INNOVATIVE SOLUTIONS TO REDUCE ENVIRONMENTAL POLLUTION

in air, soil, and water

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Assist. Prof. Zeynep KARCIOĞLU KARAKAŞ

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PREFACE

Our world is facing unprecedented challenges due to environmental pollution. Agricultural and industrial activities are increasing intensively due to the growing human population and, thus, increasing needs. These activities lead to the depletion of natural resources and a significant waste problem. Consequently, environmental pollution in our world is increasing and diversifying daily. From contaminated drinking water supplies to air filled with harmful emissions and soils tainted with hazardous substances, the consequences of pollution have never been more evident. Yet, despite the magnitude of these challenges, scientists, engineers, and activists worldwide are working hard to solve environmental problems. The effective removal of pollutants in air, water, or soil is vital for the future of our planet and environmental sustainability. Unfortunately, traditional treatment methods may be insufficient to eliminate these pollutants. Therefore, new environmental remediation technologies need to be developed, and existing methods must be modified with new technologies. In this study, recent methods for removing various pollutants in air, water, or soil are discussed, and some of the scientific studies in these fields are presented. By adopting these innovative approaches, I believe we can secure a brighter, cleaner, and healthier tomorrow. I hope that our work will be helpful to all researchers and students researching the protection and sustainability of our environment.

I hope our book will inspire positive change for a cleaner and greener world.

Assist. Prof. Zeynep KARCIOĞLU KARAKAŞ
Editor

CHAPTER 1

NEW STRATEGIES FOR CONTROLLING AIR POLLUTION IN URBAN CENTERS

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INTRODUCTION

In contemporary and burgeoning urban hubs, the escalating urban populace and the process of urbanization have elevated the significance of the air pollution predicament (Cohen *et al.,* 2004). Factors such as intensifying human activities, industrial activities, increasing the number of vehicles, energy consumption, and waste management in cities increase the concentrations of air pollutants, resulting in negative consequences that threaten human and environmental health (Mage *et al.,* 1996). Urban air pollutants significantly affect public health and cause health problems such as respiratory diseases, heart, and circulatory system problems that have serious impact on human health (Samet and White, 2004).

Urban air pollution is caused by harmful gases and particulate matter (pm) concentrated in the atmosphere through the accumulation of different pollutants. Human activities such as industrial activities, intensive use of fossil fuels as energy sources, power generation, vehicles, pesticides, and improper management and incineration of waste are the sources of air pollutants in the atmosphere. These contaminants markedly taint the air within urban areas, leading to major harmful effects on human well-being, the ecosystem, and the atmospheric conditions.

Airborne pollutants cause many negative effects. Human health impacts include increased risk of respiratory infections, asthma, bronchitis, lung cancer, cardiovascular disease, and premature death. In addition, air pollution can damage vegetation, pollute water resources, disrupt ecosystem balance, and reduce biodiversity. It can also contribute to climate change and accelerate global warming (Bernstein *et al,*. 2004).

In new-generation metropolises, various measures are being taken to reduce air pollution, which causes many environmental problems, with the help of important smart city technologies and smart applications. These include increasing energy efficiency, switching to clean energy sources, reducing industrial emissions, controlling vehicle exhaust emissions, improving waste management and recycling practices, preventing deforestation, and using next-generation smart control methods. In addition, individuals being careful in their daily habits such as conscious consumption and energy use, and decision-makers implementing more sustainable and green policies can contribute towards combating air pollution (Garzon *et al.*, 2018; Kalajdjieski *et al.* 2020). Institutions and policy makers, as well as individual city dwellers, can make a significant contribution to increasing the technologies and policies that can reducing air pollution levels and improving air quality is a top priority for the city. In terms of measures that can be taken individually, we can contribute to reducing air pollution by means of small steps such as saving energy, choosing sustainable transportation methods, recycling, reducing the use of environmentally harmful substances and planting trees. Paying heed to air quality indicators is equally crucial, and refraining from extended outdoor activities during periods of elevated air pollution levels is imperative to safeguard our well-being.

Various measures are taken at national and international level to reduce air pollution. These include investing in clean energy sources, controlling industrial emissions, tightening vehicle emission standards, increasing energy efficiency, improving waste management, protecting green spaces, and raising environmental awareness.

Improving air quality within the city is possible through the implementation of an integrated air quality management system covering the entire city, including individuals and legal entities as stakeholders, as well as mitigation and control mechanisms, control policies, and green technologies.

This book chapter highlights the importance of new technologies and strategies to combat air pollution in urban centres and presents the advantages that can be gained by implementing these technologies and strategies. It also discusses the factors such as policy adjustments, technological innovations, and public awareness that are necessary for the success of these strategies.

Air pollution control in urban centres is vital for the environment and human health. By implementing new strategies, a cleaner, healthier, and more sustainable green living environment can be achieved. Thus, innovative approaches for air pollution control and the benefits that these approaches can provide can be demonstrated.

AIR POLLUTION IN CITIES

Air pollution is a particularly serious problem in large cities and densely populated areas. Air pollution in cities increases due to a number of factors (World Health Organization, 1992; Mage *et al,*. 1996, Marlier *et al.,* 2016).

Factories, power generation plants, and other industrial facilities located in urban industrial production zones are major sources of air pollution. Pollutant gases and particulate matter (pms) from these facilities are released into the atmosphere, increasing air pollution. Fossil fuels, especially coal, and oil, used in urban households and commercial buildings contribute to air pollution. Sources such as home heating systems, stoves, fireplaces, and generators release pollutants as a result of combustion (Perera *et al,*. 2019). Construction projects in cities can also release dust, pollutant gases, and other air pollutants into the air. Construction vehicles, building materials, and concrete processes are factors that increase air pollution (Wieser *et al,*. 2021). Landfills and waste incinerators in cities can contribute to air pollution when poorly managed. Burning waste causes the emission of harmful gases and particles. These factors are major contributors to air pollution in urban areas. Urban air pollution can affect urban residents, causing respiratory diseases, cardiovascular diseases, allergic reactions, cancer, and other health problems (Tian *et al*., 2013).

A variety of air contaminants lead to urban air pollution. Among the pivotal air pollutants in the metropolitan atmosphere are the inorganic varieties, encompassing carbon oxides (CO/CO_2), sulfur oxides (SO_2/SOx), nitrogen oxides (NO_2/NOx), ozone (O_3), heavy metals, and particulate matter (especially $pm_{2.5}$ and pm_{10}). Additionally, compounds of organic origin, such as volatile organic compounds (BTX/VOCs), polyaromatic hydrocarbons (PAHs), dioxins and their derivatives, hydrocarbons (HC), and CFCs, hold significant influence (Krzyzanowski *et al.,* 2014). Vehicles constitute a large part of the mobility of urban residents, especially in megacities. Traffic-induced air pollution is one of the most important problems in megacities and is resulted in especially by old vehicles with inadequate emission control systems. Airborne pollutants originating from vehicular traffic encompass carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2), particulate matter (both pm_{10} and $pm_{2.5}$), as well as volatile organic compounds (VOCs) (Samet, 2007). Heavy traffic in cities, especially old vehicles with inadequate emission control systems, leads to the release of pollutant gases and particles such as carbon monoxide, nitrogen oxides, and particulate matter into the atmosphere (Wang *et al.*, 2008).

Electricity generation facilities release noxious gases into the environment due to the incineration of fossil fuels like coal and natural gas. Especially notable is the substantial emission of sulfur dioxide (SO_2), nitrogen oxides (NOx), and particulate matter from coal-fired power plants.

The agricultural sector in urban peripheries can contribute to air pollution through activities such as chemical fertilizers, pesticides, and animal husbandry. Volatile organic compounds (VOCs) and ammonia gas from pesticides and fertilizers can negatively affect air quality (Nelson, 1972).

In cities, temperature inversion, a meteorological phenomenon that increases the accumulation of air pollution, can occur. Temperature inversion causes pollutants to accumulate and not disperse in the atmosphere when a layer of cold air is trapped near the surface (He *et al.*, 2017).

Fires in urban areas release pollutants into the atmosphere as a result of events such as fires in trees, forests, houses, or industrial plants. The combustion process produces particulate matter, harmful gases, and smoke (Sapkota *et al.*, 2005).

These air pollutants are the main origins of air pollution in cities. Air pollution can cause respiratory diseases, cardiovascular disorders, allergic reactions and other health problems (Gurjar *et al.*, 2010). It also has negative impacts on vegetation, water and soil pollution, climate change, and ecosystems. Due to all these negative environmental impacts, various measures should be taken to reduce air pollution. Reducing air pollution and improving air quality in cities will contribute to the creation of a more sustainable and green environment, while also contributing to the reduction of universal environmental problems such as global warming, and climate change.

NEW TECHNOLOGIES TO REDUCE AIR POLLUTION

New technologies are needed to control air pollution in urban centers and provide a quality living environment. Since traditional methods are insufficient, innovative and sustainable solutions are being researched and implemented. In this section of the study, new strategies used to control air pollution in urban centers will be discussed and their impacts will be discussed.

New strategies focus on various areas such as promoting the use of clean energy sources, improving public transportation systems, increasing energy efficiency, reducing industrial emissions, and protecting green spaces. Furthermore, technological developments and advances such as data analytics offer new opportunities to monitor, measure and manage air quality. These next-generation applications are important steps to reduce air pollution in cities and create a sustainable environment. The combination of these applications is crucial to ensure a cleaner and healthier living environment.

These methods are based on various techniques used to monitor and assess air quality in cities. Identifying and monitoring air pollution levels is critical for taking preventive measures and improving air quality. Air quality monitoring and assessment is an area where governments, organizations, and society need to work together to create healthier and more sustainable cities.

Air Quality Monitoring Networks and Applications

Temporal and spatial monitoring of air pollution levels and air quality is important for improving air quality and preventing urban air pollution. Advanced air quality monitoring networks and mobile applications provide access to air pollution maps, air quality indices and real-time information on health impacts.

There are specially established monitoring networks in cities to monitor air quality. These networks consist of air quality monitoring stations placed at various locations. These stations contain sensors, filters and instruments that measure pollutants in the atmosphere. The measured data is usually converted into an indicator, such as an air quality index, and made public. These stations measure pollutants to determine air quality. For example, a particulate matter counter is used to measure particulate matter (pm_{10} and $pm_{2.5}$). Gases such as nitrogen oxides (NO_X) and sulphur dioxide (SO_2) are measured with gas analyzers. Similarly, special sensors and analyzers are used to measure other pollutants such as carbon monoxide (CO), ozone (O_3), volatile organic compounds (VOCs) (Xie *et al.*, 2017; Gao *et al.*, 2016).

Sensor technologies and data analytics are used to monitor and analyze air quality. Sensor networks monitor air pollution levels in real time, providing instant data. This data can be used to understand air quality impacts and develop effective solutions (Okokpujie *et al.*, 2018; Penza *et al.*, 2017). The development of small-sized, portable sensors has provided a major advance in detecting and monitoring air pollution. These sensors allow individuals to easily measure and monitor air quality. Through mobile apps or wearable devices, users can track air pollution levels in their environment in real time and take necessary actions. These small devices allow individuals to measure air quality directly. Portable sensors measure the concentration of pollutants, temperature, humidity and other parameters, providing instantaneous air quality (Parmar and Chattopadhyay, 2017; Gao *et al.*, 2016).

Especially in urban areas, air pollution monitoring and prevention studies are trying to be made possible by designing the cheapest possible and modular units (Alvarado *et al.*, 2015; Balram *et al.*, 2019; Bohrn *et al.*, 2011; Brzozowski e*t al.*, 2019; Castell *et al.*, 2018; Clements *et al.*, 2019; Cordero *et al.*, 2018; Curto *et al.*, 2018; Herisanu *et al.*, 2019; Johnson *et al.*, 2018; Mead *et al.*, 2013; Miskell *et al.*, 2017; Morawska *et al.*, 2018; Popoola e*t al.*, 2018; Weissert *et al.*, 2019).

With the developing sensor technology, there are many studies that can measure air pollutants in outdoor air with the help of sensors and reveal the air quality (Balram *et al.*, 2019; Bohrn *et al.*, 2011; Castell *et al.*, 2018; Harkat *et al.*, 2006; Hu *et al.*, 2011; Huang *et al.*, 2013; Järvinen *et al.*, 2015; Jiang *et al.*, 2018; Jovasevic-Stojanovic *et al.*, 2015; Kaivonen and Ngai 2019; Lin *et al.*, 2016; Malky *et al.*, 2019; Mead *et al.*, 2013; Thompson, 2016). At this point, it should be kept in mind that sensor technology is a newly developing technology and may be inadequate in measuring some parameters (Su, 2018; Tille, 2012).

Digital environmental monitoring and management systems include technological solutions used to monitor, analyze and manage air quality. These systems use technologies such as sensors, data analytics, artificial intelligence and cloud computing to collect and analyze air quality data and inform decision makers. Thus, air pollution sources can be identified, problems can be solved quickly, and future policies and interventions can be designed more effectively (Ayele and Mehta, 2018, Dhingra, *et al.*, 2019).

Utilizing computational methods for air quality modeling, which aids in digital air quality surveillance, constitutes an approach employed for the prediction of urban air pollution levels. These models simulate air quality through the amalgamation of meteorological parameters, emission origins, and atmospheric chemical insights. Consequently, anticipations regarding atmospheric pollution levels within a designated area can be ascertained (Srivastava and Rao, 2011).

Data-driven decision-making is important in combating air pollution. Air quality data and other relevant data are analyzed using advanced analytical and artificial intelligence techniques. These analyses are accustomed to identify sources of air pollution, develop preventive and corrective measures, and ensure effective management of resources. Meteorological data are also taken into account to determine air quality. Factors such as wind speed and direction, air temperature, and humidity can affect the spread of air pollution. Therefore, monitoring and analysis of meteorological data essential for understanding the causes and distribution of air pollution.

Health indicators are used to determine the impact of air quality on human health. Respiratory diseases, cardiovascular disorders and other health problems can be associated with air pollution levels. These indicators give an overview of air quality by analyzing data such as disease incidence, hospital admissions and mortality rates. In addition, people's sensory evaluations can also be taken into account to assess air quality. In particular, factors such as odor, appearance and overall perception of air quality can provide information on air pollution levels. This method can be used to evaluate public understanding of air quality and provide feedback (Kumar *et al.*, 2015; Cole *et al.*, 1999).

Smart City Technologies

Air pollution prevention efforts in smart cities involve a range of technological and managerial interventions. Sensors enable air quality data to be collected and analyzed. This data is published in publicly available air quality indices, helping to inform the public. Also, traffic management and planning, as well as strategies to reduce fuel consumption and emissions, are being developed. The use of electric vehicles, increasing bicycle lanes and walking paths are among the methods that can be implemented to reduce air pollution. In addition, using energy more efficiently and switching to renewable energy sources are two sustainable ways to improve air quality. These methods are the main strategies used in air pollution prevention and mitigation efforts in smart cities (Dutta *et al.*, 2017; Iskandaryan *et al.*, 2020).

Air pollution and prevention efforts in smart cities include various methods such as the use of environmentally friendly technologies, data analysis and management, and transition to renewable energy sources. The main objective of these efforts is to reduce air pollution and protect public health (Myeong and Shahzad, 2021).

Smart city technologies help reduce air pollution by optimizing energy and resource use. For example, smart lighting systems save energy and reduce carbon dioxide emissions that affect air quality. Smart building automation and energy management systems also reduce air pollution by improving energy efficiency.

Smart city technologies are used for environmental sustainability and air quality improvement in cities. Using technologies such as Internet of Things (IoT) devices, smart lighting systems, energy management systems, energy efficiency and air quality can be improved.

Green and Sustainable Transportation

Reducing car use and switching to cleaner modes of transportation is an important step to reduce air pollution. Improving the public transportation network, increasing bicycle and pedestrian routes, and encouraging environmentally friendly vehicles such as electric and hybrid vehicles have a positive impact on air quality. At this point, it is important to make urban transportation green and sustainable. For this purpose, measures such as improving public transportation systems, expanding bicycle sharing systems, and encouraging the use of electric scooters and bicycles can be taken. Shared transportation models can also be implemented to reduce car sharing and traffic congestion. The use of electric vehicles instead of fossil fuel vehicles is an important step to reduce air pollution in cities. With the widespread use of electric vehicles, exhaust emissions are greatly reduced and air quality is improved. In this context, it is important to establish charging stations and implement incentive policies. To reduce air pollution in cities, transportation planning should be designed to reduce air pollution. Expanding public transportation networks, increasing bicycle lanes and pedestrian areas, reducing traffic congestion and keeping emissions under control should be established transportation policies (Faria *et al.,* 2017; Tomaszewska and Florea, 2018; Ruggieri *et al.,* 2021).

In addition to electric vehicles, the development of bicycle lanes and pedestrian-friendly infrastructure encourages people to reduce their use of motorized vehicles. Thanks to these practices, environmentally friendly alternatives such as cycling and walking can be preferred for urban transportation. Approaches that support hybrid and electric vehicles in urban planning help reduce air pollution. Practices such as the proliferation of charging stations, parking spaces reserved for electric vehicles, and the promotion of electric vehicles for urban delivery and transportation encourage clean and low-emission transportation. Promoting the use of hybrid and electric vehicles is an effective way to reduce air pollution in cities. Electric vehicles improve air quality as they operate with zero or low emissions. Therefore, measures such as infrastructure development, incentives, and tax breaks can be taken to encourage the use of electric vehicles. As electric cars become widespread, they can improve air quality by replacing fossil fuel-powered vehicles (Johansson *et al.,* 2017; Ferrero *et al.,* 2016; Wu and Zhang, 2017).

As one of the sub-components of smart cities, intelligent transportation systems optimize traffic flow, reducing traffic congestion and stop-and-go times that affect air pollution. These systems can have features such as synchronization of traffic lights, traffic density monitoring, and routing. Intelligent transportation systems involve the use of next-generation technologies in traffic management and planning. These systems reduce congestion, lower vehicle emissions, and reduce air pollution. Solutions such as smart traffic lights, algorithms that optimize traffic flow, and integrated applications with public transport systems can improve air quality (Qureshi and Abdullah, 2013; Brohi *et al.*, 2018).

Energy Efficiency Clean Energy

The reduction of energy consumption and the improvement of energy efficiency are effective strategies for mitigating air pollution. It is important to take energy efficiency measures in homes and workplaces, use more efficient heating, cooling, and lighting systems, and prefer energy-efficient appliances.

Electrification of energy consumption in cities and increasing energy efficiency play an important role in reducing air pollution. Applications such as electric heating and cooling systems, energy-efficient lighting and electronic devices, energy management systems optimize energy consumption and contribute positively to air quality. Heating systems commonly used in cities can be improved in terms of energy efficiency and low emissions (Spiru and Simona, 2017).

Turning to renewable energy sources in cities prevents air pollution by reducing the use of fossil fuels. Solar power and other renewable energy sources, wind energy, and hydroelectricity can be preferred to meet energy needs in cities. The use of renewable energy sources instead of fossil fuels is encouraged to reduce air pollution. For example, the use of cleaner fuels such as natural gas reduces pollutant emissions and improves air quality. It is also important to favor renewable fuels such as biomass, hydrogen and biodiesel. The development and commercialization of environmentally friendly energy sources, such as solar, wind, hydroelectric, and nuclear energy, is essential to reduce greenhouse gas emissions and mitigate climate change. To accelerate this process, governments can implement incentive policies and, where necessary, mandatory regulations. The adoption of environmentally benign energy reservoirs within urban locales assumes significance in aligning with worldwide objectives to mitigate the progression of global warming and climatic alterations. The transition towards sustainable energy origins, encompassing solar photovoltaics, wind turbines, hydroelectric power, and geothermal resources, remains feasible not solely in industrialized nations but also in developing economies, provided there exists financial backing (Omer, 2008; Boudri *et al.*, 2002; Koengkan *et al.*, 2021).

Green Infrastructures

Green infrastructure is an approach to protect and restore natural ecosystems in cities. It includes measures such as afforestation, green roofs, green barriers, urban parks, water bodies and the creation of natural habitats. Green infrastructure improves air quality, absorbing harmful emissions, purifying the air and providing natural filtration (Tiwari *et al.*, 2019).

Tree planting, the creation of parks and gardens, and the use of green roof and wall systems improve air quality and help absorb air pollutants. Rooftop gardens, vertical gardens and green walls are practices that integrate natural vegetation into the urban environment.

Green buildings within green infrastructure provide an environmentally friendly living space by using energy efficiency and sustainable building materials. Green building technologies improve air quality by increasing energy efficiency. Well-insulated structures, energy-saving lighting systems, intelligent thermal control systems, and the use of recycled materials reduce the environmental impact of buildings and improve indoor air quality. Energy-efficient buildings save energy in heating, cooling, and lighting systems. Buildings with high energy efficiency reduce energy demand and have a positive impact on air pollution. Solutions such as well-insulated buildings, energy recovery systems, and solar panels can be used for energy efficiency (Allen *et al.*, 2015).

As the use of renewable energy sources increases, the storage and management of clean energy has become important. Next-generation clean energy storage systems can play a vital role in the transition to a sustainable energy future by storing excess energy generated by solar panels and wind turbines, improving energy efficiency, and reducing reliance on fossil fuels.

Other Alternative Solutions

High-tech systems and devices are being developed to control air pollution. For example, air purifiers and air filtration systems can be deployed to improve indoor and regional air quality by removing particulate matter, allergens, and other pollutants from the air. These systems protect human health by removing harmful particles and pollutants from the air (Yewele *et al.,* 2022). Air purifiers, especially those used indoors, reduce pollutants that people are exposed to through respiration. High-tech filtration systems that capture and remove pollutants from industrial activities can improve air quality.

Digital technologies and remote working can optimize business processes, reducing traffic and emissions. Digital meetings and remote working applications can prevent air pollution by reducing business travel.

Scaling up sustainable agricultural practices in cities can reduce air pollution from agriculture. Organic farming methods limit the use of pesticides and fertilizers and protect soil health.

Urban vegetation can play a significant role in mitigating air pollution by absorbing pollutants, filtering particulate matter, and releasing oxygen. Some plants clean the air by absorbing harmful pollutants. For example, trees, shrubs, and other green plants absorb carbon dioxide and produce oxygen, improving air quality. Therefore, it is important to create green spaces and vegetation in cities. These plants can be used indoors and in urban landscapes, contributing to improved air quality. For example, plants such as aloe vera, peace lily, areca palm, and weeping fig have the ability to sequester pollutants such as formaldehyde, benzene, and trichloroethylene in the air (Leung et al. 2011; Barwise and Kumar, 2020).

New-generation technologies are being developed in the aviation sector to reduce air pollution. For example, aviation technologies are used for more efficient aircraft engines, low-emission aircraft fuels, optimizing flight routes, and controlling flight emissions (Ranasinghe *et al.,* 2019).

Sustainable waste management plays an important role in reducing air pollution in cities. Expanding recycling and waste separation systems reduces gas emissions and environmental impacts from landfills. It is important to properly segregate waste, promote recycling processes and reduce the amount of waste. Waste management and recycling practices help reduce sources of air pollution. Proper waste management prevents methane gas formation and air pollution in landfills. In addition, recycling, and reuse processes ensure the effective utilization of resources (Kanhai *et al.*, 2021).

In order to meet human needs and fulfill economic activities in megacities, many industrial facilities are concentrated in the industrial and industrial zones of the city. It is important to control industrial emissions and use low-emission technologies in industrial facilities. Leaks should be detected instantaneously with sensor-based measurement systems and systems that provide instant data to decision makers should be widely used. Measures such as pollutant gas treatment systems, filtration and purification technologies, and strict enforcement of emission standards reduce industrial air pollution.

POLICIES TO REDUCE AIR POLLUTION IN CITIES

It is important to adopt and implement green and environmental policies to prevent air pollution and improve air quality. Governments should support sustainable development and environmental protection policies in cities, make environmentally sensitive decisions and take effective measures to improve air quality. It is also necessary to address air pollution on a global scale and find solutions through international cooperation and agreements (Hewitt *et al.*, 2020).

Emission standards for sources of air pollution should be set to encourage vehicles, power plants, factories, and other industrial facilities that cause less damage to the environment. Steps such as encouraging low-emission vehicles and mandating filtration and treatment systems can improve air quality (Duque *et al.*, 2016).

Various policies can be implemented to reduce traffic congestion and promote sustainable transportation. Measures such as improving public transportation networks, creating bicycle and pedestrian-friendly zones, and promoting car-sharing systems can reduce motor vehicle use and emissions (Bigazzi and Rouleau, 2017).

Controlling emissions from industrial facilities is important to reduce air pollution. Tightening emission controls, developing waste treatment facilities, and implementing recycling and waste reduction policies can improve air quality.

Protecting and increasing green areas is an effective way to decrease air pollution. Steps such as afforestation projects, the creation of parks and gardens, and the protection of vegetation can improve air quality and oxygen production. Policies to improve the green infrastructure in cities should be prioritized by city administrators. It is important to integrate strategies to reduce air pollution in urban planning. Air quality can be improved through planning principles such as separating residential, industrial, and commercial zones in areas with high air pollution, creating green corridors, and taking wind directions and topographical features into account (Cetin, 2019).

Effective policy and management mechanisms should be implemented to reduce air pollution. It is important to establish regulations to combat air pollution, ensure participation in policy-making processes, manage resources effectively, and establish control mechanisms (Li *et al.*, 2019).

Air pollution is a problem that can often transcend borders. Therefore, cooperation and coordination at the regional and international levels are important. Cooperation activities such as sharing information and experience, setting common policies and standards, and technology transfer provide an effective solution to combat air pollution (Abas *et al.*, 2019).

Innovation and research and development investments are important for the development of new technologies to combat air pollution. Innovative solutions can offer more effective and sustainable ways to reduce air pollution. New filtration systems, clean energy technologies and other innovations can help cities improve air quality.

It is important to tighten environmental standards to prevent air pollution. Stricter emission standards should be set and regularly inspected to control air pollution sources. Furthermore, environmental violations should be prevented through the imposition of criminal sanctions.

It is important to increase public awareness of the effects of air pollution, health risks and environmental impacts. Raising public awareness on air pollution, encouraging healthy lifestyles and promoting measures that can be taken at home and at work contribute to improving air quality. Education and awareness raising to combat air pollution is a process that aims to raise awareness and mobilize individuals and society to protect air quality by informing people about the effects, causes and solutions to air pollution. Information about the impacts of air pollution, prevention and personal responsibilities can be provided through tools such as campaigns, seminars, training programs and social media.

CONCLUSION

Urban areas grappling with air pollution confront a substantial predicament, inducing detrimental repercussions on both human well-being and the ecological equilibrium. Nonetheless, novel methodologies and approaches must be harnessed to effectively manage this challenge and enhance atmospheric purity. This research endeavors to dissect innovative strategies viable for curtailing air pollution within urban hubs, subsequently delving into their conceivable ramifications.

Promoting clean energy sources is an important part of the new strategies. The reduction of fossil fuel consumption and the increased adoption of renewable energy sources are essential strategies for mitigating greenhouse gas emissions and improving air quality. Furthermore, steps such as improving public transportation systems, creating bicycle lanes and increasing pedestrian-friendly areas can be effective in controlling air pollution by reducing individual car use. Improving energy efficiency is also an important strategy. Measures such as reducing the energy consumption of buildings and using energy-efficient lighting and heating systems can contribute to combating air pollution. Furthermore, controlling industrial emissions, regulating waste management and protecting green areas are also important to improve air quality.

Technological advances offer new opportunities in the fight against air pollution. Sensors and data analytics developed to monitor and measure air quality allow for more effective management of air pollution. This means that sources of air pollution can be better understood and policymakers can make more informed decisions. However, technology alone is not enough to control air pollution. Public awareness and participation is also crucial. Enhancing public understanding of the impacts of air pollution, including the associated health risks and individual mitigation measures, is a critical step towards achieving sustainable change.

The importance of new strategies and approaches for controlling air pollution in urban centres has been emphasized in detail in the sections above. At a time when traditional methods are inadequate, strategies such as promoting clean energy sources, improving public transportation systems, increasing energy efficiency and reducing industrial emissions can be effective in improving air quality. Furthermore, technological advances offer new opportunities to monitor and manage air quality. However, factors such as policy arrangements, public awareness and participation are also important for the success of these strategies.

The combined efforts of local governments, policymakers, civil society organizations and individuals play a major role in reducing air pollution and making urban centres more liveable. Shaping these efforts based on sustainability and community well-being will help us create a healthier and more liveable environment for future generations.

As individuals, we can also contribute to the fight against air pollution. We can choose alternative transportation options such as public transportation or bicycles to reduce car use. We can reduce electricity consumption by saving energy and taking energy efficiency measures in our homes and workplaces. In addition, steps such as recycling, reducing the amount of waste and choosing environmentally friendly products are also measures we can take individually against air pollution. Environmental awareness of society in general should be increased and a sustainable urbanization approach should be adopted.

As a result, the serious problem of air pollution in cities and its negative impacts on human health and the environment can only be reduced through the use of new generation strategies and technologies, the right policies and measures, and a cleaner sustainable environment.

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CHAPTER 2

SECONDARY AEROSOLS IN ATMOSPHERIC FINE PARTICLES ($PM_{2.5}$)

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INTRODUCTION

The world, which is trying to keep up with the ever-increasing population, changing and developing industry and technology, has had many environmental problems in the adaptation process. Air pollution is one of them. Air pollution define as the presence of air pollutants in the air for a period and amount that can harm living and non-living things. In other words, it can be said that the quality of the breathable air is deteriorated. The presence of substances other than the natural components of the content of the atmosphere or the presence of the natural component over the usual amount conforms to the definition of air pollutant. Among the air pollutants, particulate matter (PM), nitrogen oxides (NO_X), sulfur dioxide (SO_2) and carbon monoxide (CO) are at the forefront.

PM is called solid particles, liquid particles, granule and particles suspended in the atmosphere in various sizes. Although the pernicious effects of atmospheric PM on the environment and living things are known, it is difficult to comment on the magnitude of the results. Particulate matter has been the most interesting subject in recent years, especially in the scientific world, due to the inability to determine both the source and the formation and transformation mechanisms.

PM is usually studied in two fractions. These are PM_{10}, which includes particles of 10µm and smaller, and $PM_{2.5}$, which includes particles of 2.5µm and less. $PM_{2.5}$ is the fraction that should be studied because of its small size, easy movement and penetration, and more harmful content.

$PM_{2,5,}$ which is mostly anthropogenic (the result of human activities), can cause significant damage to living health and the atmosphere due to its small size and chemical composition. For this reason, the amounts and compositions of particulate matter in the fine fraction have been studied intensively in the world in recent times. Determining the chemical content of $PM_{2,5}$ will help in identifying the sources of pollutants and thus will be effective in taking measures to reduce the pollution levels of the regions.

AIR POLLUTION

The world is in a state of constant development and change. These developments and changes also bring some problems. Environmental problems come first among them. Air pollution has a great place in environmental problems. Living things need clean air to survive. Since there is no clear definition of clean air, it is quite difficult to argue quantitatively about air pollution. However, an agreement has been reached that the composition of clean air is within certain values, and everything above and outside these values is considered an air pollutant.

In short, air pollution described by the World Health Organization (WHO) as the pollution of the outdoor or indoor environment by any physical, biological, or chemical factor that changes the natural properties of the air. It is one of the biggest problems of our time due to its impact on climate change, health problems, and increases in mortality. Climates change and the impacts of global warming seriously affect more than one ecosystem, causing problems such as food security problems, melting of ice and icebergs, extinction of animals, and damage to plants. In addition, human induced air pollution appears to be one of the maximal public health hazards in the earth, taken that it causes approximately 9 million deaths per year. Atmospheric pollution mainly impresses those living in great urban region where emissions of roads conduce the most to the degradation of atmospheric quality. There is also the big danger that in the event of an accident in industrially dense urban areas a toxic fog could spread, with fatal consequences for the surrounding population.

In developing countries, the air quality problem is more critical due to uncontrolled urbanization and overpopulation with the development of industrialization. This spearheads to worse quality of air, especially in countries in the world with a lack of knowledge on ecological appropriate management and social inequalities. The utilization of fuels such as solid fuel, wood fuel for indoor needs due to low income subjugates people to polluted and poor quality air. About three billion people in the world use these energy sources for their daily cooking and heating needs (Manisalidis *et al.*, 2020). Therefore, it becomes necessary to take many precautions. As a result, the measures taken prevent several pollutants and increase public awareness. Air quality regulations of countries around the world are implemented, air quality monitoring stations operate and their data are made available to the public over the Internet.

Air Pollutants

Atmospheric pollutants can be divided into two according to their chemical structure. These are gaseous pollutants and particulate matter. The main gas pollutants are carbon monoxide (CO), tropospheric ozone (O_3), .nitrogen oxides (NO and NO_2), and sulfur dioxide (SO_2).

Air pollutant sources are handled in two classes, natural sources and human activities (anthropogenic) sources. Natural sources of atmospheric pollutants are forest fires, volcanic eruptions, dust storms, plants, seas and oceans. The principal anthropogenic sources can be listed as heating (gas, liquid and solid fuel stoves and heating boilers), industry (thermal power plants, solid waste incineration and plants industrial processes), and transportation (motor vehicles, airplanes, ships and railways).

The effects of air pollutant gases are generally examined in three categories: global, regional, and local. For example, events such as the depletion of the ozone layer and the greenhouse effect, which affect the entire earth, are global effects. Acid rain, which affects certain regions in the world, is one of the effects of atmospheric pollution on a regional scale. The local effects of air pollution are in the form of pollution of air in residential and industrial areas.

One of the pollutants that have an important place in city air quality is SO_2, which is constituted during the combustion of sulfur-containing fuels, for example fuel oil and coal, as a result of metal melting processes and other industrial processes. Its main sources are heating thermal power plants, and industrial processes. SO_2 locally damages the respiratory system of people and shortens the visual distance by turning it into sulfate. This gas also causes a significant amount of acid precipitation on a regional scale.

Nitrogen Oxides (NO and NO_2) are generally formed by the reaction of O_2 and N_2 in combustion at high temperatures and high air excess. Its most important resources are transportation and industry. NOx cause destroying of living respiratory systems, the formation of "photochemical smog" and the formation of acid precipitation.

Carbon Monoxide (CO) is one of the most common pollutants emited into the air, usually as a result of incomplete combustion. The primary source of carbon monoxide in urban areas is motor vehicles and heating facilities, and the secondary important source is solid waste storage facilities. Although it is not very harmful in the outer atmosphere, it is quite toxic in the inner atmosphere.

Tropospheric ozone (O_3) is a pollutant of secondary formed by the reaction of photochemical formed of nitrogen oxides (NOx) and volatile organic compounds (VOC), known as ozone precursors, under effective solar radiation. Tropospheric ozone, which has a toxic effect, causes a decrease in the level of vision, causes damage to the lung and respiratory system human health, and irritation to the eyes and throat area. It also has negative effects on agricultural products, ecosystems, and structures.

Particulate Matter (PM) is all solid and liquid particles that are larger than the molecular size of gases and remain suspended in the air for a while. particulate matter; It is of natural origin such as volcanic activities, fires, winds, and sea waves, and anthropogenic such as the combustion of coal and petroleum products, industries, construction works, and agricultural activities. Particulate matter has quite different effects. The effects increase as the concentration and residence time in the atmosphere increase. In addition, it is possible to collect atmospheric pollutants in 2 groups according to their formation forms. Primary pollutants that remain in the air as they are removed directly from the pollutant source, and secondary pollutants constituted when these primary pollutants react in the atmosphere with some other species present in the air. Particulate matter is the pollutant with the largest region of air pollution, including these two groups.

Particulate Matter

Particulate matter (PM) is a complex mixture of minimal solid particles and liquid droplets suspended in atmosphere and varying in chemical composition, sizes of particle, shapes of particulate, surface areas, solubility in the water and sources, with physical and chemical properties that vary with space and time. The general chemical content of PM consists of inorganic species such as nitrate and sulfate, organic species such as polycyclic aromatic hydrocarbon (PAH), organic and elemental carbon, earth-derived elements, and metals. In addition, there is the contribution of biological species (WHO 2013; Pacitto *et al.*, 2019).

The adverse health impact of Particulate Matter (PM) sources on human health may be related to certain PM components, for example organic carbon (OC), elemental carbon (EC), metals, and ions. In particular, heavy metals in PM may be associated with toxicological problems resulting from bioaccumulation affecting the central nervous system. Exposure to particulate matter causes adverse health effects such as cancer, asthma attacks, cardiovascular disease, chronic bronchitis, diabetes, premature death, increased number of emergency room visits, and increased hospitalization rate. In addition to the effects of PM on human health, it affects the climate change both directly by absorption-scattering ways of solar radiation and indirectly by forming cloud condensation nuclei. PM may remain on the water surface, soil, building, metal, etc. by precipitation after various processes depending on its chemical and physical properties. They can also cause serious environmental damage on surfaces. PM concentration and composition are strongly variable and are related to many agents such as emission sources, climatical conditions, and geographic location (Bayraktar 2006; Chithra and Shiva Nagendra 2013; Dolar and Saraç 2015; Castro *et al.*, 2018; Galvao *et al.*, 2019).

PM_{10}, which constitutes the most significant part of atmospheric PM, is defined as particulate matter (coarse particulate matter) with an aerodynamical diameter of 10 micrometer (μm) and below. PM_{10} cannot be held by the mucous membranes and cilia that prevent the passage of harmful substances in the body, and thus they can settle in the alveoli and bronchi. The 10-micron is not a sharp border between respirable and non-respirable particulates but recognized by regulatory agencies as the most appropriate fraction for airborne particulate matter monitoring. (Iovino *et al.*, 2014; Kim *et al.*, 2015). However, particles with an aerodynamical diameter equal to or less than 2.5 μm (fine particulate matter ($PM_{2.5}$) are considered more damaging than bigger-sized particulates. This is because they may penetrate deeper parts of the human breathing tract such as the bronchi and alveoli, penetrate cell membranes more effectively, and act as carriers of carcinogenic and toxic compounds. Considering the health effects of fine particles and their relationship to resources in the city center, it is even more considerable to focalize on the $PM_{2.5}$ fraction. As a result, the direct and indirect effects of $PM_{2.5}$ on both air quality and atmospheric visibility, radiation balance, nutrient precipitation, and health are known, and for these reasons, it has get more attention in recent years (Theodosi *et al.,* 2018; Shivani *et al.,* 2018; Pacitto *et al.,* 2019; Guo *et al.,* 2020).

Establish and define air quality aims to reduce or prevent the damaging effects of atmospheric pollution on the human health and environment, comment atmospheric quality based on defined criterias and methods, maintain and otherwise improve the current condition where air quality is well, collect adequate information on air quality various sanctions are implemented in the world to report the public through warning thresholds. In the European Commission Directive (ECD) 2008/50/EC, ambient air quality and clean air legislation for Europe (2008), the annual average and daily limit values for PM_{10} are determined as 40 and 50 μg m^{-3}, respectively. The annual mean value for $PM_{2.5}$ in ECD is set as 25μg m^{-3}. However, since this limit value is not thought to adequately preserve health, the World Health Organization (WHO) recommended annual and daily average limit values for $PM_{2.5}$ as 10 and 25 μg m^{-3} (Scerri *et al.,* 2018).

Atmospheric $PM_{2.5}$ And Its Components

$PM_{2,5}$ with small diameters and large surface areas can easily absorb acidic oxidants, heavy metals with toxic properties and harmful organic substances. These particulates can also act as fate for bacterias, fungis, viruses, and other microbes. Due to their slow sedimentation rates and low weight, they float in the atmosphere for a long and are transported over a long distance, causing air pollution there. They can go the human circulatory system and respiratory system. PM studies have shown that $PM_{2.5}$ can go in more damaging matters in the air, stay in the atmosphere longer and intihale the respiratory system faster than PM_{10} (Miranda *et al.,* 2018; Chai *et al.,* 2019).

Having a complex mixture of primary and secondary particulates, $PM_{2.5}$ is released into the atmosphere from both natural sources and anthropogenic sources. On a global scale, $PM_{2.5}$ can be spread directly as particulates from combustion or mechanic processes, but can also be formed and grown in the air by condensation of the low-volatility products of atmospheric chemical reactions of inorganic and organic precursors. In short, fine particles are released into the atmosphere from industrial production processes, automobile exhausts, biomass combustion, and secondary conversion of gases (Huang *et al.,* 2012; Weagle *et al.,* 2018; Luo *et al.,* 2018). $PM_{2,5}$ main components are soil dusts, ions (SO_4^{2-}, NO_3^-, NH_4^+, etc.), carbonaceous particles, and trace metals. Carbonaceous particles include elemental carbon (EC) and organic carbon (OC) fractions. It is significant to comprehend the sources and chemical species of $PM_{2.5}$ to assess health effects and develop control systems (Shivani *et al.,* 2018; Luo *et al.,* 2018; Weagle *et al.,* 2018).

Particulate matter composition diversity and concentration density are highly variable and are related to many factors. For example weather conditions, specific atmospheric chemistry, emission sources, and geographic location. The health effects of PM are strongly dependent on its composition, which includes elemental carbon (EC), organic carbon (OC), inorganic ions, cluster elements, and toxic metals (Chithra and Nagendra 2013; Mohseni Bandpi *et al.,* 2017). Because of all these, studies on carbonaceous aerosols in $PM_{2,5}$ have been done in recent years. (Kim *et al.,* 2012). In urban and rural regions, carbonaceous particles are an significant part of PM. Carbonaceous PM includes of elemental carbon (EC) and organic carbon (OC), which is a heat-stable component. It also contains 20-90% of $PM_{2.5}$ (Plaza *et al.,* 2006; Cheng *et al.,* 2010; Keywood *et al.,* 2011; Siciliano et al., 2018).

Water-soluble ions, including nitrate, sulfate, ammonium, and alkali cations, are the main components of $PM_{2.5}$ and can directly affect the acidity, hygroscopicity, and cloud nucleation capacity of particles. Water-soluble ions play an significant role in deteriorating visibility, acting as condensation nuclei in altering the earth's radiation balance and also accelerating cloud and fog formation (Ding *et al.,* 2018; Zhang *et al.,* 2018; Zhou *et al.,* 2018). Fine particulate matter, especially nitrate, and sulfate,has a light-scattering effect.

Water-soluble ions (NO_3^-, SO_4^{2-} and NH_4^+) and carbon components contribute significantly to the loss of visibility (Wang *et al.,* 2018).

According to their formation, the main chemical components of $PM_{2.5}$ are separated primary and secondary aerosols. Primary aerosols are formed from pollutants remaining in the air as they are expelled directly into the air from pollution sources, while secondary particles are produced from the reactions of primary air pollutant precursors that consist of in the air (Xu *et al.,* 2020).

SECONDARY AEROSOLES

It is possible to collect secondary aerosols in two groups, especially secondary organic aerosols (SOAs) and secondary inorganic aerosols (SIAs). SOAs are primarily created by photochemical reactions of volatile organic compounds (VOCs) in the environment, followed by condensation or self-nucleation of semi-volatile oxygenated products. SIAs are mainly composed of nitrate, sulfate and ammonium manufactured by photochemical reactions of gaseous pollutants (nitrogen oxides (NOx) and sulfur dioxide (SO_2)) in the air.

Secondary Organic Aerosol (SOA)

Secondary organic aerosol (SOA) is an important atmospheric secondary pollutant that affects its visibility in the atmosphere, human health, and climate change. SOA occur in the air by oxidation reactions of hydrocarbons. These are reactions that lead to the formation of volatile or non-volatile organic compounds inclusived in gas phase oxidation stages to create fresh aerosols by nucleation or condensation on pre-existing aparticulates (Srivastava *et al.,* 2018; Liang *et al.,* 2019). In short, SOA, which is one of the principal components of atmospheric organic particles, occur by the condensation of gas-phase oxidation results of volatile organic compounds, and its physical and chemical properties do not remain constant during atmospheric lifetimes ranging from 48 to 72 hours.

The most active precursors that act a role in SOA formation are anthropogenic and biogenic VOC (Denjean *et al.,* 2015; Zhang *et al.,* 2018). Aromatic species such as benzene, toluene, and xylene from solvent use, vehicle exhaust, and biomass combustion are the most important anthropogenic precursors, while VOCs such as isoprene and monoterpenes released by various vegetation types are biogenic SOA precursors (Zhang *et al.*, 2018). Besides, the secondary organic aerosol is typically featured by a higher degree of oxidation as it contains molecules with oxygenated functional groups (carbonyl and hydroxyl groups) (Siciliano *et al.*, 2018).

SOAs are mainly constituted by the gas phase conversion of VOCs initiated by ozone, light or free radicals, for example nitrate radicals ($NO_3^{\cdot}$) and hydroxyl radicals ($HO^{\cdot}$). The mechanisms that initiate the photochemical reactions of VOCs, including light, ozone, and free radicals, are represented in Figure 1. Volatile organic compounds can be cleaved by light and free radicals to arrive their real state, thereby initiating subsequent reactions that spearhead to the creation of more free radicals.

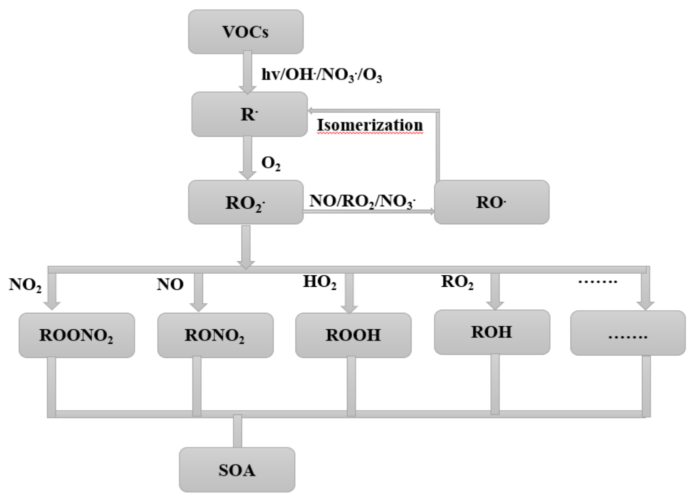

Figure 1. Treatment of Volatile organic compounds in the production of SOAs. VOC can be decomposed in light to form free radicals, thereby initiating subsequent reactions (Xu *et al.*, 2020).

Direct detection of SOA is quite difficult. However, it is possible to utilize the EC tracer method, which is an indirect and very useful method for the quantitative determination of SOA (Rodrigo *et al.*, 2009; Siciliano *et al.*, 2018). This method is based only on the primary carbonaceous aerosol representation with minimal OC/EC from fossil fuel burning due to its simplicity and low-cost advantages. Considering that all primary OC and EC are emitted to the air from the same source, it is accepted that the EC component OC can be used as best tracer for the part of OC emited from primary resources of combustion. With this approach, secondary aerosol formation directly enhances the concentration of organic carbon and the numeral value of the OC/EC ratio. In this context, it can be said that secondary formation occurs for the cases that exceed the expected OC/EC for the emissions of primary sources in a region. In this method, if the OC/EC exceeds the minimum value, it indicates the secondary contribution (Pio *et al.,* 2011). With the help of Equations 1 and 2 developed by Turpin and Huntzicker (1995), the amount of secondary organic carbon can be calculated.

$$OC_{primary} = (OC/EC)_{primary} * EC \qquad \text{Equation 1}$$

$$OC_{secondary} = OC_{total} - OC_{primary} \qquad \text{Equation 2}$$

$OC_{primary}$; only primary emitted organic carbon, $(OC/EC)_{primary}$; The minimum value of OC and EC ratio, OC_{total}; measured OC value, $OC_{secondary}$; is the contribution of secondary formation to the total OC.

The $(OC/EC)_{primary}$ ratio in these equations depends on meteorology and photochemical activity, it is quite difficult to find the value of this ratio. Various ways have been used to determine this ratio. These:

- Using a comprehensive emissions inventory,
- To make particulate matter measurements in areas such as tunnels where only the source of combustion both EC and OC is
- To use the minimum of value OC/EC ratio in a study period,
- Taking the average of the three lowest ratios,
- Using linear regression of a portion of the dataset (eg. 15%) containing low rates,
- Using PM measurements with EC and OC taken on days or hours when there is no precipitation, cloudy, high NO_2, O_3, and photochemical activity is low (Giugliano *et al.,* 2005; Saylor *et al.,* 2006; Kim *et al.,* 2012; Mbengue *et al.,* 2018; Bhowmik *et al.,* 2021).

Finally, using secondary organic carbon, secondary organic aerosol can be estimated with the help of equation 3.

SOA = k * OC secondary Equation 3

Here SOA; secondary organic aerosol, k; is fixed. The constant coefficient k value is the ratio of organic matter to organic carbon. That is, it is used to convert OC into organic matter. This ratio is a multiplicative factor that meets the OC and the carbon-free mass (eg hydrogen, oxygen, nitrogen) and ranges from 1.2 to 2.6 (Chan *et al.*, 2010; Mancilla *et al.*, 2015; Hui *et al.*, 2019; Bhowmik *et al.*, 2021).

In addition, the presence of other primary and secondary pollutants in the environment also gives information about this formation. When comparing the concentrations of NO_X and ozone with the EC and OC species, a good correlation is generally observed between NO_X and elementel carbon because of the primary character of both and because the EC originates from a non-photochemical source. In addition, if NO_2 and O_3 correlated well with OC, this confirms secondary aerosol formation (Plaza *et al.*, 2006; Rodrigo *et al.*, 2009). In addition, from a toxicity point of view, SOAs are known to be more toxic than their predecessors (Xu *et al.*, 2020).

SECONDARY INORGANIC AEROSOL (SIA)

NO_3^-, SO_4^{2-}, and NH_4^+, which are considered the main components of $PM_{2,5}$, are secondary inorganic ions. They can act as condensation nuclei in altering the Earth's radiation balance and also accelerating cloud and fog formation, reducing atmospheric visibility, increasing $PM_{2.5}$ concentrations, and increasing haze formation due to their aerosol hygroscopicity. The proportion of SIAs in $PM_{2.5}$ varies greatly regionally and seasonally and ranges from 25% to 45% worldwide. Therefore, a better comprehension of the composition, chemical and physical properties, sources, behavior, and formation mechanisms of SIAs is required (Zhang *et al.*, 2018; Zhou *et al.*, 2018; Xu *et al.*, 2020).

Among the anthropogenic sources, the principal source of NO_X and particulate NO_3^- is emissions of vehicle (Jiang *et al.*, 2018). However, high NO_3^-, SO_4^{2-} levels may be associated with burning in winter in some regions. In addition, industrial and agricultural activities can also affect ion exchange. For example, the use of fertilizers in activities of agricultural application might conclude in more NH^{4+} formation in particulates (He *et al.*, 2017).

It exists in some important chemical forms that can affect the properties of fine particulate matter. For example, ammonium sulfate ($(NH_4)_2SO_4$) is a specific chemical form of the major SO_4^{2-} and NH_4^+ ions and has a hygroscopical effect on PM and enhances the hygroscopical growth of mix of organic salts with $(NH_4)_2SO_4$ (He *et al.*, 2017).

There are some reaction equilibria between nitrate, sulfate, and ammonium, which are affected by the presence of aerosol, fog, and cloud, and meteorologic conditions, for example relative humidity and temperature. Due to the volatility of $NH_4\ NO_3$ (ammonium nitrate), the formation process of $(NH_4)_2SO_4$ is more complex than that of $(NH_4)_2SO_4$. Also, the reaction of ammonia (NH_3) and nitric acid (HNO_3), ($HNO_3(g) + NH_3(g) \rightleftharpoons NH_4\ NO_3\ (s)$) is one of the pricipal processes in an particulate. The reaction is influenced by temperature fluctuations and eventually reaches gas-particle equilibrium. Generally, the $NH_4\ NO_3$ occurs in regions with high concentrations of NH_3 and HNO_3 and low temperatures (Zhao *et al.*, 2015).

Secondary inorganic aerosols are formed by gaseous up-to-particle transformation processes under suitable meteorological conditions. For example, SO_2 formed by burning coal and some biomass as a precursor, and NOx produced from vehicle exhaust can be easily oxidized through the heterogeneous and homogeneous reaction and then converted to the particulate SO_4^{2-}, NO_3, respectively (Zhou *et al.*, 2018; Guo *et al.*, 2020).

Secondary inorganic aerosol can be studied as nitrate SIA and sulfate SIA. The formation and transformation of nitrogen compounds in the air associate to free radicals and photochemical reactions. Therefore, multiple reactions centered on NOx and HNO_3 can form a systematic network representing the transport and fate of nitrogen compounds in $PM_{2.5}$ (Figure 2).

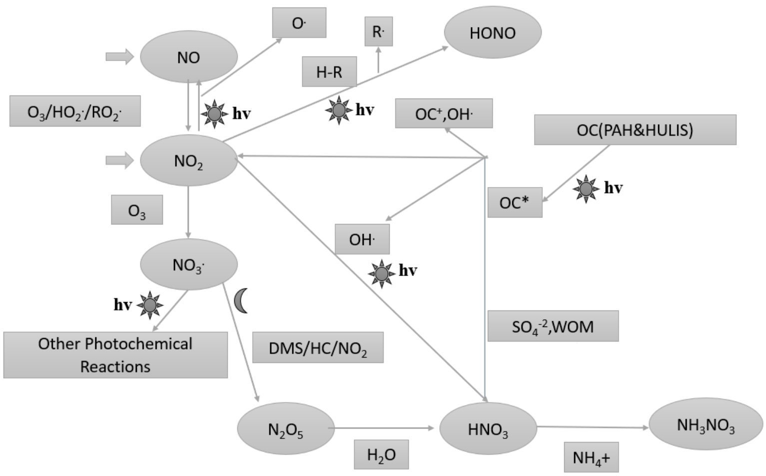

Figure 2. Formation and transformation of nitrogen secondary inorganic aerosols in the atmosphere. HC: Hydrocarbon; DMS: Dimethylsulfide; HULIS: Humic like substance; WOM: Water-Soluble Organic Material; PAHs: Polycyclic Aromatic Hydrocarbon); OC: Organic Carbon, The symbol of moon shows that the reaction does not require light, while the symbol of sun and 'hv' show the photochemical reaction (Xu *et al.*, 2020).

The commonly accepted sulfate formation mechanism has three steps. First, atmosferik SO_2 dissolves to form sulfurous acid. Second, the sulfurous acid is oxidized to H_2SO_4. Various oxidants are used that containig O_2 in this reaction. Finally, H_2SO_4 consubstantiates with NH_4^+ and metal ions to manifacture sulfate secondary inorganic aerosols. Photosensitizers such as xanthone, flavone, and HULIS in particulate take in light and transform into excited triad states. These excited photosensitizers then oxidize SO_2 with atmospheric water to form sulfate SIA. Similar to nitrate secondary inorganic aerosol, there are electron and energy transfers in reactions (Fig. 3).

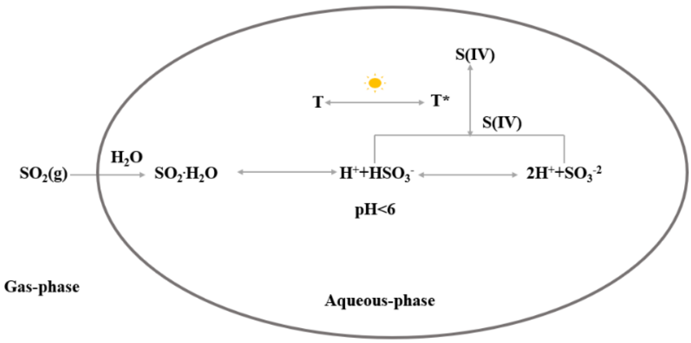

Figure 3. Formation and transformation of sulfate secondary inorganic aerosols in the atmosphere. Sulfite and bisulfite forms sulfate secondary inorganic aerosols in $PM_{2.5}$ by photosensitive oxidation. "T" and "T*" show photosensitizers and their excited triads, respectively. The symbol of sun shows that the reaction occurs only in light (Xu *et al.*, 2020).

In addition, the photoreactions of sulfate and nitrate secondary inorganic aerosols can be interrelated. Free radicals such as NOx produced by photolysis of particulate nitrate SIA and nitrogen-containing compounds can play as oxidants to oxidize the sulfite to sulfate SIA. Given that NOx is important for both sulfate and nitrate secondary inorganic aerosol formation, sulfate, and nitrate secondary inorganic aerosol formation can compete under certain conditions. Therefore, it can be concluded that while the nitrate SIA formation mechanisms in $PM_{2.5}$ are clearer, the sulfate SIA formation mechanisms are more complex. Although each specific production route is dependent on various reaction states such as light intensity, humidity, and temperature, the role of photochemical reactions is essential in the formation of SIA. In addition, in terms of toxicity, SIAs are known to be less toxic than their predecessors (Xu *et al.*, 2020).

In addition, SO_4^{2-} /EC, NO_3^- /EC, and NH_4^+/EC rates are also high on hazy days. The fact that these rates are high indicates that secondary organic aerosols are formed in the region under excessive humidity (Wang *et al.*, 2018).

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CHAPTER 3

RECOVERY OF URBAN TREATMENT SLUDGE AND USAGE IN CULTIVATION OF HERBACEOUS PLANTS

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INTRODUCTION

The waste that arise as a result of the increasing rate of urbanization, population, developing industry, technology, and increasing consumption bring along significant pollution in terms of the environment. Many methods used to solve the problem also bring different problems. In general, the waste that is intended to be disposed of randomly or incinerated has begun to cause irreversible damage to the environment and natural resources. Instead of unconsciously trying to destroy the waste, separating them at the source and reusing them in different areas will contribute to the countries' economy by reducing the waste load and the need for raw materials (Akat *et al.*, 2013).

The fact that our resources are not unlimited has made exhaustion and impoverishment inevitable. Because of the thoughtless use of our existing resources, the natural balance of the environment has deteriorated over time, and this situation has started to cause permanent problems. For this reason, the recovery and reuse of 'waste' has become a topical issue studied extensively in recent years. In recent years, the transition from the unsustainable linear economy process to the circular economy process, which we can describe as sustainable and green, has gained momentum worldwide. In this sense, it has been adopted as an important principle all over the world to bring all kinds of waste into the economy both in a symbiotic relationship and by recycling.

The solid residue part that comes out as a result of the treatment of waste water is called "Treatment Sludge". The treatment process cannot reach its full purpose without proper disposal of the sludge. Sewage sludge is a valuable resource with its high content of organic matter, elements such as nitrogen, phosphorus and potassium. Many researchers have stated that the use of this resource for agricultural purposes will be an alternative or support to the use of organic and inorganic fertilizers (Dolgen *et al.*, 2007).

Today, in parallel with the increase in the number of wastewater treatment plants, there is a great increase in the amount of treatment sludge. The obtained treatment sludge must be disposed of in a way that does not harm the environment. Many methods are used for this purpose. Among these methods, the use of sewage sludge, which is an environmentally and economically suitable method, has gained importance by applying it to the soil (Bilgili & Açıkgöz, 2011).

Due to the amount and variety of organic matter, the use of sewage sludge as fertilizer by applying it to the soil has many positive features. In addition, adversely affects the environment and human health; It prevents the presence of uncontrolled applications of heavy metals (manganese, copper, zinc, cobalt, chromium, lead, nickel, cadmium, etc.), toxic organic chemicals, and pathogenic microorganisms. For this reason, the content of the treatment sludge should be analyzed before it is applied to the soil, and for this purpose, different treatment sludge should be tested in different soils and the most appropriate doses should be determined.

In this study, the positive and negative aspects of the use of sewage sludge in soil and herbaceous plant cultivation will be detailed and evaluated within the framework of profit and loss.

OVERVIEW OF URBAN TREATMENT SLUDGE

Sewage sludge can be defined as solid materials that are converted into a sedimentable or floatable form as a result of physical, chemical, and biological treatment processes in drinking water and water. Waste sludge is a mixture of solid and liquid that occurs for treating water and wastewater, which must be purified due to its nature and can cause harm to the environment if left untreated. Due to excessive doses of organic matter, nutrients, pathogenic microorganisms, and a large amount of water content, they need to be treated (Yıldız *et al.*, 2009).

Since the sludge formed because of treatment is prone to putrefaction and deterioration, it must be disposed of. The load and qualities of the treatment sludge released from the wastewater treatment plants (WWTPs) are related to the composition of the wastewater and the treatment processes used for treating the water treatment processes. There are three types of sludge released from WWTPs. These; pre-sedimentation sludges are chemical and biological sludges.

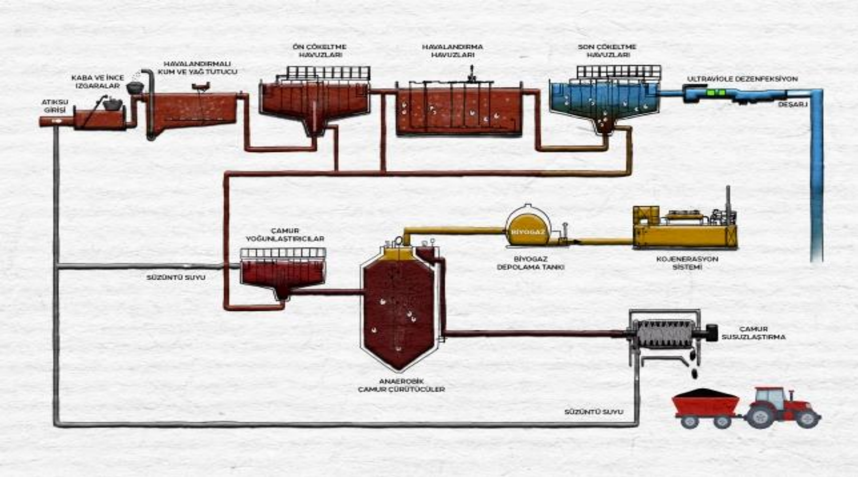

Figure 1. Classical domestic wastewater treatment plant model (Yüksekdağ *et al*., 2020).

An average domestic wastewater treatment plant is shown in Figure 1. The wastewater is first passed through the screens to be removed from the coarse and fine materials and reaches the ventilated oil and sand holding unit. Then, by adding pressurized air to the water, the oil molecules and solid particles contained in the water are lifted above the water and removed from the water by stripping. The next pool is pre-sedimentation. A physical treatment is carried out in this pool and self-precipitating solids are collected at the bottom of the unit. The pre-sedimentation sludge taken from the bottom of the pond is sent to the thickeners. The water in the upper part is transferred to the aeration pool. Biological treatment begins here. Biological treatment is the decomposition of suspended or dissolved organic components in wastewater as a result of the activities of bacteria and their transformation into stable inorganic compounds that escape into the atmosphere, remaining in the liquid, with biological flocs that can precipitate. After biological treatment, biological sludge is formed by the stabilization of bacterial forms and their accumulation at the bottom of the pool. This sludge is sent to the sludge thickening unit. While the wastewater is released into the sea, lakes, and rivers after treatment, the sludge accumulated in the sludge condensation pond is treated by anaerobic sludge decomposing tanks. Anaerobic treatment, briefly, can be explained as the conversion of organic and inorganic substances into products such as CO_2, CH_4, H_2S, and NH_3 by breaking down with the help of microorganisms in an oxygen-free environment. Finally, the sludge is removed by becoming solid in the sludge dewatering unit.

Figure 2. Domestic waste sludge

Depending on the type and purpose of the treatment, the types of treatment sludge differ. If we group them;

- Pre-sedimentation sludge formed by settleable solid particles
- Chemical sludge formed as a result of chemical treatment and coagulation
- Biological (final sedimentation) sludge formed as a result of biological treatment activities

There are two main sludge outlets in a conventional wastewater (domestic) treatment plant. These are pre-sedimentation sludge resulting from physical treatment and biological sludge formed because of biological treatment activities.

Pre-sedimentation sludge; They are gray-colored, sticky dense, and malodorous sludge that are formed as a result of processes applied to wastewater, provided that the dissolved organic/inorganic substances and gases in different sizes and dimensions, floating collapsing solids are removed from the wastewater.

Biological (final sedimentation) sludges; are microbiologically more stable sludge that are from wastewater because of the use of organic and partially inorganic pollutants by microorganisms as energy and nutrient sources.

To properly dispose of the sludge resulting from the physical and biological treatment of wastewater, first of all, the moisture content must be minimized. Among the techniques used basically for this; dewatering, conditioning, densification, and drying methods can be listed. Among the techniques used to stabilize the sludge are incineration, stabilization, and composting. In addition to these methods, after the necessary analysis of the dewatered treatment sludge to a certain extent, it is possible to store it in sanitary landfills by its content and final disposal (Gül, 2018).

Although progress has been made in wastewater treatment, excessive release of sewage sludge is still one of the biggest disadvantages. The amount of sewage sludge continues to increase day by day and the cost required for the treatment of these wastes covers approximately 60% of the total operating costs (Yıldız & Oran 2019).

General Content of Urban Waste Sludge

Domestic wastewater; includes wastewater generated at homes, domestic waste from non-industrial workplaces, and institutional wastewater from institutional sites mixed into sewers. Except for the decentralized WWTP, most large facilities, which were established for the treatment of domestic sewage in small settlements, treat some commercial and industrial wastewater along with domestic Water. Generally, if only domestic Waste comes to the plant, there are not many variables in the character of the wastewater. The domestic wastewater content from region to region can vary according to the socio-economic, geographical, and meteorological characteristics of the region. However, even in the same region, the character and amount of wastewater can change seasonally or periodically due to reasons such as opening or closing schools, and population variability in holiday resorts (Öztürk *et al.*, 2016).

The content of treatment sludge may vary according to the region where the sludge is obtained. It may contain Fe, Cu, Hg, Al, Cd , As, Co , Pb, Cr, nitrogen, acids, metal salts, organic phosphorus, sulfates, alkalis, dyes, hydrocarbons, organic compounds, phenols, oxidizers, etc.).

Table 1. Stabilized purification in the mud average for physically and chemical features

pH	7.34
Salt (µS/cm)	1194
Organic matter (%)	74.99
C/N	11.6
Total N (mg/g)	3.75
Total P (mg/kg)	3715
Total Na (mg/kg)	1081
Total Cd (mg/kg)	0.77
Total Pb (mg/kg)	9.33
Total Ni (mg/kg)	41.04
Total Cu (mg/kg)	15.81
Total Al (mg/kg)	2575

(Çapan Mustafaoğlu *et al*., 2023).

DISPOSAL METHODS OF URBAN WASTE SLUDGE

Stabilization: Reducing the pathogens contained in the sludge obtained after treatment and minimizing the resulting odor, in addition; it is a sludge disposal method applied to eliminate problems such as decay and decomposition. Environmental conditions created by chemicals added to eliminate, decay, and odor prevent the proliferation and growth of microorganisms, thus contributing to stabilization. The main stabilization methods are stabilization with lime, composting, aerobic, and anaerobic degradation. The stabilization of sludge from WWTP can be examined under 3 main headings. These are chemical, biological, and Thermal methods. When stabilization applications are examined in terms of disinfection applicability, some raw treatment sludges can be disinfected, while others cannot be completely disinfected. The sludge from WWTPs must be well stabilized to have the desired dryness. Realization of sludge stabilization; Removal of basic pathogens is necessary for preventing undesirable odor and putrefaction. Sludge stabilization is effective for gas production and volume reduction stabilized treatment sludge. Stabilized sludge does not have a negative effect on groundwater quality, vegetation, or soil improvement and can be used in an ecologically safe manner when desired.

Conditioning: This method is defined as the process of increasing the ability of the sludge to release water. Mechanical densification can be applied by physical methods such as conditioning, heating, melting, and solidification, which are an important part of sludge dewatering, or by supplementing with organic-inorganic chemicals and the use of ashes from sludge incinerators. It is a process developed to make sludge dewatering more convenient. Chemical conditioning and heat treatment are the most used methods for this process.

Densification: It is a process that removes the water contained in the sludge, increasing the solids density, and consequently reducing the volume of the sludge. After the thickening process, the sludge does not lose its fluidity. The main reasons for using sludge thickening systems in WWTPs are; high sludge concentration is to obtain more economical digester storage with less volume. The solids concentration can be increased twenty-five times by condensation.

Dewatering: This process is a physical method applied to reduce the moisture content of the sludge. As a result of this process, there is a serious reduction in volume, and at the same time, it helps the mud cake to be easily transported and the cake to be odorless and unsuitable for putrefaction. Sludge from WWTPs must be converted from liquid to solid for disposal. The sludge resulting from condensation is subject to dewatering.

Combustion: Exothermic oxidation of combustible materials in sludge is called. Sludge with reduced water content can ignite at 420-500 ºC in an oxygen-containing environment. Combustion of all organic solids takes place at a minimum temperature of 760-820 ºC. As a result of the incineration process, solid wastes are reduced by 75% in mass and 90% in volume. The sludge from the WWTPs is incinerated and disposed of. The ashes resulting from the combustion can be used as asphalt filler, in the chemical industry, and in recent years to obtain phosphorus.

Landfill: Applications where treatment sludge is accepted as a single (monolithic) or stored together with municipal solid wastes in a designated area.

In recent years, another method of disposal of treatment sludge is its use in the soil. The most important and striking aspect that distinguishes this practice from other disposal methods is that the waste sludge is disposed of while being reused in another area at the same time. Thus, waste sludge will be removed from WWTP and it will be able to be used as fertilizer in the soil thanks to the nutrients it contains (nitrogen, phosphorus, calcium, magnesium, potassium, sodium). In this case, waste can be reused by gaining value and will make a great contribution to the economy.

USING WASTE SLUDGE AS FERTILIZER IN SOIL

In our country and in many countries, the discharge of waste to nature without treatment is restricted by laws and regulations. For this reason, the establishment of wastewater treatment plants has become mandatory. With the increase in wastewater treatment plants, the amount of treatment sludge released as the final product of the plant is also increasing. Wastewater subjected to physical, chemical, and biological treatment units is purified from the pathogens and toxic substances in its content at the maximum level and the sludge obtained is used as a living environment in agriculture, biological repair processes, landscaping areas, and plant cultivation in a way that does not adversely affect the environment. It is also possible to dispose of (Akat *et al*., 2015).

Figure 3. Soil applications of waste sludge

Environmentally friendly sludge disposal methods are very costly and time-consuming. It also requires expert knowledge. The use of sludge for land application compared to other disposal methods is very common recently. Because waste sludge contains a high amount of organic matter and nutrients (N, P, K) for plant growth, and this content increases plant yield in the applied land (Nahar *et al*., 2020).

In addition, when the treatment sludge, which is rich in organic matter content, is given to the soil environment, it also increases the solubility of heavy metals in the environment by decreasing the pH of the root part due to the accelerated microbiological activity. However, this situation is even more promising in the soils of our country with high pH and high lime content (Çimrin *et al*., 2000).

Among the many disposal methods, the disposal of treatment sludge by soil is one of the important techniques in terms of its economic contribution. It is an important advantage that this disposal method to be chosen is economical and easy to implement. Evaluation of Wastewater and treatment sludge, which is the output of wastewater, is very important in this respect (Öztürk *et al*., 2020).

In recent years, waste sludge; It is widely used in soil, growing herbaceous and woody plants and even in agricultural areas. Applying the waste sludge to the soil is not a job to be done haphazardly, because if the waste sludge is given to the soil more than necessary, the plants that will grow in this soil, the heavy metals and some chemical substances in the waste sludge can damage the plants and this may create extra pollution, so the waste sludge must be analyzed before it is placed in the soil. It should be given in appropriate doses that will not harm the soil and plants.

USAGE OF TREATMENT SLUDGE IN HAZELNUT PLANT GROWING

Fertilizer use is essential to enrich the soil in terms of organic matter and increase its water-holding capacity. The fact that the sludge needs to be disposed of as a ‘waste’ and also has a fertilizer quality makes it an important material that can be used in the soil. The high organic matter and plant nutrients in its content and its low cost make it a material that can replace commercial fertilizers in plant production. There are many studies on the beneficial effects of applying sewage sludge to herbaceous plants. These studies show that treatment sludge application improves the physical, chemical, and biological properties of the soil.

It is important that the herbaceous species to which the waste sludge will be applied should be bio-accumulator plants to tolerate the heavy metal species in the sludge more easily. The tolerance level of each plant towards heavy metal in the sludge content varies. It means that a plant has a high bio accumulator feature. That is, that means that use of chemicals such as heavy metals (manganese, zinc, chromium, copper, lead, nickel, and cobalt cadmium) in the waste sludge at a minimum level and maximum use of the fertilizer feature of the waste sludge.

The fact that some of the sewage sludge has properties that adversely affect the environment and human health, in addition to its agriculturally positive qualities, prevents the uncontrolled use of waste sludge in agricultural areas. The first negative effects; Manganese, zinc, chromium, copper, lead, nickel and cobalt heavy metals such as cadmium, salts and pathogenic microorganisms include toxic organic chemicals. On the other hand, since the treatment sludge cannot be obtained homogeneously on a continuous or regular basis, it is prevented to use it directly or to create a product by converting it into commercial material. In short, the fact that the properties of the sludge obtained from different facilities are different can also change the contribution of the sludge to the yield and the possibilities of use. For this reason, before the treatment sludge is given to the soil environment, its content properties must be determined by analyzing it, and in this direction, the most appropriate doses of treatment sludge with different properties should be determined by applying them to different soils (Çakır, 2018).

Diplotaxiserucoides In a study investigating the effects of sewage sludge and mineral fertilizer applications on plant growth, it was determined that there was an increase in biomass in plants treated with sewage sludge compost and the plant formed a larger root system, but flowering was delayed (Korboulewsky *et al.*, 2002)

In a study done Its contribution to plant yield and growth was investigated in Limoniumsinuatum ‘Compindi White’ species. Treatment sludge was added to the growing media; There was a significant change in root lengths and number of flowers per plant by 95%, and the number of leaves and stems by 99% on the wet weight of the upper part of the plant (Akat *et al*., 2015).

Bozkurt *et al*. (2001) In their study on the use of urban sewage sludge as a nitrogen source in winter barley, compared inorganic nitrogen fertilizer and sewage sludge and found that nitrogen content and uptake in the plant increased in all applications compared to the control, this increase was higher in sewage sludge applications. Fe, Mn, and Cu concentrations increased, but only Zn and Cu amounts of purification in the soil and stated that they remained below the toxic level.

In a study conducted; In order to determine the cultivation possibilities of ornamental cabbage plant in sewage sludge, as a growing medium; 0% sewage sludge + 100% soil medium (S1), 25% sewage sludge + 75% soil medium (S2), 50% sewage sludge + 50% soil medium (S3), 75% sewage sludge + 25% soil medium (S4) and 100% sewage sludge + 0% soil medium (S5) were used, and the plants were grown in pots in an open field. Without trying; Parameters such as pH, EC, root weight, stem diameter, root length, plant diameter, plant height, head weight and total number of leaves were reached. The highest head weight and the total number of leaves were obtained from the living environments created with the ratios of S2 (103.99 g, 40.42 pieces) and S5 (90.53 g, 38.42 pieces) (Akın, 2018).

In another study, the effects of waste sludge on the growth parameters of the corchorus plant were investigated and its positive effects were observed. During the sludge applications, the effects on the soil after plant harvest were also investigated and it was determined that there was an increase in the amount of organic matter and a decrease in the pH value from 8.33 to 7.61. It has been determined that the amount of toxic and heavy metals accumulated in the plants is well below the limit values, and it has been shown that the waste sludge can be safely applied to the corchorus plant (Eid *et al.,* 2020).

In a recent study, the development of the plant and heavy metal uptake were observed by giving the waste sludge and a different soil type in different proportions to the growth medium of the carrot plant. Results showed that sludge application significantly affected soil pH, organic matter (OM), electrical conductivity (EC), potassium (K) and available phosphorus (P). Due to the treatment sludge application, the content of heavy metals such as lead (Pb), cadmium (Cd), nickel (Ni) and chromium (Cr) increased in the soil and plant. Carrot growth was positively affected by the treatment sludge application. It was recorded as maximum fresh weight (66.3 g plant-1) in 30% sludge application and maximum dry weight (5.61 g plant-1) in 50% waste sludge application (Nahar *et al.*, 2020).

In a study in which the waste sludge application was given to the growth pot medium of the tomato plant at certain rates; fruit mass was determined at the highest level in pots treated with 20% mud compared to all treatments. Yield of tomato fruit in order; control was determined as <10%<30%<20%. The lack of sufficient nutrients in the control and 10% mud pots retarded the growth of the tomato, while the toxicity that increased with the increase in the 30% mud applied pot suppressed the growth of the tomato. The development of the pot with 20% mud applied was optimum (Elmi *et al.*, 2020).

In a study that is an example of the application of waste mud to ornamental plants; Waste sludge was applied to the ornamental plant species Clarkia amoena (Ground azalea) with increasing doses. With the application of wastewater treatment sludge, shoot length and number of flowers per plant were affected at 1% significance level, while root length was affected at 5% significance level. The highest values of shoot length (36.90 cm) and root length (19.25 cm) were determined by soil material + 75% wastewater treatment sludge mixture, the highest value for flower number (253 pieces/plant) was soil material + 25% wastewater treatment sludge mixture. has been reached. The lowest values were obtained from the soil material that did not use wastewater treatment sludge, which is the control medium, as expected, with 32.44 cm in shoot length, 133 units/plant in flower number and 16.25 cm in root length (Demirkan, 2014).

In most of the studies, it has been determined that the application of sewage sludge to herbaceous plants improves the plant positively, reduces the flowering period of flowering plants, and increases the number of flowers. However, in these applications, the type of plant, the content of the waste sludge to be applied and the application dose are important. For this reason, first of all, these applications should be done in the micro area and according to the results, they should be applied in the macro areas.

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CHAPTER 4

ADSORBENTS USED FOR THE REMOVAL OF DYE

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INTRODUCTION

The adsorption process continues to maintain its importance for ease of use, functionality, and low cost in various sectors within the treatment processes. As a matter of fact, scientific studies on adsorption processes support this argument. Direct discharge of dyestuffs to the receiving environment affects the living life negatively. It is known that it even causes the death of living things in the environment. Therefore, it is essential to remove the dyestuffs. Various methods are used for dye removal.

These methods are divided into three parts. First, in chemical methods; electrochemical methods, ozonation, Fenton reagent method, oxidation, chemical precipitation, flocculation and cucurbituril treatment. Secondly, physical methods include adsorption, membrane separation, and ion exchange methods. Finally, biological methods are divided into aerobic, anaerobic and biosorption. The adsorption process is a widely used technique for removing dyestuffs from wastewater generating high-quality wastes (Rozada *et al.*, 2003). When scientific studies with adsorption method are examined, it is seen that experiments are made on dyestuffs depending on the adsorbent types, and positive and negative results are obtained.

ADSORPTION

The process of attaching atoms, ions or molecules to a fixed surface is called adsorption. The adsorption process was first observed in gases by the Swedish C.W. Scheele in 1773 and in liquids by the Russian scientist J. T. Lowitz in 1785. The fixed surface is called adsorbent, and the adherent material is called adsorbate. While choosing the adsorbent, it is expected that it will be environmentally friendly, recyclable, easy to obtain, have a stable form and a large surface, and also have a low cost (Balcı, 2018).

Adsorption Mechanism

The adsorption process on the solid surface takes place depending on the diffusion kinetics. The diffusion process that occurs due to the concentration change can occur in three ways:

- Film diffusion: The solute molecules that are desired to be adsorbed creates a surface film by entering the adsorbent in solution.

- Pore diffusion: It is in the form of attracting molecules towards the adsorption center in the adsorbent pores.
- In the event of adherence of solute molecules to the adsorbent surfaces, the bonding and adherence events between the solute molecule and the pore surface of the adsorbent are completed by following all these steps.

Apart from the diffusion phenomenon, it is also possible for the molecules to adhere to the surface of the substance with the effect of adhesion forces. Molecule adsorption is mainly related to film diffusion, pore diffusion and adhesion forces (Yener, 2004). Figure 1 shows the adsorption mechanism.

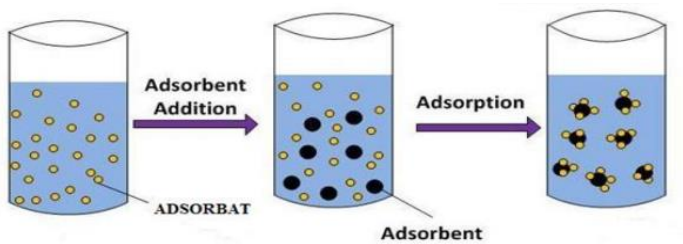

Figure 1: Adsorption mechanism (Çiftçi *et al.*, 2016)

As shown in Figure 1, the adsorption of the adsorbate from the solution by the adsorbent takes place in four stages:

1. Transport of adsorbate in solution,
2. Transport to the film layer round the adsorbent of the dissolved part from the solution,
3. Transport to the adsorbent surface from the film layer,
4. Transport to active areas in the interior from the surface, settlement in pores (Kıvanç, 2011).

Parameters Influencing Adsorption

The parameters that directly influence the adsorption process are generally surface field, construction of the adsorbent, pH, temperature, and mixing speed (Hema *et al.*, 2007).

Surface area and adsorption capacity vary in direct proportion. The small particle size, large surface field and poriferous structure of the adsorbent increase the adsorption capacity (Koçer, 2013).

The construction of the adsorbent directly affects the adsorption course. The chemical structure of the adsorbent, the functional groups on its surface, the interactions of these groups with the adsorbate and the electric field are very important during adsorption.

pH is effective in determining the surface properties of an adsorbent besides the degree of ionization of the molecule (Yagub *et al.,* 2014; Nandi *et al.,* 2009). Therefore, the initial pH of a solution is the factor influencing the capacity of an adsorbent in water purification. In addition, the dependence of adsorption on pH is related to the ionization state of the metal and adsorbent functional groups in the solution (Yagub *et al.*, 2014).

Another parameter affecting adsorption is temperature. Generally, the adsorption efficiency increases with increasing temperature. However, if the adsorption happens in exothermic conditions, the adsorption yield decreases as the temperature increase will decrease the amount of adsorption. It can be said that the adsorption processes in the literature are generally exothermic processes (Parlayıcı, 2016).

The mixing speed in the adsorption operation indicates whether the bonding among the adsorbent and the adsorbate in the aquatic environment will form a physical or chemical bond. While there is a decrease in the adsorbent's adsorbent capacity at extremely fast and slow mixing speeds, high yields are obtained at appropriate mixing speeds (Edik, 2016).

ADSORBENTS

Adsorbents are leaving in two as natural adsorbents and artificial adsorbents according to their types (Figure 2).

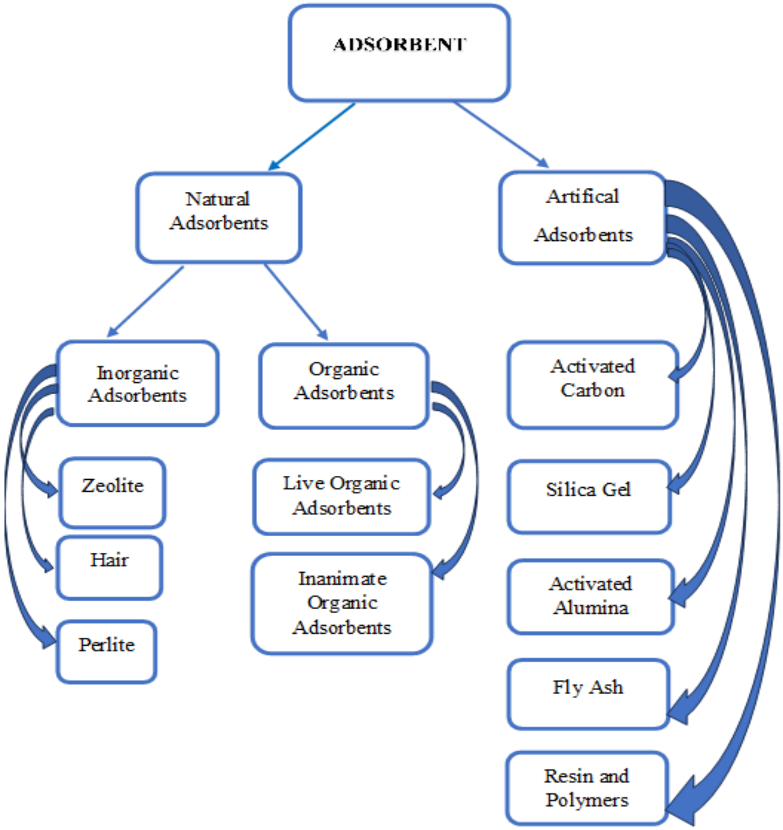

Figure 2: Classification of Adsorbents

Natural adsorbents are structurally;

- Inorganic adsorbents
- They are classified as organic adsorbents.

Examples of inorganic adsorbents are zeolite, clay and perlite. Organic adsorbents are basically divided into two as living organic adsorbents and inanimate organic adsorbents. While microorganisms are found in living organic adsorbents, there are used cellulose, chitosan, tree bark, sawdust, resin, hard fruit peel and seed pulp, agricultural peel wastes, fruit vegetables, high temperature furnace slag, fertilizer, domestic wastes in inanimate organic adsorbents (Demir *et al.*, 2014).

The use of natural adsorbents is common due to the low amount of waste generated after the adsorption process, the ease of obtaining them, and the features of processing without the need for pre-treatment. However, the disadvantage of natural adsorbents is that they are not suitable for all materials.

Artificial adsorbents are substances that have high production costs and can have toxic effects. In recent years, many cheap and environmentally friendly adsorbents have been produced (Abas *et al.,* 2013; Mohan *et al.,* 2017).

Activated carbon, silica gel and activated alumina, fly ash from industrial wastes, as well as resin and polymers are the most widely used commercial adsorbent types.

MATERIALS USED AS ADSORBENTS

In scientific studies, studies on adsorbents converted into activated carbon attract attention. The strong chemical stability and low density of activated carbon-based adsorbents also explain the reason why they are preferred (Dutta *et al.,* 2021).

It has been observed that activated carbon-based adsorbents are examined in two separate classes: activated carbon obtained from waste materials and mercantile activated carbon. Activated carbons obtained from various fruit and vegetable peels are classified as activated carbon obtained from waste materials. Adsorbents used only for dye removal without considering the evaluation and examination of waste material are included in mercantile activated carbon. Mercantile activated carbon-based adsorbent studies conducted in recent years were examined.

In his study in 2019, Marahel developed an adsorbent based on tin sulfide nanoparticles coated with new activated carbon to remove methylene green from wastewater. It was stated in the study that the adsorption kinetics was in accordance with pseudo-second order kinetics. As an isotherm pattern, its suitability for the Langmuir isotherm has been determined. It was stated that the maximum adsorption capacity was 14.22 mg/g for 0.2 g [SnS-NP-C] (Marahel, 2019).

The research carried out by Rahman in 2021, he examined the removal of methylene blue dye from the environment utilization activated carbon synthesized from acorns and observed an adsorption efficiency of 97.18% (Rahman, 2021).

In the study conducted in 2022, activated carbons obtained from cherry pits were investigated. Mercantile activated carbons Merck-2514 and Merck-2184 were used for comparison. Methylene blue, Victoria blue, orange-II was chosen as dyestuffs. After a 4-hour activation, it was observed that the activated carbons obtained from sour cherry pits were close to the adsorption levels of mercantile activated carbons. It has been stated that the micropore size of the adsorbents is 1.5 nm (Güzel *et al.*, 2022).

Activated carbon studies obtained from waste materials are generally activated carbon studies obtained from tea, safflower seed wastes and various vegetable and fruit peels.

The adsorbent obtained from the seed wastes of moringa, which is generally consumed as tea, was used in the scientific study (Raji *et al.*, 2022). As a result of the study, it was determined that moringa seed wastes could be used in the adsorption process and it was specified that it complied with the Langmuir isotherm.

Angın *et al.*, who used Safflower seed meal in their study, preferred Levafix Red as dyestuff. In order to increase the adsorbent capacity, safflower seed meal was turned into activated carbon and the study was examined. When the results were examined, it was stated that it could be used as a low-cost adsorbent in dye removal (Angın *et al.*, 2013).

Methylene blue dyestuff was examined in the study using adsorbent obtained using only pyrolysis, KOH/pyrolysis and H_3/PO_4 pyrolysis methods of 3 different activated carbon samples made from walnut shell raw material. It has been concluded that the adsorbents are suitable for the adsorption process (Li *et al.*, 2020).

As a result of the pyrolysis of activated carbon created by pyrolysis of rice husk at diverse temperatures, it was determined that the methylene blue adsorption capacity was 95% (Lemos, 2019).

In the study examining the adsorbing effect of the adsorbent formed from the perlite wastes entering the artificial adsorbent on the methylene blue dyestuff, suitable conditions were created for adsorption. The findings determined that perlite wastes can be used as adsorbent and comply with endothermic conditions (Selengil *et al.,* 2022).

The adsorption capacity on the orange G dyestuff, an adsorbent of peanut shells obtained from activated carbon, was investigated. As a result of the study by Kızıltaş *et al.,* it was determined that peanut shells met the conditions of use as an adsorbent (Kızıltaş *et al.,* 2022).

In the investigation led by Tünay *et al.,* waste sludge produced after the electrocoagulation system was used as adsorbent. Three different dyestuffs, viz Yellow HE4R, Crimson HEXL and Remazol Black 5, were used for the study. 88% color removal was obtained in three types of dyestuffs (Tünay *et al.,* 2012).

In the study where malt meal obtained from the brewery was used as an adsorbent, reactive red 24 dyes the removal efficiency of methylene blue was examined. In the study, pH 7 was determined for methylene blue and pH 1.5 for reactive red 24 dye. It was determined that both adsorption processes fit the Langmuir isotherm and pseudo-second-order kinetic model (Ay *et al.,* 2023).

In the study where sugar bagasse-based biocomposites were used as adsorbents, the obviation of acid red 1 dye was examined. Under the determined optimum terms, the temperature was determined as 30°C, pH was 2 and the amount of adsorbent was 0.05 g. As a result of the adsorption process, it was finalized that biocomposites can be used as adsorbents (Kamran *et al.,* 2022).

Fish wastes obtained from restaurants or fishermen are also one of the most used adsorbents for dye removal. Various fish species have been the subject of scientific studies.

Figueirodo et al. carried out adsorption experiments with anodonta shell, sepia and squid wastes obtained from the seafood industry. They used CI reactive green 12 and CI direct green 26 as dyestuff. As a result of the experiments, it was determined that the fish waste with the top adsorbent capacity was squid, followed by sepia and anodonta, respectively (Figueirodo *et al.,* 2005).

Fish bones obtained from the fisherman's shop in Iran were used as adsorbent. CI Basic Yellow 28 (BY28) and CI Basic Blue 41 (BB41) were provided as dyestuffs. As a result of the adsorption process experiments, 75% removal efficiency was obtained for both dyestuffs (Ebrahimi *et al.*, 2013). Examples of adsorbent studies related to the adsorption method are given in Table 1.

Table 1: Sample studies on dyestuff removal by adsorption method

Adsorbent used	**Dyestuff**	**Removal Yield (%)**	**Source**
Natural Clay	Methylene blue	94.69	Bingul, 2022
Mucor Circinelloides	Reactive Orange 13	95,765	Celik *et al.*, 2021
Metal Oxide Nano Particles	Congo red	79-86	Liu *et al.*, 2019
Gum Tree Leaves	rhodamine B and ethyl violet	88	Bensenane *et al.*, 2021
Fruit Stalks	crystal violet	96	Takabi *et al.*, 2021
Sugar cane	Methylene blue	98.32	Andrade Siqueira *et al.*,2020
Raw Corn Cob	Bromophenol blue and bromothymol blue	96.53, 94.39	Abubakar *et al.*, 2019
Activated ZnO Particles	Methylene blue	99	Kamaraj *et al.*, 2020
Double hydroxide supported metal frame with MgAl layer	Methylene orange	99	Chakraborty *et al.*,2013
Treptacantha barbata	Methylene blue	69-100	Ucuncu *et al.*, 2022

FUTURE PERSPECTIVE

It is clear that the discharge of dyestuffs into the receiving environment will cause adverse conditions for the living creatures in the environment. For example, if the receiving environment is a water source, it is clear that it will reduce the light transmittance on the surface of the water and accordingly reduce the oxygen level in the water. Depending on these conditions, it is inevitable that the creatures living in the water source will lose their lives in a short time. In addition, all macro and micro living things fed from the water source will transfer the toxic substances they have taken into their body with the food chain from the living thing to the living thing and the toxic accumulation will increase day by day.

Since it is known that there is not a single sample, it is clear that problems should be reduced depending on each different discharge environment. For this reason, the introduction of dyestuffs into the receiving environment without any treatment should be prevented.

It is known that there are different methods for the removal of dyestuffs, but it is used in scientific studies due to the advantages of adsorption.

When the literature studies are examined, it is seen that many types of adsorbents from natural and artificial adsorbents are examined. It can be said that in order to realize the sustainability of the studies, new ones should be added to the existing studies.

In the current studies, it is thought that the adsorbents were selected due to the abundance of vegetables, fruits and flower seeds, and also based on the geographical conditions in which the study was carried out.

As a matter of fact, economy and easy availability are at the forefront of the materials that are considered when choosing adsorbent. It is noteworthy in scientific studies that the adsorbents obtained from fish bones are not carefully selected and the waste fish bones are collectively made. Specific species of fish species should be selected, adsorption studies should be continued and the gap in the literature should be filled. There are studies with fish waste bones in scientific studies, but they are insufficient.

In scientific studies, especially methylene blue is used as a dyestuff. The easy availability of methylene blue can be said as a reason.

It is thought that studies should be increased due to the development of both dyestuff diversity and adsorbent types.

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CHAPTER 5

AN OVERVIEW OF THE USAGE OF MXENES IN ENVIRONMENTAL REMEDIATION APPLICATIONS

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INTRODUCTION

The rapid increase in industrialization activities on a global scale brings with it the problem of rapid and uncontrolled release of many different pollutants that cause air, water, or soil pollution. The release of these pollutants significantly increases concerns over environmental sustainability. Industrial wastewater discharged into receiving environments without being subjected to any treatment process is one of the significant sources of the environmental pollution we are exposed to today. Industrial wastewater, released from various industries such as textile, leather, dyeing, printing, plastic, food, and medicine, contains enormous amounts of toxic matter, such as pesticides, dyestuffs, and heavy metals.

Generally, environmental pollutants are divided into two separate classes: organic and inorganic. When the characteristics of wastewater are surveyed today, it is seen that pharmaceutical residues, dyes, toxic heavy metals, and some toxic chemicals are the primary sources of water pollution. Therefore, developing new methods for removing these pollutants with an effective, safe, low-cost, practical, and environmentally friendly approach before they are discharged into the receiving environment or updating existing methods with new technologies should be a priority goal for scientists working in this field.

For this purpose, today, water purification methods, such as adsorption, advanced oxidation processes (AOPs), and membrane separation, are the most popular technologies to capture, isolate, degrade, and detect environmental pollutants and toxic chemicals. These methods are considered practical and low-cost environmental remediation technologies. However, new materials need to be developed for these processes. Layered and two-dimensional nanomaterials such as graphene, graphene oxide, boron nitride, and metal-organic frameworks (MOFs) have been spread to applications aimed at environmental improvement due to essential properties, such as their layered structures, large surface areas, high chemical activity, mechanical flexibility, ease of functionalization (Rasool *et al.*, 2019; Huang *et al.*, 2019).

Various studies have been dedicated to the usability of materials such as polymers, wastes, natural materials, nanostructures, carbon-based materials, metals, and metal oxides as adsorbents, photocatalysts, or sensors for these technologies. (Fanourakis *et al*., 2020). Another material class that has recently found widespread use for this purpose is the MXene family. MXenes, one of the newest members of the two-dimensional materials, are seen as promising materials for solving environmental problems. Recent scientific studies have reported that MXenes have a significant potential for removing many pollutants (inorganic or organic), especially organic dyes, pharmaceuticals, radionuclides, and heavy metals. Moreover, it is reported in some studies that MXenes can effectively neutralize microorganisms without causing additional harm to the environment.

MXenes and General Characteristics

MXenes are nanomaterials consisting of two-dimensional transition metal carbides, nitrides, and carbonitrides that have attracted much attention recently. They were first discovered in 2011 by researchers at Drexel University. Since their discovery, these materials have been used for different purposes in various applications with unique properties and have been the subject of extensive scientific research.

MXenes have a layered structure similar to graphene, another important 2D nanomaterial. The molecular structure of MXenes usually consists of transition metal atoms (M) stacked between two layers of carbon or nitrogen atoms (X). The general chemical formula of MXenes is $M_{n+1}X_nT_x$. Where "n" indicates the number of transition metal layers and "T_x" represents surface functional groups such as hydroxyl (-OH) or fluorine (-F).

MXenes are usually synthesized via selective etching of the "A" layer (usually aluminum) from the corresponding MAX phases (e.g., Ti_3AlC_2).The etching process results in a layered structure consisting of stacked sheets with a chemical structure of $M_{n+1}X_nT_x$. Although methods such as acid treatment or electrochemical etching are generally preferred in MXene synthesis, new and more environmentally friendly alternative methods continue to be investigated.

MXenes exhibit essential properties such as good electrical conductivity, mechanical strength, thermal stability, and high surface area. Thanks to these properties, they find applications in various applications. Moreover, MXenes are also known for their ability to store and intercalate ions. These properties make them potential materials for energy storage devices such as supercapacitors and batteries. The etching process results in a layered structure consisting of stacked sheets with a chemical structure of $M_{n+1}X_nT_x$. Although methods such as acid treatment or electrochemical etching are generally preferred in MXene synthesis, new and more environmentally friendly alternative methods continue to be investigated.

While MXenes were first used in energy storage applications, today, they are widely used in various fields such as chemical catalysis, sensors, and water treatment applications. In addition, they are also known to be used for specialized applications such as anode material for lithium-ion batteries, catalysts for water separation, and electromagnetic shielding in aviation.

One essential feature that makes MXenes unusual materials is their easily tunable surface properties. Changing the type of transition metals in their structure, surface functional groups and number of layers makes it possible to customize them according to the intended use. Thanks to these variations, it is possible to synthesize specific MXene structures for many applications.

Despite their extraordinary properties, some challenges must be overcome for MXenes to find more widespread use. For example, their stability in water and possible effects on human and environmental health have not yet been fully clarified. Therefore, many scientific studies should be carried out on these materials in the future.

With their inherent chemical properties, high hydrophilicity, and strong electrochemical properties, MXene-based materials are considered attractive for environmental improvement technologies such as adsorption, sensors designed for pollutant detection, membrane separation, photocatalysis, and electrocatalysis. Since the performance of MXene-based materials in these technologies is still in a continuous development process, many new scientific studies are estimated to be conducted in the near years on the development of the diversity, chemical abilities, and surface properties of MXenes and composites created by hybridizing them with various materials.

The Synthesis of MXenes

To examine the usability of MXenes in removing environmental pollutants, they were used for various purposes in various environmental applications, and their activities were tested. The synthesis of MXene compounds is based on the selective etching of component "A" from an MAX phase compound. Hydrofluoric acid (HF), known for its strong etching effect, is generally used for etching (Naguib *et al.,* 2011). It is known that MAX phases with different chemical compositions exist. Many researchers have confirmed that MXene species can be synthesized from almost all MAX phases, the A phase of which is Aluminum, by the method based on HF etching. On the other hand, since HF is highly corrosive, it necessitates the development of new, greener, and environmentally friendly methods for producing MXenes. The broader usage of MXene compounds in environmental applications is only possible if these materials can be produced more environmentally friendly and at lower costs. Accordingly, in the selective etching of the Al phase, which is the first and fundamental step in MXene synthesis, studies are being carried out to develop new abrasives that can provide etching and delamination simultaneously instead of the dangerous and highly corrosive hydrofluoric acid.

MXenes for Environmental Applications

MXenes have attracted the attention of researchers with their usability for different purposes in solving various environmental problems, like many other two-dimensional materials. In many scientific studies conducted for this purpose, promising results have been obtained for the future. It is possible to examine the usage purposes of MXenes in environmental applications under various headings, such as water treatment, chemical catalysis for water treatment, sensors for environmental monitoring, membrane technologies, and air purification.

As mentioned before, MXenes are known to have very high surface areas and active surface functional groups. Thanks to these properties, they offer excellent adsorption potential. It is known that various heavy metals, organic pollutants, and some ions can be effectively removed from water by adsorption with MXenes.

On the other hand, MXenes have the potential to be used as catalysts in various water treatment processes. In some studies, MXenes are known to be used as catalysts in various advanced oxidation processes, such as Fenton, photo-Fenton, or photocatalysis, for the degradation and removal of organic pollutants. In addition, MXenes are also known to be used as catalysts in some electrochemical processes. Moreover, the electrical conductivity and surface reactivity of MXenes make them a potential material for developing sensors to detect environmental pollutants and contaminants. Thanks to MXene-based sensors, real-time monitoring of gases, heavy metals, and other pollutants in air or water could be possible.

MXenes also have significant potential in membrane processes thanks to their layered structure. MXenes, when combined with suitable catalysts or semiconductors, can be used as photocatalysts in photocatalytic processes designed for air purification. In this way, green pollutants such as volatile organic compounds (VOCs) and nitrogen oxides (NOx) in the air under sunlight or UV radiation can be decomposed and eliminated.

MXenes have extraordinary properties, such as high electrical conductivity, redox activity, adjustable surface chemistry, and superior water dispersibility. These properties make MXenes preferable for environmental purification technologies such as membranes, adsorption, photocatalysis, or chemical sensing of various pollutants (Chertopalov & Mochalin, 2018).

The surface functionalities of MXene-based materials can significantly affect the performance of these materials in applications carried out by direct surface interaction, such as adsorption or membrane separation. At the same time, there is a strong relationship between surface functionalities and these materials' physical and chemical properties.

Unlike graphene, another essential member of the two-dimensional materials family with relatively lower hydrophilicity, MXene-type materials offer higher hydrophilicity and chemical activity in ion exchange or redox-based processes thanks to their surface functionality. Moreover, when the high surface areas resulting from the 2D structure are combined with the strong redox ability, these properties turn MXene-based materials into a crucial alternative material that can be used as photocatalysts and electro-catalytic sensors, especially for the degradation and detection of environmental pollutants (Schultz *et al*., 2019; Li & Wu, 2019).

The rapidly increasing use of MXene-based materials in environmental remediation and sensing technologies requires a clear and explicit demonstration of the surface properties of these materials and their effects on the performance of the hybrids they form with other materials. This book section aims to discuss MXene-based electro-catalytic sensors, designed for the qualitative and quantitative detection of various toxic chemicals, the usability of MXenes and their hybrids in a wide range of environmental remediation applications ranging from adsorption and membrane separation to photocatalysis, and possible future developments in this regard.

Although MXenes have a significant potential for environmental applications, more research is needed in this field. Almost all of the studies on this subject are still at the laboratory scale. In the coming period, large-scale studies should be carried out, and the activities of MXenes in natural wastewater treatment processes should be comprehensively investigated. Therefore, MXenes are expected to be increasingly important in solving environmental problems shortly.

MXenes in the Removal of Pollutants by Adsorption

Adsorption is known as the most widely used technique in environmental remediation processes. It is possible to remove various pollutants in air and water environments simply and effectively by adsorption. MXenes exhibit good adsorption properties with high surface areas and adjustable surface chemistry by changing the surface functional groups. These properties allow MXene and MXene-based composite adsorbents to absorb and remove various pollutants from water and air environments.

Many studies have been carried out on the adsorptive properties of MXenes. These studies have reported that a wide range of pollutants, such as heavy metals, organic pollutants, dyes, and ions, are effectively removed from water.

It is estimated that the high performance of MXenes in adsorption processes is due to the electrostatic interactions arising from the high surface areas of these materials and surface functional groups such as -OH and -F on their surfaces. MXenes exhibit a highly effective adsorption behavior in removing some heavy metal ions by adsorption. MXenes especially adsorb toxic heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and chromium (Cr) and prevent their release into ecosystems and thus have a substantial potential to reduce environmental risks caused by heavy metal pollution significantly. On the other hand, the adsorption ability of MXenes is not limited to the adsorption of heavy metals. MXenes have a substantial adsorption potential in removing a wide range of organic or inorganic pollutants, such as pharmaceuticals, pesticides, industrial chemicals, and radionuclides in water or wastewater.

Although using MXenes as adsorbents for environmental applications promises excellent prospects, a cost-effectiveness evaluation should be carried out by considering factors such as regeneration and reusability to be applicable in natural wastewater. In addition, further research should be carried out on optimizing operating parameters. Ongoing research and development studies in this field are critical in revealing the current potential of MXenes in improving environmental quality and reducing pollution problems.

MXenes have a significant potential to reduce the presence of a wide variety of pollutants of organic or inorganic origin in natural water bodies or the air and thus provide safe drinking water sources and clean air for future generations.

Dyes, an indispensable component, especially in the textile, metal, automotive, paper, and printing sectors, seriously threaten the ecosystem when mixed with water and can cause unusable water pollution. Therefore, regarding environmental improvement, wastewater containing dyestuffs must be treated effectively before being discharged into the receiving environment. To date, many new materials and methods have been developed for degrading dyestuffs from wastewater. Adsorption, one of these methods, has become the most preferred method due to its low cost and simple applicability. There are many materials currently being used as adsorbents. However, studies continue to develop new materials for more effective and selective removal. In this context, the usability of MXenes as adsorbents is a subject of interest. To date, many scientific studies have been conducted showing that MXene-type materials have the potential to be an ideal adsorbent material for the removal of dyes from wastewater due to their unusual properties such as their high specific surface areas, negatively charged surfaces, lamellar structures, and highly hydrophilicity. The usage of MXenes in removing dyestuffs will continue to be a subject of interest to researchers in the future. Many details need to be investigated, especially regarding the selective removal of different types of dyestuffs by changing the surface charge of MXenes.

The first study examining the usability of MXene compounds with a multilayer structure as adsorbents for dye removal was carried out by Mashtalir et al. (Mashtalir et al., 2014). This study investigated the adsorption behaviors of Methylene blue (MB) and Acid blue 80 (AB80) dyes on multilayer $Ti_3C_2T_x$ type MXene compounds. Methylene blue is a cationic dye, while Acid Blue 80 is an anionic dye. In this study, the adsorption capacity of methylene blue on MXene was defined as ~39 mg/g, whereas Acid Blue 80 dye was almost not adsorbed. The adsorption of methylene blue but not Acid Blue 80 points to electrostatic interactions between the surface of the MXene compound and the dyes.

In a study carried out by Peng et al. (Peng *et al*., 2018), the researchers proposed a new method to synthesize Ti_3C_2 and Nb_2C-type MXene compounds. Accordingly, researchers used Ti_3AlC_2 and Nb_2AlC compounds as MAX phase precursors to produce MXene. Here, unlike the traditional approach, instead of directly adding hydrofluoric acid to chemically etch the MAX phase precursors, they applied the solvothermal method by adding $NaBF_4$ and HCl to the medium and synthesized the required hydrofluoric acid (HF) in situ. The researchers report that MXenes produced by this method have a higher specific surface area than MXenes produced by the conventional HF etching method. In adsorption experiments with methylene blue, the researchers reported a high adsorption capacity (189 mg/g) for h-Ti_3C_2, whereas they observed a relatively weaker adsorption capacity for h-Nb2C.

Cai et al. [Cai *et al.*2020] transformed the MXene compound in the form of a 2-dimensional (2D) Ti_3C_2Tx type sheet into a rod-like structure by treating a raw MXene type compound, which has not been subjected to any treatment yet, with Phytic acid (PA) under hydrothermal conditions. Here, while the hydrothermal reaction time transformed MXene into a rod-like structure, Phytic acid contributed to obtaining an amphiphytic (containing hydrophilic and hydrophobic groups together) structure due to the interactions between them and the surface groups. In adsorption experiments in which PA-MXene composite was used as adsorbent and Methylene Blue (MB) and Rhodamine B (RhB) dyes were used as pollutants, adsorption capacities were determined as 42 and 22 mg/g, respectively, even after 12 consecutive adsorption cycles. Moreover, researchers have reported that removal efficiencies were observed as 85% and 84%, respectively.

Heavy metals in water or wastewater are important pollutants due to their substantial toxicity and chemically stable nature. Even prolonged exposure to low concentrations of heavy metal ions can be highly hazardous. Therefore, these substances must be removed quickly and effectively from heavy metals wastewater. For effective removal of heavy metals in wastewater, methods such as chemical precipitation, filtration, adsorption, and electro-dialysis are widely applied (Caroline *et al.,* 2017). Since minimal amounts of heavy metals can cause significant toxicity, they must be removed from water, even if minimal concentrations (ppm to ppb). However, removing these pollutants in minimal concentrations is not easy. Biological treatment processes or chemical treatment methods are generally ineffective at low concentrations. When the studies carried out to date on this subject are examined, it is seen that adsorption is the most effective method for removing low-concentration heavy metals. Based on this information, there is a need to develop effective and low-cost adsorbent materials to remove heavy metal ions with ppb concentrations from wastewater. It is known that MXenes have affluent functional and large surface areas. Therefore, MXene-based materials and their derivatives are seen as potential adsorbents for removing heavy metal ions from wastewater by adsorption. Some studies on this subject show that MXenes exhibit outstanding performances in the adsorption of various heavy metal ions.

In another study, a standard MXene compound with $Ti_3C_2T_x$ structure was used as an adsorbent to remove copper ions from aqueous solutions (Shahzad *et al.,* 2017). Researchers have reported that the delaminated MXene compound was highly influential in Cu^{2+} adsorption. It is known that separating the layers in MXene compounds significantly increases the specific surface area of the material and, therefore, significantly increases the adsorption capacity. Adsorption experiments were performed with $Ti_3C_2T_x$ compound with separated layers (delaminated) and multilayered (undelaminated) $Ti_3C_2T_x$ compound. In these experiments, they reported that the separated $Ti_3C_2T_x$ compound displays a higher and faster adsorption behavior than the multilayered $Ti_3C_2T_x$ compound. Researchers report that approximately 80% of the Cu^{+2} ions in the solution could be removed within 1 minute, and adsorption capacity was defined as 78.45 mg/g.

In a study conducted by Ying et al. (Ying *et al.,* 2015), an MXene-based material was used as an adsorbent for the removal of chromium Cr (VI) ions, which are considered one of the critical water pollutants with strong toxic and carcinogenic properties. The researchers used a two-dimensional $Ti_3C_2T_x$ type MXene for this purpose. The researchers used HF (10%, w/w) solution to separate the MXene layers. Moreover, the adsorption capacity for Cr (VI) adsorption onto $Ti_3C_2T_x$ nanosheets was defined as 250 mg/g. Researchers report that the adsorption efficiency largely depends on the MXene compound's structure and the medium's pH value. Additionally, it has been stated that charge interactions between positively charged chromium and MXene can be quite effective on adsorption.

Pandey et al. (Pandey *et al.,* 2018), $Ti_3C_2T_x$ type MXene was used to remove bromate ions (BrO_3^-), whose toxic effects in aqueous solutions are well known. The researchers reported that the BrO_3^- ions reduction performance of $Ti_3C_2T_x$ nanosheets was significantly affected by operational parameters such as MXene concentration, pH, temperature, and contact time. It was reported that bromate ions in solution were removed entirely within 50 minutes (~321.8 mg/g) at optimum conditions defined in the study, at pH seven and 25°C.

As a result of nuclear activities such as nuclear power plants, scientific research centers, or mining activities carried out to produce radioactive substances, wastewater containing various levels of radioactive substances is generated. The radioactive ions in these wastewaters reaching the soil and water resources pose a significant environmental threat. Therefore, treating this wastewater effectively and efficiently is vital for environmental sustainability. It has been evaluated that MXene class materials have a significant potential for the adsorption removal of radioactive substances in wastewater with their surface capabilities and adjustable adsorption properties. Promising results have been reported in many studies conducted for this purpose (Rahman *et al.,* 2018; Hwang *et al.,* 2020).

In some other studies, MXene or its derivatives were also used in the treatment of wastewater containing radioactive substances such as Re (VII), Th (IV), and Eu (III). Wang et al. examined the adsorption of radioactive Re (IV) from wastewater on an MXene-based material (Wang *et al.,* 2019). The three-dimensional (3D) MXene-polyelectrolyte nanocomposite was produced to adsorb perrhenate ion (ReO_4^-) in aqueous solutions. For this purpose, PDDA (poly diallyl dimethylammonium chloride) was added to a Ti_2CT_x type MXene compound, thus rearranging the surface charge of the MXene compound and increasing its stability. The researchers reported that the Ti_2CT_x/PDDA composite they produced removed Re(VII) ions with very fast adsorption kinetics and high selectivity in an aqueous solution environment containing Cl^- and SO_4^{2-} anions at a concentration approximately 1800 times higher than the concentration of Re(VII) ions. In this study, the adsorption capacity was defined as 363 mg g^{-1} in the experiment performed under optimum conditions.

In a study conducted by Li et al. (Li *et al.,* 2019), the usability of a Ti_2CT_x type MXene as an adsorbent in Th(IV) removal by adsorption method was examined. For this purpose, two types of MXene were prepared: dry and hydrated. Here, it has been observed that MXenes prepared in hydrated form provide better removal. Researchers report that the experiment conducted with the hydrated MXene compound reached sorption equilibrium in 720 minutes. In this experiment, adsorption capacity was defined as 213.2 mg/g. Additionally, they observed that the hydrated Ti_2CT_x compound exhibited adsorption performance with excellent selectivity even in the presence of competing ions in the medium. Moreover, it has been reported that adsorption performance is not affected by the general ionic strength in the environment but varies depending on the pH value of the environment.

MXenes in the Removal of Pollutants by Membrane Filtration

Membrane technology is an effective, environmentally friendly, and practical method frequently used in desalination and wastewater treatment. An ideal membrane for this purpose should have features high flux, higher selectivity, more stability, and resistance to contamination and chemicals such as chlorine (Goh & Ismail, 2018). In addition, the membrane thickness must be optimized not to lose its separation performance and mechanical stability while maximizing water permeability.

The use of MXenes or MXene-based composites as membranes in environmental applications is an emerging research area. Like many other developing fields, some issues must be carefully investigated or various challenges to overcome. MXene-based membranes can potentially be used for water treatment or gas separation applications.

The most widely used application areas of membrane technology are water treatment and desalination. MXene-based membranes have been used as membranes in water filtration and desalination applications, and their performances have been investigated. In these studies, it has been observed that MXene-based membranes are effective in separating impurities such as suspended particles, organic compounds, and ions from water with their high surface area and nano-sized thickness. MXene membranes can also be designed with special pore sizes and surface chemistries to achieve high selectivity and permeability for some particular purposes. In addition, MXene-based membranes are known to be very effective in gas separation processes.

It is possible to produce fragile and highly selective membranes with these materials. In this way, these membranes can be used in gas separation processes. The unique electronic properties and tunable surface functional groups of MXene-based membranes can allow selective permeation of certain gases while blocking others.

Membranes operating based on ion exchange with MXene membranes can also be designed. These membranes facilitate the transport of specific ions. These materials can be used primarily in applications such as water softening and ion-selective sensors. MXene-based membranes can also be integrated into sensors designed to detect various types and quantities of environmental pollutants. Thus, the sensitivity and selectivity of the sensors can be increased. It is possible to design purpose-specific MXene-based membranes by adjusting structural properties such as composition, surface functionalization, and pore size to meet specific environmental requirements. This tunability allows membranes to be customized for different applications.

While MXenes and MXene-based composites are promising for using membrane technology for environmental purposes, many scientific studies are required for performance changes due to prolonged and repeated use. Shortly, according to the data obtained from scientific studies to be carried out on this subject, further development of MXene-based membranes and, as a result of this development, an essential role in improving water quality and reducing environmental pollution is expected.

Ren et al. conducted the first study on using an MXene-based membrane in water treatment applications (Ren *et al.,* 2015). The researchers report preparing a membrane by immobilizing a $Ti_3C_2T_x$-type MXene compound onto a membrane-structured support using vacuum filtration. Higher hydrophilicity of $Ti_3C_2T_x$ permits the passage of water molecules between the layers, and thus, an ultra-fast water flux is obtained. The researchers report that the membrane they prepared is impermeable to cations with a radius more significant than the gap between the layers of MXene-type materials (~6 Å). These studies showed that the produced membrane exhibited an excellent separation performance against positively charged metal cations such as Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, Ni^{2+}, and Al^{3+}.

Han et al. (Han *et al.,* 2017) prepared an MXene-coated polyether sulfone (PES) ultrafiltration membrane for dyeing, desalination, and wastewater treatment. Researchers report that their new composite membrane has rough, dense surface layers and homogeneous component distribution. In this study, it was observed that there was a strong relationship between the rate of rejection of dyes and inorganic salts by the membrane and the amount of MXene added. In addition, 92.3% efficiency was achieved under optimum conditions in experiments with Congo red dye, while excellent rejection rates of 80.3% were observed in experiments with gentian violet.

MXene-based membranes have also been used for filtration of air contaminants. In a study performed by Gao et al. (Gao *et al.,* 2019), a composite membrane obtained by combining PAN fiber and two-dimensional MXene nanosheets was used to remove particulate pollutants in the air. Researchers report that the produced membrane provides a good PM 2.5 removal efficiency of 99.7% while reducing the required filtration pressure. It is claimed that this high efficiency may also be due to the adsorption of contaminant particles on the large and accessible surfaces of MXene layers.

MXenes as Photocatalysts

Photocatalysis is an environmental technology favorable for environmental sustainability, based on the degradation of organic pollutants through photocatalytic oxidation. Although the photocatalytic effect was first observed for TiO_2, dozens of semiconductors have been used in the photodegradation process of various organic pollutants with promising results. In photocatalysis experiments with these semiconductors, one of the critical factors limiting the performance of the photocatalyst used is the rapid recombination of electron (e^-) and hole (h^+) pairs released by photoexcitation. By combining MXene compounds with photosensitive semiconductors, new photocatalysts are emerging. These new catalysts are better dispersed in aqueous solutions while at the same time increasing the adsorption ability of the catalyst. In this way, it is aimed to effectively reduce charge carrier recombination, a challenge that limits the activity of photocatalysts. Therefore, MXene compounds can be used as unique substrates to obtain much faster photocatalysts.

MXenes have great potential as photocatalysts, especially in removing various pollutants in water or air by photocatalytic degradation. To date, many different Mxene or MXene-based composites prepared by various methods have been used as photocatalysts in the photocatalytic degradation processes of these pollutants, and excellent results have been obtained. The use of MXenes as photocatalysts is generally based on their ability to absorb and process light energy to facilitate chemical reactions, as in other types of photocatalysts. The high surface areas of MXenes and the active functional groups on their surfaces make MXenes an important potential photocatalyst for effectively removing organic pollutants in water or air.

Photocatalysts are materials that increase the reaction rate by showing a catalytic effect, especially when exposed to irradiation in the ultraviolet (UV) and visible light regions. Similarly, it is known that some MXenes or MXene-based composite materials can exhibit perfect photocatalytic activity under (UV) and visible light irradiation. In this way, they form various reactive oxygen species in the environment. These reactive oxygen species then cause redox reactions that result in the degradation of organic pollutants. Thus, organic pollutants in air or water environments are entirely mineralized.

When MXenes are used as photocatalysts, it is possible to effectively remove various organic pollutants such as dyestuffs, organic solvents, pesticides, drug residues, and pharmaceuticals in water by photocatalytic degradation. When exposed to ultraviolet (UV) and visible light irradiation, they can convert a wide range of organic pollutants into harmless by-products such as H_2O and CO_2 by forming electron (e^-) and hole (h^+) pairs participating in oxidation-reduction reactions. These materials are very useful in wastewater treatment and in removing harmful substances from water environments.

Similarly, MXenes and MXene-based composites can be used in photocatalytic air purification systems. In these systems, light can be provided from an artificial source and directly from the sun. MXenes have the potential to effectively degrade volatile organic compounds (VOCs) and oxides of nitrogen (NO_x) in indoor and outdoor air. In this way, they can significantly improve indoor or outdoor air quality.

Moreover, it is also possible to obtain self-cleaning surfaces by coating various outdoor surfaces with MXenes. This way, MXenes exposed to radiation can break down organic pollutants on surfaces exposed to sunlight. This method may make it possible to keep buildings, vehicles, and other outdoor structures clean.

Another critical application of photocatalysis is photocatalytic water splitting. Studies show that MXenes are used for photocatalytic water splitting from water to produce hydrogen (H_2) gas. As hydrogen is a clean, environmentally friendly, and sustainable renewable energy source, using MXenes in H_2 production for fuel cells is promising for environmental sustainability. MXenes can be used directly as photocatalysts in these studies and composites with other semiconductor-based photocatalysts. Moreover, the photocatalytic reaction can be combined with sensor technologies to detect pollutants in air and water rapidly. For this purpose, MXene-based photocatalysts can also be used to detect pollutants in real-time and measure their concentrations.

Mashtalir et al. (Mashtalir *et al.,* 2014), an MXene compound, was reported for the first time as a photocatalyst for degrading organic dyes. Researchers used a $Ti_3C_2T_x$ type MXene compound as a photocatalyst for the photocatalytic oxidation degradation of Methylene Blue (MB) and Acid Blue 80 (AB80) dyes from wastewater under ultraviolet (UV) irradiation. In this study, in the experiments carried out in a dark environment without UV radiation, it was observed that 18% of the MB dye could be removed in 20 hours, while no removal was observed in the AB80 dye. On the other hand, 81% degradation efficiency for AB80 dye and 62% degradation efficiency for MB was observed after 5 hours under UV irradiation. These results clearly show that the process occurs due to photochemical interactions. It is stated here that the photochemical process in question originates from TiO_2 released by the partial surface oxidation of the $Ti_3C_2T_x$ compound. TiO_2 provides photocatalytic activity, while Ti_3C_2 is a substrate, contributing to rapid charge transport. The data obtained from this study inspired many subsequent studies, and TiO_2/Ti_3C_2 composites were used in many different photocatalytic applications.

Zhang et al. (Zhang *et al.,* 2018), hematite (α-Fe_2O_3), which is used as another widely used photocatalyst, was composited with a Ti_3C_2 type MXene compound in a study by and they prepared the α-Fe_2O_3/Ti_3C_2 MXene composite. Researchers have applied the ultrasonic-assisted self-assembly method for synthesis, and they used the composite they prepared as a photocatalyst in the photocatalytic removal of methylene blue dye. It was observed that the dye in the solution degraded almost completely in approximately 120 minutes.

Before they reach the catalyst surface, the recombination of photogenerated charge carriers is an important limiting factor in semiconductor-based photocatalysts. While recombination prevents the repeated and long-term use of semiconductor-based photocatalysts, it can also lead to significant losses in process efficiency. Therefore, this problem must be overcome in the future. Combining these semiconductor photocatalysts with other co-catalysts or support materials to form heterojunctions or composites has the potential to significantly increase the amount of active free radicals, such as $\bullet O^{-2}$ and •OH while minimizing the recombination of photogenerated charge carriers. For example, in a study performed by Lu et al. (Lu *et al.* 2017), a heterojunction structure was obtained by combining a Ti_3C_2 type MXene with two semiconductors, such as TiO_2 and CuO, which are also used as photocatalysts on their own. The researchers then used the composites they synthesized as photocatalysts for the photocatalytic degradation of methyl orange dye and reported that 99% of the dye was degraded in approximately 80 minutes.

Ferrite-based materials are semiconductor materials widely used in many fields with advantages such as high chemical stability, easy production, advanced magnetic properties, and tunable surface properties. Many scientific studies have been conducted using these materials as photocatalysts, and promising results have been obtained. Photocatalytic activities are expected to increase significantly when ferrites are combined with MXene-based materials. Some studies have been carried out for this purpose. For example, Cao et al. (Cao *et al.*, 2020) applied a sol-hydrothermal method aiming to produce the $CuFe_2O_4$ spinel phase in situ in order to obtain a structure in the form of $CuFe_2O_4$/MXene photocatalyst. They reported that they successfully produced the target material. The researchers used the composite they produced with sulfamethazine, an organic pollutant of pharmaceutical origin. They used it as a photocatalyst in the photocatalytic degradation process and reported that they observed a degradation rate of 59.4%.

In a study by Li et al. (Li *et al.*, 2018), it was reported that Ti-based MXenes can be converted entirely into TiO_2@C composites when appropriate chemical conditions are provided. It has been reported that TiO_2@C nanostructures in the form of sheets can be produced by grinding the two-dimensional Ti_2CT_x-type compound in high-energy ball mills. Researchers reported that the Ti_2CT_x compound in this structure serves as a titanium and carbon source, and the TiO_2 nanoparticles formed in the process are distributed homogeneously on single or several-layer carbon sheets.

Moreover, in the photocatalysis tests, it was reported that a significant part of the TiO_2@C compound produced and the methylene blue content in the solution, such as 85.7%, was wholly degraded in 360 minutes.

Metal sulfides are also widely used materials for photocatalytic purposes. To date, attempts have been made to produce high-performance photocatalysts by combining many metal sulfur compounds with MXenes. For this purpose, researchers have synthesized various metal sulfur-doped MXene derivatives such as $In_2S_3/TiO_2@Ti_3C_2T_x$ (Wang et al., 2018), $CdS@Ti_3C_2@TiO_2$ (Liu *et al.*, 2019). In these studies, it was observed that the catalytic activities of metal sulfides, which are promising photocatalysts on their own, increased significantly when combined with MXene.

MXenes as Electrocatalytic Sensors

The first and most essential step of environmental treatment technologies is the qualitative and quantitative identification of environmental pollutants. Sensor technologies are of vital importance in detecting and tracking pollutants. For this purpose, electrocatalytic-based sensors synthesized by various methods are pretty effective. This method has significant advantages, such as simplicity, applicability, and high selectivity. The essential characteristics of the electrocatalytic sensor, such as sensitivity and selectivity, are primarily related to the chemical structure and composition of the sensor.

Therefore, materials with a very high active surface area, high conductivity, and high redox activity have the potential to be used in electrocatalytic sensor technologies. These features can significantly increase the sensitivity and selectivity of the prepared sensor towards a particular contaminant. MXenes are also expected to significantly improve sensor technology with their tunable surface chemistries, hydrophilicity, and functionalizability (Soomro et al., 2020).

MXenes, with their unique electrical, chemical, and surface properties, have significant potential for developing high-performance sensors for environmental sensing and monitoring systems. Sensors are vital to ensure the safety and quality of water, natural water bodies, or indoor and outdoor air. MXenes or MXene-based composite materials can be easily integrated into sensor devices designed for the detection or concentration determination of various environmental parameters and pollutants. MXene-based sensors can operate based on various sensing mechanisms, including resistive, capacitive, or electrochemical changes. The choice of mechanism depends on the specific application and the desired sensitivity and selectivity.

For this purpose, in some studies, MXenes have been used as gas sensors for detecting and measuring certain gases in the environment, and it has been determined that MXenes or some MXene-derived composites show perfect activity as sensors in environmental applications. MXenes can show detectable changes in electrical conductivity or other properties when exposed to gases targeted for detection. In this way, MXenes have the potential to be used as sensors in a wide variety of applications such as air quality monitoring, detection of toxic gases in the air, and even leak detection in industrial environments.

Moreover, MXenes can also be used as chemical sensors to detect various chemicals in liquid or gaseous media. Thanks to their high surface areas and surface functional groups, MXenes interact with specific molecules in the environment, causing measurable changes in electrical, optical, or other sensor properties. While some MXenes can be used directly as sensors in their natural state, some MXenes can be used to increase the efficiency of other sensors. MXenes and MXene-based materials have a strong potential as sensors to detect specific ions in solutions. MXene-based sensors can be integrated into environmental monitoring systems to measure temperature, humidity, pH, and pollutants. In this way, they can provide real-time data crucial for monitoring and assessing environmental conditions, thus identifying potential hazards.

Using MXene-based materials, new and advanced composites can be produced by efficiently combining them with metal nanoparticles, carbon-based materials, or many different materials to achieve much-improved sensitivity and selectivity. Thus, developing advanced electrocatalytic sensors for detecting environmental pollutants using MXene-based materials is possible.

Future Perspective

When MXenes were first discovered, they were widely used in supercapacitor applications for energy storage. In the future, MXenes are expected to be used more in designing energy storage devices such as supercapacitors and lithium-ion batteries, especially with their high electrical conductivity and large surface area. Another topic where MXenes find the most widespread use is environmental remediation technologies. These materials, widely used in water treatment, chemical catalysis, and environmental sensor technologies for this purpose, are expected to be used even more. In the future, as researchers further explore their properties, it is predicted that the use of MXenes will spread to even more diverse areas.

One of the most critical challenges limiting the widespread use of MXenes is the difficulty of their production. Researchers will try to make MXenes more accessible for commercial applications by developing more efficient, more environmentally friendly, and cost-effective methods for synthesizing MXenes. On the other hand, one of the most essential advantages of MXenes is the ease of functionalization. Various surface properties, surface functional groups, and surface areas of MXenes can be designed to tailor them for specific applications. It is expected that more progress will be made in this area in the future. With the increase in studies in this research area, new MXene species with improved or entirely new properties suitable for various needs are expected to emerge. One of the areas where MXenes are widely used is the field of electronics. With their excellent electrical conductivity, MXenes will likely find more space in next-generation electronics.

The production and use of new materials always raise environmental concerns. Most methods currently applied for producing MXenes are far from environmentally friendly and sustainable. More scientific research should be conducted on the possible environmental impacts of both the production and disposal of MXenes. Developing more sustainable processes for this purpose is vital for the widespread use of these materials. Moreover, the synthesis, functionalization, and use of MXenes for various purposes require interdisciplinary cooperation. Accordingly, researchers from various fields should continue to work together to unlock the full potential of MXenes. Moreover, as with any new material, as MXenes are used increasingly in consumer products and industrial applications, toxicity concerns must be addressed in more detail. Therefore, it is also essential to carefully investigate the toxicity of MXenes and the possible effects that may occur as a result of long-term exposure.

Although MXenes show significant promise in environmental remediation applications due to their unique properties, they face several challenges due to their recent development and use. MXenes are known to have highly active surfaces and large surface areas. Thanks to these properties, MXenes can exhibit excellent adsorption properties. Advanced adsorption properties make MXenes an excellent alternative adsorbent for removing heavy metals and various toxic chemicals. Moreover, shortly, MXenes and their derivatives will likely be used more effectively in treating wastewater from mining activities and many other industrial wastewater.

Moreover, the high surface area and strong adsorption properties of MXenes can be utilized for other water treatment methods. They can be further utilized to remove organic pollutants, dyes, pesticides, endocrine disruptors, and other harmful pollutants from wastewater.

Moreover, MXenes or some MXene-based composites exhibit perfect catalytic activity in the degradation of various organic pollutants. These materials are expected to be more widely used in treating various industrial wastewater by catalysis-based methods.

Another essential property of MXenes, excellent electrical conductivity, makes these materials suitable for electrochemical sensors. MXene-based sensors can detect many pollutants in real-time and enable continuous monitoring. These sensors can provide valuable data for essential environmental monitoring and remediation efforts.

In addition to the many advantages mentioned above for using Mxenes in environmental applications, some challenges limit the broader use of these materials. It is estimated that these challenges can be overcome with the data obtained from new scientific studies on these issues. Due to the high adsorption capacity of MXenes, useful substances or chemicals that may be present in the environment can be removed from the water together with the pollutants. In order to prevent this situation, it is necessary to provide selectivity to MXenes in adsorption processes with various surface modifications to be applied.

Another critical challenge is to increase production quantities and thus reduce costs. It is known that relatively large quantities of MXene are required for environmental applications. The methods currently applied to produce MXenes involve complex, lengthy, environmentally unfriendly, expensive, and energy-intensive processes. Therefore, it is clear that more scientific research is needed in this field. MXenes in large-scale applications will only be possible with new, cost-effective, environmentally friendly, sustainable production methods.

In addition, it is emphasized that the stability of MXenes has been weak in some studies conducted so far. However, the stability of these materials under harsh conditions is an important parameter that may affect their widespread use. Before large-scale utilization, MXenes are expected to retain their adsorption and catalytic properties for long periods or after repeated use.

One of the challenges to be overcome regarding MXenes is the toxicity of these materials and the possible effects that may occur as a result of long-term exposure. Extensive research is needed in this regard.

In addition, the disposal or storage of MXene-based materials that have been used for various purposes also needs to be addressed. New methods must be developed to reproduce or safely dispose of MXenes or MXene-based composites. In addition, the possible interactions of MXenes, which are chemically highly active substances, with possible pollutants in wastewater environments should be handled carefully because there may be unwanted side reactions between MXenes and pollutants or other chemicals in the environment.

As with every new technology development, it is crucial to comprehensively reveal these materials' properties using MXenes in environmental remediation applications. This can only be possible with a multidisciplinary approach, continuous research, and innovation. To this end, collaboration between scientists and engineers must be strengthened, and potential challenges must be carefully assessed.

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CHAPTER 6

GENERATION AND IMPLEMENTATION OF DISINFECTANT ON SITE: SUSTAINABILITY, EFFICIENCY AND IMPLEMENTATION STRATEGIES

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INTRODUCTION

The rapid increase in the world population since the industrial revolution has led to an increase in the demand for natural resources. With technological developments, production has increased and the sustainability of natural resources has been put at risk. As a result of the uncontrolled consumption of natural resources; important environmental problems such as air pollution, water pollution, and soil pollution have emerged. Therefore, the capacity of nature to renew and clean itself has been exceeded. These pollutions have led to problems such as decreased biodiversity, climate change, epidemics, and the inability to access clean drinking water resources. Treatment technologies have been developed to improve this situation.

Water is a natural resource of vital importance for almost all life forms. Water is one of the most fundamental components for the sustainability of vitality, peace, and economy.

Environmental pollution; depletion of drinking water resources and cause damage to natural aquatic ecosystems. The resulting harmful effects have far-reaching consequences for both human and ecological well-being. Pesticides, household wastes, industrial wastes, and other pollutants pollute water resources and adversely affect aquatic ecosystems. This situation poses a serious problem in terms of drinking water safety and environmental protection.

According to the United Nations Environment Program (UNEP) data, 2.9 billion people in the world live without clean drinking water due to diminishing and polluted water resources, and this number is increasing day by day (Akduman Vural, 2018).

Disinfection processes stand out as an important parameter in the fight against environmental pollution. In drinking water and wastewater treatment, disinfection neutralizes microorganisms in water sources and makes water and wastewater safe for human and environmental health. One of the most important requirements of the water treatment process is water disinfection processes (Ünver and Aksu, 2011). Disinfection process; It plays an effective role in eliminating pollutants such as bacteria, viruses, and parasites that can be carried by water, encountered in drinking water systems, and at the outlet of treated water. Therefore, it also makes it possible to prevent diseases transmitted through water.

Although there are various disinfection methods such as disinfection with heat and light, ozonation, ultraviolet (UV) rays, chlorination, ultrasonic disinfection, and membrane filtration, the most widely used disinfection process is the chlorination process.

There are many reasons why chlorine is widely preferred in disinfection. One of these reasons is that it is effective against many pathogenic microorganisms. Another reason is that water maintains its effectiveness during storage and distribution as well. In addition to these, the fact that it is more economical and accessible than other disinfectant types is one of the reasons why it is widely preferred.

Chlorine and its compounds are chemicals used in disinfection processes. After chlorine gas (Cl_2) is produced, it is stored as liquefied in large pressure tubes. It is transported to water treatment plants by rail or road tankers. Both the transportation and storage of chlorine gas carry great risks as they may cause the formation of a toxic vapor cloud in the event of a possible accident.

Sodium hypochlorite (NaOCl), one of the chlorine compounds, is considered the most economical disinfectant after chlorine. This chlorine compound also needs to be transported and stored. It tends to degrade in storage depending on various factors such as storage temperature, age, and the presence of contaminants (Yılmaz, 2022).

Among the disinfection applications, the most preferred process is the applications in which chlorine and its compounds are used. However, the risks that may arise during the storage and transportation of chlorine appear as problems that should not be ignored in terms of human and environmental health. During the transportation and storage of chlorine, leakages or accidents that may cause environmental pollution may occur. Therefore, appropriate management and safety protocols should be implemented to reduce the risks of chlorine use.

On-site disinfectant generation is an effective and innovative process that will minimize the mentioned hazards and increase human and environmental safety by providing on-site chlorine generation for disinfection.

In this chapter, on-site disinfectant generation and application process; have been discussed in detail within the scope of sustainability, effectiveness, and implementation strategies.

ON-SITE DISINFECTANT GENERATION

Chlorine and its compounds are the most widely used chemicals among used chemicals in water and wastewater disinfection applications (Yılmaz *et al.,* 2021). The on-site disinfectant generation process is a treatment process developed for the more effective use of chlorine and its compounds. Hypochlorite is the most widely used active chlorine compound in disinfection. This is due to its pathogen-killing effect, non-toxicity (at the concentrations used), ease of use, and low cost. NaOCI and HOCI have widespread use in homes, hospitals, industrial facilities, and water management systems. The chlorine compound widely used in drinking water disinfection is NaOCI. NaOCI dissolves in water to produce HOCI and OCI^-. These compounds are also very effective for the removal of organic pollutants in the aquatic environment. However, when NaOCI is stored in powder form in an anhydrous form, it tends to degrade due to atmospheric conditions. Therefore, it is not very possible to store and transport large volumes of NaOCI. Dissolved NaOCI is more stable than solid. But it needs to be kept in a cold environment to be kept intact. If it is not stored under appropriate conditions, it releases chlorine gas as a result of decomposition. Chlorine gas is also a gas that has harmful effects on the environment and human health. Using the on-site disinfectant generation process, it is possible to produce hypochlorite more efficiently, effectively, and safely in an electrooxidation cell (Kim *et al.,* 2021, Abdul- Wahab *et al.,* 2009). On-site disinfectant generation; It is based on applying electricity to an electrooxidation cell where anodes and cathodes are used to produce other types of oxidants such as chlorine and sodium hypochlorite with a solution of sodium chloride (salt) and water.

The basic working principle of the on-site disinfectant generation process is the generation of sodium hypochlorite from a NaCl solution in an electrooxidation cell. In addition, when the electric current is removed, the oxidants formed in the system are stored and suitable for instant use.

Generated sodium hypochlorite is a technology used for disinfecting water. The process is used in hospitals, medical sterilization (Cheng *et al.,* 2016), animal farms (Dev *et al.,* 2014), wastewater treatment plants, drinking and utility water disinfection (Özel Çelik *et al.*, 2017; WHO, 2000; Casson, 2006), swimming pools (Boal, 2009) and for industrial purposes (Topbaş, 2016).

The working mechanism of the on-site disinfectant generation process is discussed in more detail in a sub-title.

On-site Disinfectant Generation Mechanism by Electro-oxidation

On-site disinfectant generation; occurs as a result of the working mechanism of the electro-oxidation process. The electro-oxidation process is used in a variety of applications. It is widely used in areas such as wastewater treatment, formation of metal coatings, decomposition of organic compounds, and on-site disinfectant generation. Electrooxidation is an important technology because it is an environmentally friendly method and accelerates chemical reactions.

Electro-oxidation is an oxidation process in which electric current is used in chemical reactions. This process is based on initiating and accelerating electrochemical reactions with the electric current generated by the direct current source by placing anode and cathode electrodes in a conductive solution medium. While oxidation takes place at the anode, reduction reactions occur at the cathode. These oxidation and reduction reactions, together with the chemical changes occurring at the electrodes, provide the flow of electric current. In the electrooxidation process, the substances on the anode are oxidized by losing electrons. These oxidation reactions cause electrons to be released at the anode and react with ions in the solution. The electrons are used during the reduction reactions that take place at the cathode. Substances at the cathode are reduced by accepting electrons.

The saltwater solution is used for the process of producing disinfectant in situ by electro-oxidation. In the electrolytic cell, the anode and cathode electrodes are in contact with the concentrated saltwater solution. When current is applied to the cell, the reaction of salt (NaCl) and water (H_2O) in the system will lead to the formation of sodium hypochlorite (NaOCl) (Boal 2018) :

$$NaCl + H_2O + 2e^- \rightarrow NaOCl + H_2 \quad (1)$$

As a result of the oxidation reactions occurring at the anode, two CI^- ions will give one electron each to form Cl_2 gas:

$$2Cl^- \rightarrow Cl_2 + 2e^- \quad (2)$$

Some of the CI_2 gas formed is then dissolved in water to produce hypochlorous acid (HOCl):

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^- \quad (3)$$

is balanced by reduction reactions that take place at the cathode, where water (H_2O) is converted to hydroxide ions (OH^-) and hydrogen gas (H_2) :

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2 \quad (4)$$

H_2 gas is produced during the electrolysis from the oxidant tank so that it does not cause gas accumulation.

The hydroxide ions produced at the cathode react with hypochlorous acid, initially balancing the charge with sodium cations (Na^+) from the salt and producing the hypochlorite anion (OCl^-):

$$HOCl + OH^- \rightarrow H_2O + OCl^- \quad (5)$$

Figure 1. shows the reactions that occur in the on-site disinfectant generation process in the electrochemical cell.

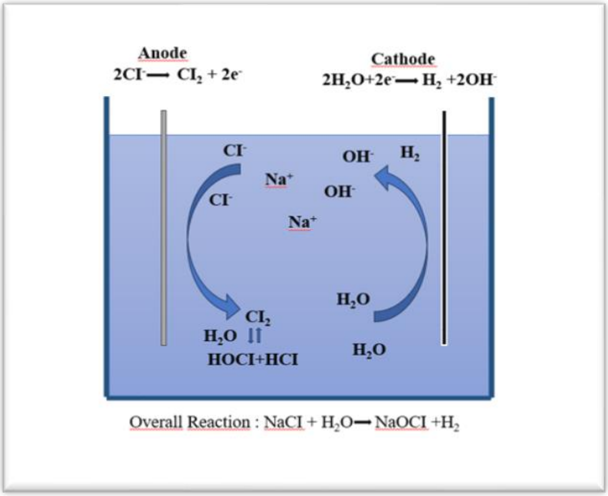

Figure 1. Reactions occurring in the process of on-site disinfectant generation

Parameters Affecting Mechanism of On-site Disinfectant Generation

On-site disinfectant generation takes place in the electro-oxidation cell. Therefore, parameters affecting electrooxidation efficiency also affect on-site disinfectant generation. It is possible to list these parameters as follows.

Electrode selection; In the electro-oxidation process, insoluble metal/metal oxide electrodes (such as Pt/Ti, Ti/Ru/Ir, Ni/Ti/Ga , steel) are used. The electrode that plays an active role in electro-oxidation is the anode. It is known that the anode formed by coating RuO_2, Co_3O_4, and MnO_2 on titanium shows better catalytic activity than other anodes. Lead, pure titanium, and graphite anodes are among the anode electrodes with successful results (Öztürk, 2019).

Arrangement of electrodes; The electrodes can be used in the reactor as parallel or in series connection. The series connection of the electrodes causes the electric current to flow by being shared between the electrodes. This leads to an increase in the total voltage and a constant current density. In a series connection, the positive and negative poles of the electrodes are connected and the electric current circulates between the electrodes in series.

In the parallel connection of the electrodes, the electric current is divided between the electrodes and flows. This causes the total current to increase and the current density to change. In a parallel connection, the positive poles of the electrodes and the negative poles are combined.

Connecting the electrodes in series or parallel may vary depending on the advantages, application requirements, and purposes. Each connection type has different advantages. It is possible to list these advantages as follows.

Serial Connection Advantages:

- ✓ The series connection increases the overall voltage between the electrodes. This can be advantageous in applications that require higher voltages.
- ✓ In the series connection, the electric current is evenly distributed over each electrode. This ensures that the disinfection process takes place evenly on each electrode.
- ✓ The series connection, using higher voltage reduces energy loss. This is advantageous in terms of energy efficiency.

Parallel Connection Advantages:

- ✓ The parallel connection increases the total current between the electrodes. This is advantageous in applications that require higher currents.
- ✓ The parallel connection allows the current to be divided between the electrodes. This is advantageous to accommodate different disinfection targets or electrode performance.
- ✓ The parallel connection ensures that each electrode is exposed to less current, as the current is divided between the electrodes. The situation reduces the wear rate of the electrodes and prolongs their life.

Connection shape benefits may vary depending on specific application requirements and electrode performance. For example, in applications requiring higher voltages, a series connection may be advantageous, while a parallel connection may be preferred to accommodate different disinfection goals or electrode performance. In any case, it is important to consider and optimize the application requirements to determine the correct form of connection.

Distance between electrodes; In the electro-oxidation process, the distance between the electrodes is an important factor affecting the in situ disinfectant generation. The distance between the electrodes affects the conduction of the electric current and the rate of the reaction. The distance between the electrodes affects the electrode efficiency. A closer electrode distance enables the efficient use of electric current and allows more reactions to occur on the electrode surface.

A farther electrode distance causes the electrical current to be dispersed and the efficiency to decrease. The distance between the electrodes also affects the energy consumption in the electro-oxidation process. A closer electrode distance results in lower resistance, resulting in less energy consumption. A longer electrode distance, on the other hand, causes higher energy consumption, as it creates higher resistance. The distance between the electrodes also has effects on the lifetime of the electrodes. A closer electrode distance leads to faster wear of the electrodes, as it will cause more intense reactions on the electrode surface. A longer electrode distance extends electrode life as it reduces the wear rate on the electrode surface. Therefore, the optimal distance may vary depending on the specific application requirements and the design of the electrodes. Careful adjustment of the optimal distance is necessary.

Current density; Current density is an important parameter in electro-oxidation treatment. Current density affects the rate of electro-oxidation reactions. However, an increase in current density does not always increase oxidation efficiency or rate. High current densities increase energy consumption and result in higher operating costs. For this reason, high current density is rarely preferred in industrial electro-oxidation applications. Correct setting of current density is important to optimize factors such as treatment efficiency, energy consumption, and disinfectant generation. Carefully determining the current density used in the electro-oxidation process and adjusting it according to application requirements is important to ensure efficient and economical generation.

The feed water flow rate; Flow rate is an important variable affecting the electro-oxidation process. Flow rate; It has an impact on the efficiency of the electro-oxidation process as it controls solution movement and interaction. It is a very important parameter to optimize disinfectant generation.

pH; neutral or slightly basic media can be preferred as HOCl and OCl^- are almost unaffected by the desorption of gases and can act as oxidizing reagents in the entire volume of wastewater (Canizares *et al.*, 2006).

Heat; The decrease in Cl_2 solubility in water at high temperatures has a negative effect on disinfectant generation efficiency. For these reasons, preventing the increase in temperature with process control applications in electro-oxidation processes would be an appropriate approach (Rajkumar and Kim, 2006).

Electrical conductivity; Although there is no consensus on the effect of conductivity on the total oxidation efficiency, it is stated that the electrochemical cell voltage decreases when the electrolyte conductivity increases for a constant current density (Anglada *et al.,* 2009).

Operation time; Generally, efficiency increases as the working time increases. In addition, since the increase in working time will increase electricity consumption, the required amount of disinfectant should be calculated and optimum working conditions should be determined.

In addition to these, some parameters that affect on-site disinfectant generation are feedwater salt concentration, process control and automation, safety, and occupational health.

The feed water salt concentration; As the salt concentration in the inlet water increases, it is expected that the disinfectant generation efficiency will increase. Working in very high salt concentrations also has adverse effects on the electrodes. For this reason, the amount of disinfectant required should be determined according to the purpose of use, and the salt concentration of the feed water required for the determined amount should be selected.

Process control and automation; control and automation of the on-site disinfectant generation process are important for generation efficiency and safety. Continuous monitoring, automatic control systems, and the use of appropriate sensors ensure the stability of the process and minimize errors.

Safety and occupational health; during the generation of disinfectant on site, safety and occupational health measures should not be ignored. Issues such as worker safety, use of chemicals, gas emissions, and waste management should be considered in terms of process safety.

These parameters are important factors affecting the disinfectant generation process on site. Control of each parameter is important to ensure an effective and safe disinfection process. Considering the application requirements and the targeted disinfection results, it is necessary to determine the appropriate parameters and optimize the process.

Although these parameters that affect on-site disinfectant generation are seen as disadvantages in some conditions, it is a process that has many advantages when the system installation is completed under optimum conditions.

The advantages and disadvantages of on-site disinfectant generation compared to the classical chlorination system are discussed in detail in the next sub-title.

Comparison of Classical Chlorination Process and On-site Disinfectant Generation Process

There are some fundamental differences when comparing conventional chlorination and on-site disinfectant generation.

In the classical chlorination system, pre-produced chlorinated products must be transported, stored, and dosed. This is one of the biggest disadvantages of the classical system. The stability and quality of chlorine and its compounds depend on proper storage. Long-term storage or exposure to heat reduces the effectiveness of chlorine.

Conventional chlorination has some disadvantages. For example, chlorinated by-products (trihalomethanes) occur in the chlorination process, these by-products are harmful to health. In addition, the handling and storage of chlorine pose safety risks.

On-site disinfectant generation, on the other hand, is a method in which the active chlorinated compounds required for disinfection are produced directly. This is usually accomplished by electrochemical methods. With this process, disinfectants are produced where needed and on time. As disinfectants are used directly where they are produced, fresher and more effective disinfection is provided. The effectiveness of disinfectants is maximized and more efficient disinfection occurs.

The on-site disinfectant generation process eliminates the need to transport and store chlorine and its compounds. It eliminates the risks of accidents or leaks that may occur during the transportation and storage of ready-made disinfectants. With this process, the use of disinfectants directly in the place where they are produced provides an advantage in terms of sustainability. It is possible to achieve a more sustainable disinfection production, especially when environmentally friendly and renewable energy sources are used in the operation of the process.

On-site disinfectant generation allows for greater control, and optimizing the disinfection generation process. For example, parameters such as current density, pH value, and salt concentration can be adjusted. When optimum working conditions are determined with these parameters, it is possible to increase the disinfection generation efficiency. In the process, less chemical use is needed in disinfectant generation. Disinfectants produced directly compared to the use of ready-made disinfectants are used more controlled and effectively. As a result of this situation, the amount of chemical waste is reduced and harmful environmental effects are minimized.

On-site disinfectant generation enables rapid response in emergencies. Especially in cases such as natural disasters, epidemics, or emergency water treatment requirements, the on-site disinfectant generation process can be operated quickly, allowing the necessary disinfectant to be produced (Campos Nogueira *et al.*, 2021).

The initial investment cost of on-site disinfectant generation is high, but the operating costs are low. Additionally, operating and storage costs are also lower than those of conventional systems (Özel Çelik *et al.*, 2017). On the other hand, the initial investment cost of the classical chlorination system is lower than the on-site disinfectant generation, but the operating costs are higher. Prominent advantages of on-site disinfectant generation are that it is safer than conventional systems and eliminates the storage and transportation processes of hazardous chemicals. In addition to these advantages, it is an advantageous process because it produces high-quality and environmentally friendly disinfectants and eliminates the storage of chlorine gas compared to conventional systems (Boal, 2018).

Using hypochlorite as a disinfectant is usually the cheapest and most convenient option. The on-site disinfectant generation process produces a sodium hypochlorite solution of less than 1%, usually between 0.6% and 0.8%. These concentrations are below the threshold for the hazardous classification; therefore, this process is quite safe, and no limitations are necessary (Zyl, 2001). In addition, the amount of chlorine by-products formed in the on-site disinfectant generation process is low. Because in the disinfectant production process, sodium hypochlorite is produced in a form suitable for use. There is no requirement for a large warehouse volume.

On-site disinfectant generation is a process that requires a more complex setup and more technical knowledge. Operations such as maintenance, cleaning, and replacement of electrodes should be done regularly.

Conventional chlorination and on-site disinfectant generation may be preferred depending on application requirements, scale, and specific conditions. Both methods have advantages and disadvantages, and the right choice should be made to meet your disinfection needs.

Sustainability of On-site Disinfectant Generation Process

The on-site disinfectant generation process offers several advantages in terms of sustainability. It eliminates the chemical transportation and storage requirements and reduces possible environmental risks as a result of accidents or leaks that may occur during the transportation and storage of disinfectants. As a result of this situation, workplace safety, and employee health are significantly protected.

On-site disinfectant generation is a more environmentally sustainable option. The use of high energy in the generation of ready-made disinfectants leads to carbon dioxide emissions. However, on-site generation can also increase energy efficiency and reduce carbon footprint by using renewable energy sources. In addition, on-site generation also reduces waste generation and allows for more efficient use of water resources.

On-site generation of disinfectants provides cost savings. The costs associated with purchasing, transporting, and storing ready-made disinfectants are eliminated. In addition, operating costs are further reduced in the long run, and energy consumption is also reduced thanks to its energy efficiency benefits.

On-site disinfectant generation enables more efficient use of water resources. Classical disinfectant generation usually requires a lot of water consumption. In on-site disinfectant generation, the amount of water used is optimized and water resources are used more efficiently.

In addition, thanks to the fresh and effective disinfectant production it provides, public health and hygiene conditions can be increased to a better level.

For these reasons, the on-site disinfectant generation process offers significant advantages in terms of sustainability. Factors such as safety, environmental impact, cost savings, efficient use of water resources, and social benefit make on-site disinfectant generation a preferred option. However, the special needs and conditions of this process should be taken into account and implemented in line with sustainability goals.

Efficiency of On-Site Disinfectant Generation Process

The on-site disinfectant generation process has the potential to provide effective disinfection. Some factors that affect the effectiveness of the on-site disinfectant generation process;

Disinfectant Type: On-site disinfectant generation enables the generation of different chlorine compounds. The effectiveness of the disinfectant varies depending on the type of disinfectant used. But in general, chlorine-based disinfectants (chlorine and its compounds) have a broad antimicrobial activity.

Dosage: Disinfection efficiency is closely related to correct dosing. In on-site disinfectant generation, correct dosing of the disinfectant is important. The amount of disinfectant should be adjusted according to water quality, microorganism load and targeted activity level.

Contact Time: A suitable contact time is required for the disinfectant to be effective. This process varies according to the type of target pathogen.

To ensure effective disinfection, the duration of action of the disinfectant on pathogens must be taken into account. Contact time is a very important parameter to ensure effective disinfection.

pH Value: The pH value is a factor that changes the effectiveness of the disinfectant. Some disinfectants may be more effective in a certain pH range, while others may be effective in a wider pH range. During in situ disinfectant generation, the pH value must be set correctly and controlled to optimize the effectiveness of disinfection.

Temperature: During on-site disinfectant generation, appropriate temperature conditions should be provided and the effect on the effectiveness of the disinfection process should be considered.

Water Quality: Water quality is important for disinfectant generation and disinfection effectiveness. Some water sources can be contaminated with organic matter, suspended solids, mineral salts, and other contaminants. These contaminants can reduce the effectiveness of the disinfectant or alter its effectiveness. During on-site disinfectant generation, water quality must be taken into account and, if necessary, the water must be cleaned with pre-treatment steps.

Taking these factors into account to ensure optimal disinfection ensures control and optimization of the disinfection process. It is important to determine the most suitable disinfection method and parameters for each application.

Implementation Strategies of On-site Disinfectant Generation Process

The on-site disinfectant generation process has the potential to serve a wide range of uses. After determining the place and purpose of use of on-site disinfectant generation, some application strategies should be considered to operate the system and provide effective disinfection.

First of all, suitable anode and cathode electrodes should be selected, and the surface area that may be sufficient for use should be calculated. Electrode selection and cleaning are important. The electrode material and surface affect the efficiency of electrochemical reactions. Cleaning the electrodes regularly or replacing them as needed is important for continuity and effectiveness.

Once the electrode sizes, numbers, and layouts have been decided, a suitable reactor should be designed. After the necessary tests are done, the process will be ready to work with a suitable power source.

After determining the concentration and duration of disinfectant generation according to the purpose of use, the conditions under which the appropriate flow, feedwater flow rate, salt concentration, and initial pH value are optimum should be determined.

The pH value affects the efficiency of the electrolysis process. A slightly acidic or neutral pH range is typically preferred for chlorine gas generation. Keeping the pH level under control will be provided the desired active chlorine generation.

The appropriate concentration of salt ensures effective chlorine generation. The salt concentration has a significant effect on the efficiency of the electrolysis cell and the generation of chlorine gas.

After these conditions are determined, if automation is installed in the process, it will be possible to work remotely automatically. The potential environmental risk rate is low, as there is no storage and transportation situation for the chemicals formed.

On-site disinfectant generation is a process without the use of harmful chemicals and processes (Rahman *et al*., 2010). The brine solution will be sufficient for the process to work. No other chemicals are needed.

The biggest cost of the system is electricity consumption. If electricity consumption can also be obtained from renewable energy sources, it will be possible for the process to be much greener.

Finally, the correct storage and use methods should be determined for the disinfectant produced. Produced chlorine gas or liquid chlorine must be safely and effectively stored or used as soon as it is produced. Safety protocols, correct operating instructions, and appropriate equipment should be used. When all these application strategies come together, an efficient and reliable on-site disinfectant production process will be provided. These strategies optimize disinfectant production while also considering factors such as sustainability, safety, and environmental compatibility.

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CHAPTER 7

SUSTAINABLE WASTE MANAGEMENT AND THE 10R CONCEPT

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INTRODUCTION

In parallel with the increasing population, technological developments, industrialization and urbanization, the problems related to waste and waste management, which are among the environmental problems that increase with pollution, are also increasing. Environmental problems from the past to the present are increasing the importance of waste management processes in developed and developing countries. The management of wastes without harming the ecosystem is closely related to the economy, especially to the environment and human health. Waste management is a process that includes the collection, transportation, regular storage, disposal and recycling of waste. Zero Waste Management, which is a more advanced version of this process, defines a waste management policy based on the re-evaluation of the wastes generated during the production phase and the prevention of waste by examining the sources of formation.

The fact that waste production continues to increase reveals the necessity of sustainable waste management. Sustainability is expressed as development that can meet today's needs (renewable) and protect the ecosystem without compromising the ability of future generations to meet their own needs (Ulaşlı, 2018). The biggest obstacle in front of sustainability is the post-modern consumption approach that has emerged as a result of globalization, using raw materials as if it will never end. In order to avoid this understanding; In addition to the balanced and effective use of raw materials, the recycling of recyclable wastes and the activation of environmentally friendly activities are very important (Yücel, 2003).

The most important thing in waste management should be the prevention of waste generation and the protection of natural resources. Waste should be treated not as a source of raw materials but as a resource to be recovered. In addition, regardless of the impact of waste on the ecosystem, it should be transformed into the concept of ecosystem assets that can be re-evaluated and brought into the economy, instead of being seen as a worthless material load and defined as garbage. Sustainable waste management is an important part of sustainability with its environmental, economic and social aspects. Regarding sustainability, waste can be examined in two separate ways. The first issue is how effectively the waste is used at the point of origin, and the second issue is the necessity of recycling the waste by evaluating it in an environmentally friendly and economical way (Aras, 2016).

Zero waste principle; Zero waste implementation studies within the scope of individuals, institutions/organizations or municipalities have become widespread all around the world, especially of late years, due to its economic pillar, minimizing energy consumption and providing clean production, guiding sensitive consumers, helping to prevent waste, providing circular raw material opportunities, creating awareness of environmental protection, and green building opportunities (Ulaşlı, 2018).

In order for waste materials to be handled within the framework of sustainable development principles and to leave a peaceful, stress-free, developed and livable world to future generations, waste management should be ensured comprehensively and the principle of zero waste should be made a standard of living. Increase in performance and benefits with a clean environment, reduction in costs and environmental risks when waste is prevented with the sense of "sensitive consumer" is realized with zero waste application. In this section, the correlation of zero waste and waste management, circular economy, 10R notion and waste management strategies within the framework of sustainable development have been tried to be detailed.

1. Sustainability concept

The fact that environmental problems have become an important issue at the national level reveals the necessity of approaches that ensure international cooperation. This necessity reveals the concept of sustainability, which is the result of the search for an economic environment that can secure the future, where living standards are high, and where health comes to the fore. The notion of sustainability is explained as maintaining a good condition with methods that do not cause damage, can be proven correct in every aspect, can be protected and applied (Evli, 2018).

Sustainability has three dimensions. The first of these is the unsustainability of the existing development; second only to meet today's needs; the third is to ensure the survival of future generations and to ensure that the pressure on the ecosystem does not harm the ecosystem while they are realised. According to these definitions, sustainable development means the effective use of resources (Eryılmaz, 2011).

Sustainability is located at the intersection of the trio environment, economy and society. In other words, these three factors must be together for sustainability. The most important thing in sustainable development is that, first of all, both economic and social policies should be integrated with the environment. In parallel with these policies, the sustainability policy will grow. In short, the sustainability policy is a policy in which the social, economic and environmental development of all stages of development can be achieved in parallel. Figure 1 shows the terms related to sustainability and what dimensions of development they provide in the sustainability policy. Sustainable systems at the top include sustainable production, consumption and triple responsibility. However, the realization of these three can be achieved by implementing the terms in the subsystems. The use of all these tools within the framework of a systematic approach and the holistic understanding of development, the creation of a sustainability policy is the way to be followed for a sustainable development in our country and even in the whole world (Clean Production Information Platform, 2018).

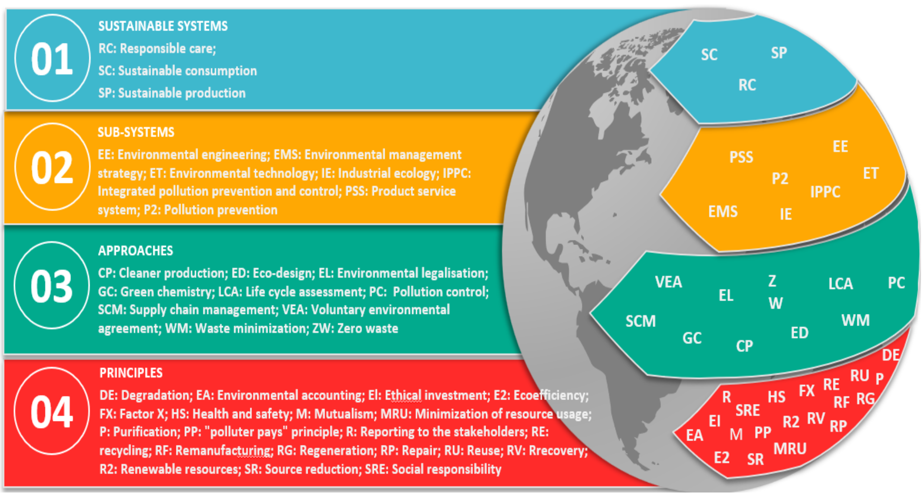

Figure 1: Sustainable development policy and the development of sustainability (Cleaner Production Information Platform, 2018)

The policies of sustainable development bring the circular economy with it. The circular economy is a production model that will enable sustainable development to achieve its goals.

2. Circular Economy Concept

European Union (EU) circular economy; It defines it as “an economic approach in which the importance of resources, equipment and products can be kept in the economy as long as possible and waste generation is at a minimum level” (Europan Commission, 2015). The circular economy concept focuses on three basic elements based on resource and system problems (Riina *et al.*, 2018). These;

- Developing and protecting natural resource capitals,
- Increasing resource efficiency,
- Maintain system efficiency.

The main aim of the circular economy approach is to minimize the waste generation. For this reason, waste management is expressed as a very important issue in the circular economy approach. With the reduction of limited natural resource consumption and processes such as sustainable production-consumption and recycling, which creates the possibility of more product increase in production, the linear economy has been replaced by the new economic approach, the circular economy. In the circular economy approach, the product that emerges in the production processes should be introduced in a way that is included in the system as it is separated into its components in the cycle. The system expressed as the principle of “cradle to cradle”; It requires all the products produced to be reused in the cycle without being wasted. The basic condition of the system in the context of sustainability; cooperation between the consumer, the retailer and the manufacturer (Can, 2017).

Zero waste, which is an important concept for the circular economy approach; It is an approach that aims to increase the efficiency of resource use, establish an active waste collection system, reduce the resulting waste, prevent waste and supply waste recycling. For this reason, efforts are made to spread the "zero waste" approach, which has been adopted by individuals, institutions and municipalities in the world.

The goals and targets of waste management within the circular economy approach exactly coincide with the goals and targets of sustainable development. This situation has reaffirmed the strategic importance of sustainable waste management, in addition the importance of determining targets correctly and following them routinely for a successful waste management (Wilson *et al.*, 2015).

3. Waste Management

According to the Waste Management Regulation, waste; As any matter or material that is thrown or letting go into the environment or that needs to be disposed of by the manufacturer or the real or legal person who in fact holds it, if waste management; It is defined as the practices that include prevention of the formation of waste, reduction at its source, reuse, decomposition according to its characteristics and type, accumulation, gathering, temporary storage, transportation, intermediate storage, recycling, including energy recovery, disposal, post-disposal monitoring, control and audit activities (Waste Management Regulation, 2017).

Waste materials are often characterized by their nature, components and quality. Changes in the quality, quantity and composition of waste can be associated with diverse factors such as the cultural, economic, social and financial situations of the people living in the studied area. These obvious factors also define first class waste management implementation to be adopted (Coker *et al.,* 2016).

Waste management purposes to minimize the effects on the environment and economy in the disposal of waste generated within the waste management system. The shortest path to reach this aim is naturally to reduce the quantity of waste.

Sorting from most desired to least desirable according to the EU waste prevention hierarchy discussed in Figure 2; prevention, reuse, recycling, energy recovery and disposal. According to this hierarchy, first of all, the generation of waste should be prevented during the manufacturing phase in order to keep the quantity of waste generated at a minimum level. Afterwards, the reuse of the wastes, recycling and recovery to obtain energy are followed by the steps. At the bottom of the hierarchy, there is the disposal of wastes that cannot be recovered in various ways.

Figure 2: EU waste prevention hierarchy (Veral and Yiğitbaşıoğlu, 2018)

The waste management process is a very sensitive issue in terms of ensuring sustainability. When sustainable waste management targets are realized today, many environmental problems will be avoided and a good investment will be provided for the future. Sustainable waste management goals are important in this respect. A correct waste management system and sustainable development can only be acquired by acting with the correct management of natural resources and the responsibility to protect the ecosystem. For this reason, a good waste prevention and sustainable development process; It can be associated with a correct management system created against the threat of waste.

4. Zero Waste Management

Zero waste; It is an come close to that aims to prevent waste generation in production, consumption and service stages, to give priority to reuse, and to protect the ecosystem and all resources by collecting wastes that are not suitable for reuse separately, collecting them separately at the source, recycling and disposal. Zero waste management, on the other hand, is expressed as a management system designed by considering cost-benefit factors at all levels, such as prevention of waste generation, reduction of waste, separate collection at source, temporary storage, transportation and processing (Zero Waste Regulation, 2019).

The reason why many countries adopt the notion of zero waste is that it promotes sustainable production and consumption, optimum recycling and resource recycling. The aim of the zero waste management system is to reduce the waste that will occur during the production of the pollution at the source with the most suitable method determined as a result of environmental problems, and to bring these wastes to a minimum with the guidance to be made in the next stage. Within a certain management order of wastes; Implementation of irregular or regular disposal, application of treatment technologies, energy recovery from produced waste, waste recycling and recycling activities are management strategies with high risks and costs. However, systems that include reuse, minimizing the amount of waste and preventing waste at source consist of lower costs and dangers (Cheremisinoff, 2003). Zero waste is a philosophy that provides holistic waste management from source to disposal. Zero waste management hierarchy is given in Figure 3.

Figure 3: Zero Waste management hierarchy

In the differences among the classical waste management hierarchy and the zero waste management hierarchy, the differences at the upper and lower levels are striking. Reuse and recycling maintain moderate levels. Zero waste management is a totalitarian waste management that identify waste as both a resource and a symbol of the unproductive of our modern society. In conventional waste management systems, waste is noted an 'has completed its life' product produced at the final stage of the product consumption period. Zero waste challenges the traditional description of waste by recognizing that waste is the transmutation of resources that occurs at the interim stage of the resource consumption course. Zero Waste Management hierarchy has 7 levels, 2 of which are by product and others by waste.

Reject/Rethink/Redesign: Covers all activities related to stopping level 1 waste at the production stage. At this level, it is aimed to create a new system that can prevent waste or to eliminate the commercialization of disposable products.

Reduction and Reuse: At the 2nd level of the hierarchy, it is to create a non-waste zone and to prevent the disposal of wastes that can be reduced or reused, and to produce solutions to bring them into the economy.

Preparation for Reuse: This is the part about the 3rd level waste area. It corresponds to the 2nd level of the classical waste hierarchy. of waste; It is the level at which reprocessing, separation from the waste state so that it can become a re-product, repair and renewal parts take place.

Recycling/Compost: Level 4 is the stage where the recycling of raw materials that can be separated and recycled within the scope of resource management can be realized. It is expressed as the level of opportunities in the hierarchy. It refers to the 3rd level of the EU classical waste hierarchy.

Material and Chemical Recovery: In the EU classical waste hierarchy, energy is recovered after the recovery level, while in the zero waste hierarchy, the ones that can be valuable among the waste types thrown together are separated and the others are disposed of in a certain order. Basically, a proposal such as "material recovery and biological treatment processes" is put forward to protect the resource value by keeping the cost of waste types at a minimum level with the heat treatment (systems carried out to change the internal structure of a substance) together with the retention of resources and materials, by catching the circular economy harmony.

Waste Management: Current EU waste legislation is obliged to collect active biological waste separately. For the biological stabilization to be carried out on a regular basis, the fulfillment of the obligations regarding the sanitary landfill directive and pre-treatment is essential. Similar systems can be designed according to the increasing and decreasing amount of residual waste of organic materials decomposed by separation at the source.

Unacceptable Waste: In the zero waste hierarchy, choices that temporarily prevent levels, consume limited resources, and cause costs are unacceptable. EU's contrary to the decarbonization agenda and considered as unnecessary investment; It is thought that activities such as the storage of unstabilized waste, the burning or co-incineration of all kinds of unsorted waste should be left in the past.

Zero Waste policy can be applied to companies, communities, industrial sectors, schools and residences, in short, in any field. In bags or equipment used in the zero waste collection system; It uses blue for recyclable waste, brown for compostable waste, green for glass waste, and gray for other waste. Within the scope of zero waste policy, mobile waste collection centers were placed at pilot points determined by the mayors of provinces in Turkey. The mobile waste collection center is indicated in Figure 4.

Figure 4: Waste Retrieval Center

Zero waste violently bolsters sustainability by caring for the environment, by decreasing and generating extra work in recycling and processing waste into the industrial cycle. The Zero Waste strategy includes not only the stated environmental and technological direction, but also the socio-economic and political directions and has many stakeholders. All these features are intertwined with nature and dynamic. For this reason, waste management systems form a mixed cluster from diverse directions. The liabilities of this mixed set are also energetic and close-knit (Song *et al.,* 2015).

Waste management should be regulatory, manageable, effective, efficient and applicable. All these features are directly related to environmental sustainability.

5. 10R Concept

Like the Waste and Zero waste management hierarchy, the 10R concept (Figure 2-3) begins with setting priorities, including strategic goals (Bag *et al.,* 2020). These targets also cover many global key environmental issues, from the circular economy to CO_2 reduction and biodegradable waste. In the circular economy, resources remain in the system for a long time, providing maximum value, and then components are recovered at the end of their life cycle (Kirchherr *et al.,* 2017; Durach *et al.,* 2017). Adopting the 10R-based approach of recycling, rethinking, reducing, reusing, repairing, refurbishing, remanufacturing, repurposing, recycling and recycling means producing cleaner. The 10R approach is a comparatively new notion. Therefore, more research is necessary to shed light on this significant part. The 10R notion is given in Figure 5.

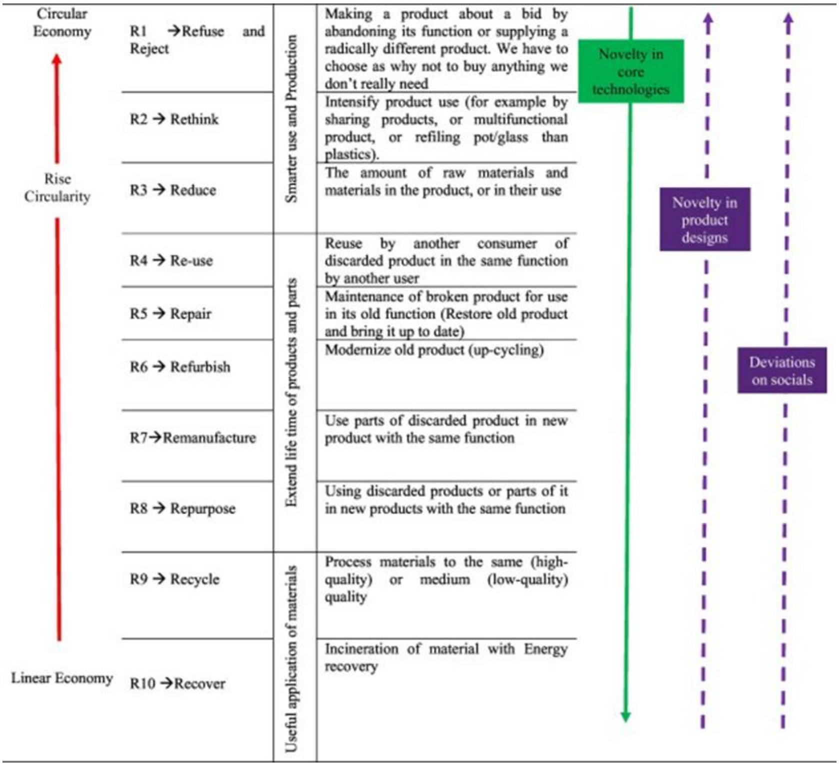

Figure 5: 10R notion (Zorpas, 2020)

As stated in Figure 5, the explanation of the 10R concept is:

(i) Refuse and Reject: Choosing among buying and not buying things that are not needed,

(ii) Rethink: Starting to rethink why something is bought and how to dispose of it.

(iii) Reduce: Reducing the quantity of waste,

(iv) Reuse: Reusing waste,

(v) Repair: Maintaining or restoring the old product,

(vi) Refurbish: Focusing on modernizing legacy products. For example; Tires can be used to grow flowers, and old wood can be used for fences.

(vii) Remanufacture: Handling the use parts that have the same function in the discarded product,

(viii) Repurpose: Use of discarded products or parts thereof in novel products with the identical function

(ix) Recycle: It is the conversion of recyclable wastes into secondary raw materials by physical and chemical processes, excluding energy recovery, and reintroducing them into the production process. For example; such as producing textile products containing fiber from plastic packaging waste, transport containers, waste water pipes, reprocessing paper-cardboard wastes and producing paper-cardboard.

(x) Recover: It is the conversion of waste into another product or energy through physical, chemical and biological processes. Biogas production by breaking down organic wastes under anaerobic conditions and converting biogas into energy are examples of recovery.

As seen in Figure 1, sustainable development policies cover Waste and zero waste management, clean production, circular economy, life cycle, 10R and many more environmental areas. The simplified version of the relationship between sustainable development policies and these areas is given in Figure 6.

Figure 6: 10R's Sustainable Development Policies with relationship

6. In Turkey Waste Management

When the developments in the 1980s are examined, the developed countries have completed the waste management process and have made conceptual phenomena such as "waste ethics", "waste management ethics", "sustainable waste management" seriously a matter of discussion. In Turkey, on the other hand, developments related to these issues took place in the following periods. Environment-oriented approaches and waste management in Turkey were added to the jurisdiction of the Ministry with the establishment of the Ministry of Environment in 1991 (Kanlı and Kavak, 2018). In the following years, progress has been made in this regard and regulations and action plans have been issued.

According to the 2014 Turkey waste distribution data from the 2016-2023 National Waste Management Action Plan; The total quantity of waste generated is 31,115,370 tons. It is examined that the most common type of waste constituted in Turkey is municipal waste with a rate of 87%. 13% of the remaining waste consists of hazardous waste, medical waste, special waste and packaging waste (Figure 7).

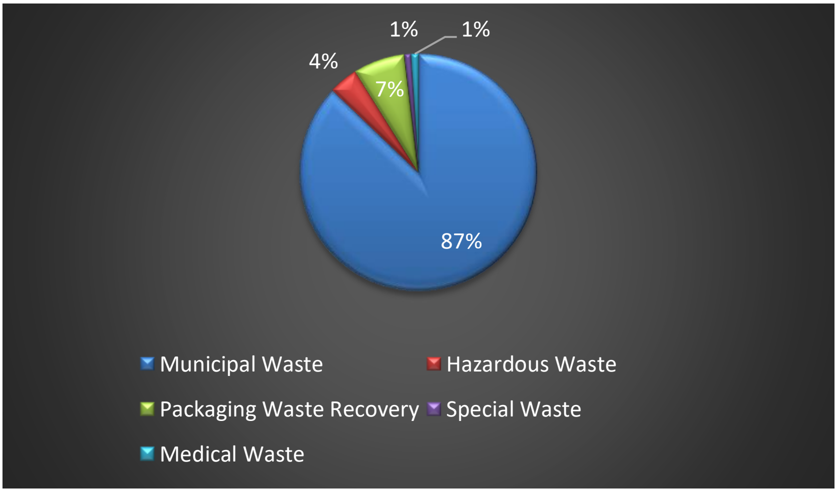

Figure 7: In Turkey Waste Distribution (%) (MEU 2016-2023 National Waste Management Action Plan, 2017)

It is important to recognize the waste characterization in terms of planning and application of waste management. Waste characterization differs from country to country. The quantity of municipal waste generated in Turkey is 27.1 million tons. The amount of waste is anticipated to be 30 million tons in 2018 and 33 million tons in 2023 (ÇMO World Environment Day Turkey Report, 2018). According to the statistics given by TUIK, the average amount of waste per individual is defined as 1.16 kg/person-day (TUIK, 2018).

While waste management in Turkey in the medium and long term is carried out in accordance with demographic, geographical, socioeconomic and technical conditions, the problem is solved with preventive and preventive environmental protection policies. In this context, there is a need for the ministry, other institutions and organizations belonging to the central government, local governments, and first of all, municipalities, business circles, voluntary organizations, associations and individuals to take an active role (Yılmaz and Bozkurt, 2010).

The regular implementation of waste and zero waste management in line with the principles of sustainable development is important to leave a clean and livable country and world for future generations. In recent years, it is known that individual, institutional or local zero waste practices have become widespread throughout the world, and it has become mandatory in public institutions and organizations in 2019 with the zero waste arrangement in Turkey.

FUTURE PERSPECTIVE

Some solution suggestions are presented below to avoid problems in sustainable waste management. These recommendations are:

- Institutions and organizations, local governments should share their duties, authorities and responsibilities.
- Local governments should cooperate with other environmental organizations.
- Institutions should employ experienced personnel.
- Waste management should be controlled, regular and applicable.
- Resources should be used in a balanced and effective manner and should not be wasted.

- Recyclable wastes should be recycled and environmentally friendly activities should be activated.
- The 10R concept should be adopted.
- The zero waste principle is a strategy that targets lifestyle and resource use, aims to prevent waste, increase waste quality, separate collection and recycling. All waste producers should adopt the practices required by the zero waste principle and plan accordingly.
- Sustainable development policies should be taken as a basis in order to leave a clean and habitable world for posterity.
- Advanced technologies should be used in many processes such as waste collection, transportation and disposal.
- Original and applicable projects related to the environment should be implemented.
- Supervision and sanctions should be fully implemented and activities in accordance with regulations should be carried out.

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