, metals compounds, cyanides, sulfates, etc.	-Contamination of water -Accumulation of heavy metals will affect the aquatic flora and fauna -Constitute public health problems if contaminated organisms are eaten -Algal growth due to nitrogen and phosphorous compounds -High concentration of metals can be toxic to biota
Thermal	-Discharge from thermal power plants, nuclear power plants, and industries that utilize water as coolant	-Increase in temperature of water body, which reduces DO content of water and affects aquatic life -Bacterial action increases -Lead to thermal stratification in the water body

Radioactive	-Mining and processing of ores -Research, agriculture, medical and industrial activities -Discharge from nuclear power plants and reactors -Nuclear weapons	-Isotopes are toxic to life forms, which can accumulate in bones, teeth and cause serious disorders

3. Treatment Technologies

Wastewater treatment technologies are the methods used to remove or reduce the harmful or unwanted contamination in the wastewater [11]. Before wastewater treatment comes in, wastewater must first be characterized as its flow, constituents, and the variability of each parameter [12, 13]. These constituents then can be decided to treat differently based on the best treatment method. The wastewater treatment can be classified into four categories, which are physical treatment, chemical treatment, biological treatment, and residual treatment. **Table 2** shows the treatment method categorized in each classification.

Table 2: Classification of Wastewater Treatment Technologies [14]

Physical Treatment	Equalization	Sedimentation	Membrane Filtration
	Screening	Flotation	Temperature Control
	Grit Removal	Filtration	Mixing
	Evaporation Treatment		
Chemical Treatment	pH Control	Coagulation and Flocculation	Adsorption Aqueous Compounds
	Chemical Oxidation/Reduction	Disinfection	Ion Exchange
	Metal Precipitation	Air Stripping	
Biological Treatment	Aerobic Biological Treatment	Anaerobic Biological Treatment	Anoxic Biological Treatment
	Constructed Wetlands	Wastewater Microbiology	
Residual Treatment	Thickening	Stabilization	Sludge Conditioning
	Dewatering	Sludge Disposal	

A few of the wastewater treatment methods will be discussed in the following sub-section, which are precipitation/ encapsulation, membrane technologies, and adsorption.

3.1 Precipitation

Precipitation is a method commonly used to treat dissolved metals in wastewater [15, 16]. In wastewater with dissolved metals contamination, the metals may be present as cations or anions [17]. Cations are positively charged elements while anions are negatively charged elements. Under optimized pH level, cations charged elements can be easily precipitated as an insoluble salt [18]. The most common examples of the precipitating salts used for metal cations include hydroxides, sulfides, and carbonates, which can be used to remove the copper (Cu^{2+}) [19], iron (Fe^{3+}) [20], lead (Pb^{2+}) [21] and cadmium (Cd^{2+}) [22]in the wastewater. The process to remove the anions with precipitation required selected cations or needs to be converted to cations by using reduction reactions before precipitation. Examples of metallic anions are Chromate ($Cr_2O_7^{2-}$) and permanganate (MnO_4^-). The process to yield a satisfying amount of precipitate is a challenging task. The precise details of crystallization, crystal growth, and establishment of equilibria for a given precipitation system may be complicated by factors such as temperature, presence of other dissolved or suspended matter, and even the container and the degree of agitation [14]. With more research being conducted on the precipitation treatment technology, this method is now being used not just on dissolved metal, but also on other anions and cations elements. Research conducted by [23] uses chemical precipitation as pretreatment for phosphorus removal in membrane bioreactor-based municipal wastewater treatment plants in Kyoto, Japan. Their research shows that ferric chloride was more effective in Total Phosphorus (TP) removal of raw wastewater while Polyaluminum Chloride (PAC) was more effective in TP removal of filtered wastewater. This chemical precipitation as a pretreatment was proved to be able to remove phosphorus effectively.

3.2 Membrane Technologies

Membrane filtration is the separation process through the use of a membrane to separate one or more bulk phases from other phases [24, 25]. Initially, membrane filtration technologies are used to treat the wastewater so that it can be recycled back for industrial uses, such as irrigation, groundwater recharge, or drinking purpose. This technology is very common in dry climates areas where clean water is scarce. Besides, membrane filtration is also used in many different physical or chemical treatment systems to remove FOG, organics, heavy metals and process water for reuse. In wastewater treatment, membrane filtration can be divided into four categories by the size of the pores, which are microfiltration, ultrafiltration, nanofiltration, and reverse osmosis [10]. The relatively large colloidal and suspended solids can be removed from wastewater by using microfiltration. For ultrafiltration, it is used to remove the greater colloidal solids and large molecular weight organics in wastewater. Ultrafiltration is commonly used for the treatment of food processing wastewater and the separation of fats, oils, and grease from wastewater. Besides that, the smaller molecular weight organics and a portion of the dissolved solids from wastewater can be removed by nanofiltration, the dissolved solids from wastewater are capable to be removed by reverse osmosis [26, 27].

According to a study conducted by Praful G Bansod [28], microfiltration and ultrafiltration are widely used in the sector such as membrane bioreactors. This is because of their high cleaning capacity and less expensive cost than other membrane filtration methods, which are nanofiltration and reverse osmosis. Another research on hazardous wastewater treatment conducted by Mashallah Rezakazemi et al. shows that a microfiltration ceramic membrane bioreactor can remove more than 90% of the chemical oxygen in wastewater in 32 hours [29]. Ultrafiltration is used by YiLiang He [30] where they use a polyethersulfone ultrafiltration anaerobic membrane bioreactor to study high concentration food wastewater. In this study, the suspended solids, colour, chemical oxygen demand, and bacteria of high-concentration food wastewater had been removed by more than 90%.

Membrane technologies offer many possibilities in the prospect of wastewater treatment with the significant reduction in the size of equipment, energy requirement, and low capital cost brought by the advancement of technology[3]. Singh and Hankins in their paper stated that membrane technology has the potential of bridging the economical and sustainability gap, amid possibilities of low or no chemical usage, environmental friendliness, and easy accessibility to many[31]. Therefore, the economy should be evaluated on a cost-benefit basis to determine the applicability of the membrane filtration process for wastewater treatment. This technique is important as it is the only treatment option in many cases that might provide an actual outcome.

3.3 Adsorption

Adsorption is one of the effective methods to remove inorganic and organic contaminants from water.[32]. Adsorption works by striving for equilibrium among various components. This process may occur in either steady-state or unsteady-state conditions. During the adsorption process, physical or chemical forces will drive the interaction between the adsorbate and adsorbent via electrostatic attraction and repulsion between molecules [33-35]. Therefore, the adsorption process can be used in many types of wastewater treatment to remove the contamination through a binding reaction between the molecules. The adsorption process can be further classified into three types, which are physical adsorption, chemisorption, and specific adsorption.

Physical adsorption occurs through the electrostatic forces inclusive of the van der Waals force, which consists of weak interaction forces through the dipole-dipole interactions, dispersing interactions, and hydrogen bonding [36, 37]. Due to the physical adsorption which does not involve the sharing of electrons, the adsorption energy is generally low. Chemisorption involved the transfer of electrons between the adsorbate and adsorbent to produce stronger bonds between the compound [38]. In this process, the characteristic of the adsorbate will be chemically changed due to the reaction. Specific adsorption occurs in cases where the reactions are having adsorption energies higher than physical adsorption but lower than chemisorption. Specific adsorption does not form a true chemical bond and is only the interaction with the specific functional group on the adsorbent surface [39]. Due to the electrostatic bonding characteristic of the adsorption process, this technique is therefore being greatly affected by polarity, charge, molecular weight, temperature, the surface area of materials, and pore size distribution[14].

Table 3: The most keywords used in different studies for wastewater treatment. Source data from literature (2019–2021), generated using VOSviewer

Selected	Keyword	Occurrences	Total link strength
☑	adsorption	218	154
☑	wastewater treatment	194	102
☑	wastewater	144	85
☑	precipitation	94	83
☑	struvite	70	68
☑	phosphate	36	60
☑	phosphorus	37	44
☑	heavy metals	61	43
☑	biochar	43	37
☑	hydroxyapatite	24	35
☑	ammonium	16	33
☑	nutrient recovery	28	33
☑	heavy metal	33	27
☑	mechanism	30	27
☑	phosphorus recovery	47	25
☑	chemical precipitation	29	24
☑	phosphorus removal	27	24
☑	photocatalysis	68	20
☑	water treatment	27	20
☑	methylene blue	29	14

A study was conducted by[40], where coconut shell is used in the adsorption process for wastewater treatment. In this study, agro-waste material which is coconut shell is chosen to evaluate the performance in removing the chromium (Cr) from wastewater. This study shows that the coconut shell was able to uptake the chromium in wastewater up to 83% in the lower pH of 1.5 and is suitable to be used for the treatment of industrial wastes with the concentration of chromium between 10 to 100mg/l. The conduct of such a research study is important as it can help in lowering the cost and increasing the capacity of wastewater treatment by using agro-waste materials. Besides, the data obtained can also be used in developing appropriate technology in the future for the design of the wastewater treatment plant. Furthermore, **Table 3** reveals that adsorption is the most often used word for wastewater treatment in the last year, with 218 occurrences. Figure 1 depicted the correlations between terms used in various wastewater treatment research.

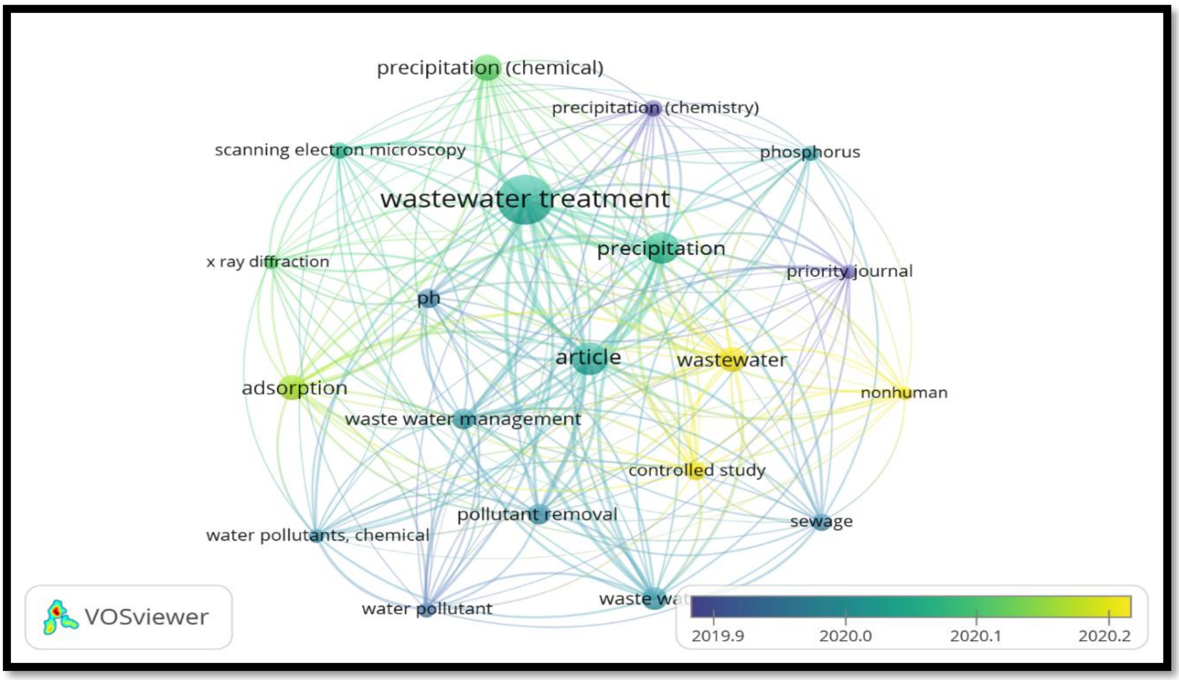

Figure 1: Network of relationships between keywords used in different studies. Source data from the literature (2019–2021), generated using VOSviewer

4. Conclusion

Wastewater treatment represents the greatest untapped potential for addressing freshwater quality and availability issues for now and for the future. Wastewater treatment technologies become the only way to deal with this disaster to secure clean water demand for human daily life. In this generation, many wastewater treatment technologies have been invented based on the four classifications, which are physical treatment, chemical treatment, biological treatment, and residual treatment. Although there has been much research conducted on the wastewater treatment techniques, the high cost of some treatment technologies had caused the treatment progress which does keep up with the wastewater produced daily. An incident such as releasing of untreated wastewater into the river or sea had been seen in many places around the world due to the maximum accumulation of wastewater hit in many treatment plants. Therefore, the current technologies must target a better cost-effective treatment method for the wastewater which can yield high-efficiency treatment outcomes. Besides, awareness of the production of wastewater must also be implanted in the mindset of all people so that we can create a better future for the coming generation.

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References

[1] V. P.Singh, "3.3 Water on Earth," in *Handbook of Applied Hydrology, Second Edition*: McGraw-Hill Education, 2017.

[2] N. Abas, N. Khan, M. S. Saleem, and M. H. Raza, "Indus Water Treaty in the doldrums due to water–power nexus," *European Journal for Security Research,* vol. 4, no. 2, pp. 201-242, 2019.

[3] E. Obotey Ezugbe, Rathilal, S., "Membrane technologies in wastewater treatment: a review," *Membranes,* p. 28, 2020.

[4] S. D. Lin, *Water and Wastewater Calculations Manual, Third Edition*. McGraw-Hill Education, 2014.

[5] R. Zakariah, N. Othman, M. A. Mohd Yusoff, and W. A. H. Altowayti, "Water Pollution and Water Quality Assessment On Sungai Batang Melaka River," *Egyptian Journal of Chemistry,* vol. 65, no. 3, pp. 1-2, 2022, doi: 10.21608/ejchem.2021.79685.3917.

[6] W. Altowayti *et al.*, "Removal of arsenic from wastewater by using different technologies and adsorbents: a review," *International Journal of Environmental Science and Technology,* pp. 1-24, 2021.

[7] P. Sharma, "Delhi: Toxic Foam Covers Banks Of Yamuna At Kalindi Kunj Again; CM Announces Action Plan," *RepublicWorld.com*. [Online]. Available: https://www.republicworld.com/india-news/city-news/delhi-toxic-foam-covers-banks-of-yamuna-at-kalindi-kunj-again-cm-announces-action-plan.html

[8] T. Bay, "Environmental groups plan to sue city of Bradenton over sewage discharges," *WTSP*. [Online]. Available: https://www.wtsp.com/article/tech/science/environment/environmental-groups-plan-to-sue-bradenton-sewage-discharge/67-0dd3030a-5b22-42e0-a208-9d8574853d92

[9] S. S. Kailas L. Wasewar, Sushil Kumar Kansal, *Inorganic Pollutants in Water, Chapter 13 Process intensification of treatment of inorganic water pollutants*. Elsevier, 2020.

[10] I. K. M.M. Ghangrekar. "Classification of Water Pollutants." (accessed.

[11] S. Ahmed *et al.*, "Recent developments in physical, biological, chemical, and hybrid treatment techniques for removing emerging contaminants from wastewater," *Journal of hazardous materials,* vol. 416, p. 125912, 2021.

[12] M. Chys, K. Demeestere, I. Nopens, W. T. Audenaert, and S. W. Van Hulle, "Municipal wastewater effluent characterization and variability analysis in view of an ozone dose control strategy during tertiary treatment: The status in Belgium," *Science of the Total Environment,* vol. 625, pp. 1198-1207, 2018.

[13] M. E. Khalifa, Y. G. Abou El-Reash, M. I. Ahmed, and F. W. Rizk, "Effect of media variation on the removal efficiency of pollutants from domestic wastewater in constructed wetland systems," *Ecological Engineering,* vol. 143, p. 105668, 2020.

[14] E. R. Alley, *Water Quality Control Handbook, Second Edition*. McGraw-Hill Companies, Inc, 2007.

[15] O. A. Oyewo, O. Agboola, M. S. Onyango, P. Popoola, and M. F. Bobape, "Current methods for the remediation of acid mine drainage including continuous removal of metals from wastewater and mine dump," in *Bio-geotechnologies for mine site rehabilitation*: Elsevier, 2018, pp. 103-114.

[16] A. Shahedi, A. Darban, F. Taghipour, and A. Jamshidi-Zanjani, "A review on industrial wastewater treatment via electrocoagulation processes," *Current opinion in electrochemistry,* vol. 22, pp. 154-169, 2020.

[17] A. Saravanan *et al.*, "Effective water/wastewater treatment methodologies for toxic pollutants removal: Processes and applications towards sustainable development," *Chemosphere,* vol. 280, p. 130595, 2021.

[18] S. Ayob *et al.*, "A review on adsorption of heavy metals from wood-industrial wastewater by oil palm waste," *Journal of Ecological Engineering,* vol. 22, no. 3, 2021.

[19] A. Pohl, "Removal of heavy metal ions from water and wastewaters by sulfur-containing precipitation agents," *Water, Air, & Soil Pollution,* vol. 231, no. 10, pp. 1-17, 2020.

[20] H. Abdel-Ghafar, E. Abdel-Aal, M. Ibrahim, H. El-Shall, and A. Ismail, "Purification of high iron wet-process phosphoric acid via oxalate precipitation method," *Hydrometallurgy,* vol. 184, pp. 1-8, 2019.

[21] Q. Chen, Y. Yao, X. Li, J. Lu, J. Zhou, and Z. Huang, "Comparison of heavy metal removals from aqueous solutions by chemical precipitation and characteristics of precipitates," *Journal of water process engineering,* vol. 26, pp. 289-300, 2018.

[22] N. Ghorbanzadeh, S. Abduolrahimi, A. Forghani, and M. B. Farhangi, "Bioremediation of cadmium in a sandy and a clay soil by microbially induced calcium carbonate precipitation after one week incubation," *Arid Land Research and Management,* vol. 34, no. 3, pp. 319-335, 2020.

[23] J. C. Jong-Oh Kim, "Implementing Chemical Precipitation as a Pretreatment for Phosphorus Removal in Membrane Bioreactor-Based Municipal Wastewater Treatment Plants," *KSCE Journal of Civil Engineering,* pp. 1-8, 2014.

[24] N. Ismail, A. Venault, J.-P. Mikkola, D. Bouyer, E. Drioli, and N. T. H. Kiadeh, "Investigating the potential of membranes formed by the vapor induced phase separation process," *Journal of Membrane Science,* vol. 597, p. 117601, 2020.

[25] G. Belfort, "Membrane filtration with liquids: A global approach with prior successes, new developments and unresolved challenges," *Angewandte Chemie,* vol. 131, no. 7, pp. 1908-1918, 2019.

[26] J. Zhang, G. Weston, X. Yang, S. Gray, and M. Duke, "Removal of herbicide 2-methyl-4-chlorophenoxyacetic acid (MCPA) from saline industrial wastewater by reverse osmosis and nanofiltration," *Desalination,* vol. 496, p. 114691, 2020.

[27] N. C. Cinperi, E. Ozturk, N. O. Yigit, and M. Kitis, "Treatment of woolen textile wastewater using membrane bioreactor, nanofiltration and reverse osmosis for reuse in production processes," *Journal of Cleaner Production,* vol. 223, pp. 837-848, 2019.

[28] J. B. Praful G Bansod, Swapnil Dharaskar, Shyam M. Kodape, "Review of Membrane Technology Applications in Wastewater Treatment and Biofuels," in *Elsevier*, 2021: Materials Today: Proceedings, p. 7.

[29] M. M. Mashallah Rezakazemi, Toraj Mohammadi, "High Loaded Synthetic Hazardous Wastewater Treatment using Lab-Scale Ceramic Membrane Bioreactor," *Periodica Polytechnica Chemical Engineering,* p. 6, 2017.

[30] P. X. YiLiang He, Chunjie Li, Bo Zhang, "High-Concentration Food Wastewater Treatment by an Anaerobic Membrane Bioreactor," *Water Research,* pp. 1-9, 2005.

[31] R. Singh, Hankins, N, "Emerging Membrane Technology for Sustainable Water Treatment," *Elsevier: Amsterdam, The Netherlands,* 2016.

[32] S. Kim, Nam, S. N., Jang, A., Jang, M., Park, C. M., Son, A., ... & Yoon, Y., "Review of adsorption-membrane hybrid systems for water and wastewater treatment," *Chemosphere,* p. 19, 2021.

[33] W. A. H. Altowayti, H. G. A. Allozy, S. Shahir, P. S. Goh, and M. A. M. Yunus, "A novel nanocomposite of aminated silica nanotube (MWCNT/Si/NH 2) and its potential on adsorption of nitrite," *Environmental Science and Pollution Research,* pp. 1-12, 2019.

[34] W. A. H. Altowayti, S. A. Haris, S. Shahir, Z. Zakaria, and S. Ibrahim, "The removal of arsenic species from aqueous solution by indigenous microbes: Batch bioadsorption and artificial neural network model," *Environmental Technology & Innovation,* p. 100830, 2020.

[35] W. A. H. Altowayti, N. Othman, P. S. Goh, A. F. Alshalif, A. A. Al-Gheethi, and H. A. Algaifi, "Application of a novel nanocomposites carbon nanotubes functionalized with mesoporous silica-nitrenium ions (CNT-MS-N) in nitrate removal: Optimizations and nonlinear and linear regression analysis," *Environmental Technology & Innovation,* vol. 22, p. 101428, 2021.

[36] Z. M. Bahari, W. A. H. Altowayti, Z. Ibrahim, J. Jaafar, and S. Shahir, "Biosorption of As (III) by non-living biomass of an arsenic-hypertolerant *Bacillus cereus* strain SZ2 isolated from a gold mining environment: Equilibrium and kinetic study," *Applied Biochemistry and Biotechnology,* vol. 171, no. 8, pp. 2247-2261, 2013.

[37] S. A. Haris, W. A. H. Altowayti, Z. Ibrahim, and S. Shahir, "Arsenic biosorption using pretreated biomass of *psychrotolerant Yersinia* sp. strain SOM-12D3 isolated from Svalbard, Arctic," *Environmental Science and Pollution Research,* vol. 25, no. 28, pp. 27959-27970, 2018.

[38] W. A. H. Altowayti, H. A. Algaifi, S. A. Bakar, and S. Shahir, "The adsorptive removal of As (III) using biomass of arsenic resistant *Bacillus thuringiensis* strain WS3: Characteristics and modelling studies," *Ecotoxicology and Environmental Safety,* vol. 172, pp. 176-185, 2019.

[39] W. A. H. Altowayti *et al.*, "Adsorption of Zn2+ from Synthetic Wastewater Using Dried Watermelon Rind (D-WMR): An Overview of Nonlinear and Linear Regression and Error Analysis," *Molecules,* vol. 26, no. 20, p. 6176, 2021.

[40] F. C. Sohail Ayub, "Adsorption Process for Wastewater Treatment using Coconut Shell," *Trans Stellar Journal Publications.Researc Consultancy,* pp. 21-34, 2014.