World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:18, No:5, 2024

Harnessing the Potential of Renewable Energy Sources to Reduce Fossil Energy Consumption in the Wastewater Treatment Process

Hen Friman

Abstract**—**Various categories of aqueous solutions are discharged within residential, institutional, commercial, and industrial structures. To safeguard public health and preserve the environment, it is imperative to subject wastewater to treatment processes that eliminate pathogens (such as bacteria and viruses), nutrients (such as nitrogen and phosphorus), and other compounds. Failure to address untreated sewage accumulation can result in an array of adverse consequences. Israel exemplifies a special case in wastewater management. Appropriate wastewater treatment significantly benefits sectors such as agriculture, tourism, horticulture, and industry. Nevertheless, untreated sewage in settlements lacking proper sewage collection or transportation networks remains an ongoing and substantial threat. Notably, the process of wastewater treatment entails substantial energy consumption. Consequently, this study explores the integration of solar energy as a renewable power source within the wastewater treatment framework. By incorporating renewable energy sources into the process, costs can be minimized, and decentralized facilities can be established even in areas lacking adequate infrastructure for traditional treatment methods.

Keywords**—**Renewable energy, solar energy, decentralized facilities, wastewater treatment.

I. Introduction

RESIDENTIAL, institutional, commercial, and industrial buildings dispose of wastewater composed of various types of aqueous solutions. To maintain public health and the environment, wastewater must be treated to remove pathogens (bacteria, viruses), nutrients (nitrogen, phosphorus), and other compounds. Various nuisances can result from the accumulation of untreated sewage.

Each year, Israel produces 530 million cubic meters of wastewater, most of which is purified and used for irrigation. Israel has the highest wastewater recovery rate in the world, at about 80% [12]. Agricultural irrigation, tourism, gardening, and industry can then benefit from wastewater treated accordingly. Even today, raw sewage poses a great danger in settlements isolated from the rest of the world or places without sewage collection and transportation networks.

A significant amount of energy is consumed in wastewater treatment processes. An attempt was made in this study to integrate solar energy as a renewable energy source.

With solar energy integrated into the process, costs will be reduced, and it will also be possible to establish decentralized facilities in areas without proper infrastructure for traditional treatment methods.

Bacteria and organic load in wastewater appear to be decreasing according to the results obtained.

A. Wastewater Treatment

Impurities, pesticides, and microorganisms can be much higher in wastewater. When the concentration of impurities is reduced, wastewater can be called water in different forms, which can be used similarly to recycled water. Three main processes are involved in wastewater treatment. A physical process involving screening or straining, sedimentation, flocculation, and filtration. Processes for chemical treatment include adsorption, coagulation, ion exchange, precipitation, and biological treatment with dispersed growth systems (activated sludge, stabilization ponds); fixed film reactors (biological filters such as tricking filters). It is normal for wastewater treatment processes to start with physical processes and then move on to chemical processes such as precipitation [1].

1. Physical Treatment Methods

One common method is sedimentation, which utilizes gravity to separate suspended solids from wastewater. The efficiency of sedimentation tanks differs with designs and operational parameters. Sedimentation is effective in removing settleable solids and heavy particles from wastewater. It has relatively simple operation and low energy requirements. Sedimentation is a well-established technology with widely available equipment. However, it has limitations in removing fine suspended solids and colloidal particles. It also requires a large footprint for settling tanks and may require chemical pretreatment for enhanced removal efficiency [2].

Flotation is highly efficient in removing small and light particles from wastewater. It offers a compact system design with a smaller footprint compared to sedimentation. Flotation is particularly suitable for wastewater with high oil and grease content. However, it requires the addition of chemicals for optimal performance, which leads to higher capital and operational costs compared to sedimentation. There can also be potential difficulties in handling and disposing of the floatation sludge [1].

Filtration provides excellent removal efficiency for fine suspended solids and microorganisms in wastewater. It can be combined with other treatment methods to enhance

Hen Friman is with Faculty of Engineering. H.I.T - Holon Institute of Technology, Holon, Israel (e-mail: henf@hit.ac.il).

performance. Filtration is suitable for various water qualities and can be tailored to specific needs. However, it requires frequent maintenance and replacement of filter media, leading to high operational and maintenance costs. If not correctly maintained, filtration systems can be prone to clogging and reduced flow rates [2].

These physical treatment methods play a significant role in removing suspended solids and particles from wastewater.

2. Chemical Treatment Methods

Chemical treatment methods play a vital role in the removal of contaminants from wastewater, and one such method is coagulation-flocculation.

Coagulation-flocculation is an effective method for removing colloidal particles, turbidity, and dissolved organic matter from wastewater. It also enhances the removal of specific contaminants, such as heavy metals, and improves the performance of downstream treatment processes. However, careful selection and dosing of coagulants are necessary for optimal performance. The generated sludge during coagulation-flocculation requires further treatment and proper disposal. Moreover, this method may result in increased chemical usage and associated costs [2].

Chemical precipitation is another chemical treatment method that demonstrates advantages in removing dissolved heavy metals, phosphorus, and other inorganic pollutants from wastewater. It can be combined with other treatment methods to achieve the desired effluent quality. Chemical precipitation offers relatively simple operation and utilizes widely available chemicals. However, precise control of pH, dosage, and mixing conditions is required for optimal performance. The process generates significant sludge that needs to be properly managed, and additional treatment may be necessary for residual chemical removal [1], [2].

Chemical treatment methods, such as coagulation-flocculation and chemical precipitation, offer effective means of removing contaminants from wastewater. The optimization of various factors, including pH, dosage, and mixing conditions, is crucial to achieve desired treatment outcomes and minimize associated challenges.

3. Biological Treatment Methods

Biological treatment methods, such as activated sludge and aerobic/anaerobic digestion, play a crucial role in wastewater treatment. Activated sludge involves the use of aerobic microorganisms to break down organic matter and remove nutrients from wastewater. It offers several advantages, including high effectiveness in removing organic matter, nitrogen, and phosphorus. Additionally, the compact system design allows for higher treatment capacity in limited space, and it can handle variations in influent characteristics and hydraulic loads. However, activated sludge is sensitive to toxic substances and shock loads, requiring continuous monitoring and operational control. The production and disposal of sludge can also be challenging [3].

Aerobic/anaerobic digestion is another biological treatment method that proves effective in reducing organic matter, pathogens, and odorous compounds. It generates biogas (methane) as a renewable energy source and provides sludge volume reduction and stabilization. However, compared to other methods, aerobic/anaerobic digestion requires longer treatment time. Anaerobic digestion specifically requires additional heating and mixing equipment, and proper management of digestate and biogas handling is necessary [1]. In the context of biological treatment methods, various operational parameters significantly impact the removal of organic matter and nutrients. The studies mentioned in the review investigate the influence of parameters such as sludge retention time and aeration intensity on treatment performance. Additionally, the review explores the use of innovative technologies like sequencing batch reactors (SBRs) to enhance the overall efficiency of biological treatment systems [3].

4. Advanced Treatment Methods

Advanced treatment methods in wastewater treatment have gained significant attention in recent research. Membrane filtration involves the use of different types of membranes, such as microfiltration and reverse osmosis, to effectively remove contaminants from wastewater. The effectiveness of these membranes in removing various pollutants is assessed in the reviewed articles. Furthermore, the review delves into research on advanced oxidation processes, including ozonation and ultraviolet (UV) irradiation, which are utilized for the degradation of persistent organic pollutants in wastewater [4].

Membrane technology has emerged as a favored choice for water reclamation from diverse wastewater streams. It offers numerous advantages in terms of reclaiming water for reuse. However, it is essential to consider the advantages and disadvantages of different membrane technologies, as well as factors like membrane fouling, cleaning, and module design [2]. Membrane filtration plays a crucial role in enhancing the purification process by effectively removing contaminants and ensuring the production of high-quality water suitable for various purposes [4].

Additionally, advanced oxidation processes are employed to degrade persistent organic pollutants in wastewater. Techniques such as ozonation and UV irradiation are effective in breaking down complex organic compounds, ensuring the removal of pollutants that are challenging to treat using conventional methods [2]. These advanced treatment methods provide opportunities for improving the overall efficiency and effectiveness of wastewater treatment processes. Further research and development in this field are necessary to optimize the application of membrane filtration and advanced oxidation processes in wastewater treatment [4].

B. Renewable Energy

The energy field is thriving. This is due to several factors: the world energy crisis, political trends that create a rise in oil prices, and other environmental topics. All of these have brought about the emergence of new and fascinating fields dealing with energy [5]. Over the years, there has been an increase in demand for electrical power [6]. The escalating demands for energy necessitate fossil-fuel power stations to increase their fuel consumption, leading to severe air pollution with detrimental effects on the environment and human health. The current trajectory suggests that we are rapidly approaching a critical threshold in terms of air pollution. To combat this pressing issue, it is imperative to prioritize the adoption of renewable energy sources and energy efficiency technologies. By transitioning away from fossil fuels and embracing renewable energy, we can significantly reduce greenhouse gas emissions and mitigate climate change. Moreover, renewable energy sources emit minimal greenhouse gases and pollutants into the atmosphere, addressing both air pollution and climate-related concerns, renewable energy technologies are becoming increasingly cost-effective, making them a more affordable option compared to traditional fossil-fuel-based power generation [7].

1. Solar Energy

Solar energy is clean energy. It produces no hazardous solid, liquid, or gaseous wastes. It does not create water or air pollution. Direct production of electricity using sunlight is accomplished using photovoltaic cells, also called solar cells. They have no moving parts and are “clean” energy. A major limitation is the cost, which greatly exceeds the cost of producing electricity using fossil fuels or nuclear power [5]. Film solar cells have transformed solar technology by serving as functional roofing materials, offering protection and durability equivalent to traditional asphalt shingles. Some solar cells are designed for concentrated sunlight and integrated into collectors that use lenses to focus sunlight onto the cells. However, this approach is limited to sunny regions and primarily used by electric utilities, industries, and large buildings. Solar cell efficiency, a crucial metric, typically reaches around 15%, meaning only a fraction of sunlight is converted to electricity due to energy limitations and material absorption. Low efficiencies require larger arrays and result in higher costs. The PV industry prioritizes enhancing solar cell efficiencies while managing costs [6]-[10].

II. Local Wastewater Treatment System

In this study, the feasibility of small wastewater treatment systems that would be suitable for treating the wastewater of a single-family unit or a small cluster of family units, depending on the conditions of the area and the amount of wastewater produced, was designed and tested. The designed facilities were ordered from a local energy production system that could also be a prototype for wastewater treatment facilities for emergency use.

A. System Structure

A small distributed wastewater treatment system was established under field conditions. The system was established in southern Israel, near the city of Keith Malachi, an area characterized by solar radiation, typical of Israel.

For energy production, three solar panels were placed towards the south measuring 0.63 m on 0.41 m and at an angle of 31°. The three solar panels are connected to the DC-to-DC charge controller which receives the voltage generated from the solar panels and charges a battery of 24 V batteries connected in parallel to each other. The batteries are connected to a voltage converter from 24 V to 220 V with a power of 600 W. The voltage converter will provide alternating current for the pumps, lighting, and controller (Fig. 1).

A GPRS-type GS828-H2 cellular controller will be installed to monitor and control the filtration system. This controller will transmit control data with the help of a cellular SIM to a server where the data will be saved and analyzed. The controller can receive analog and digital data on the system.

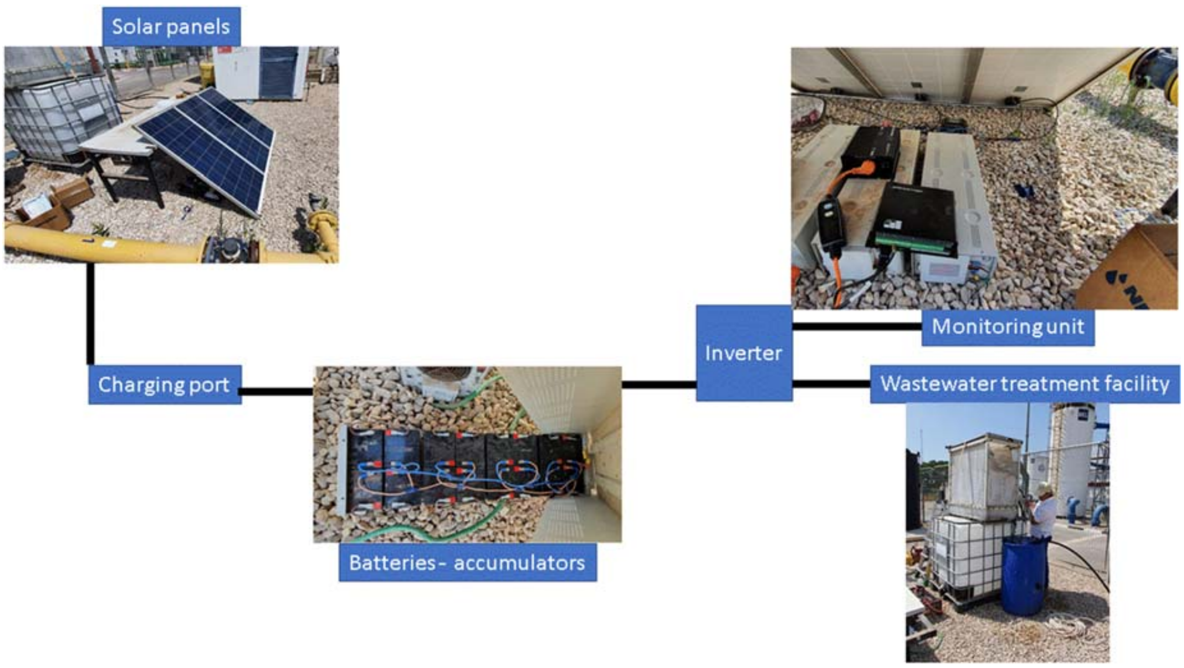

Fig. 1 System structure

III. Results

Effluent quality refers to the standard or level of cleanliness achieved in treated wastewater before its discharge into receiving water bodies or reuse applications. Several indicators are used to assess effluent quality, and these indicators may vary depending on local regulations, water quality objectives, and specific treatment goals. Common indicators for effluent quality include:

A. Turbidity

Turbidity is a measure of the cloudiness or clarity of water caused by suspended particles. A decrease in wastewater turbidity indicates improved effluent quality. Lower turbidity levels indicate that suspended solids, such as particles, sediment, and organic matter, have been effectively removed during the treatment process. Decreasing turbidity levels are desirable as they enhance the aesthetic appeal of the water, improve light penetration for aquatic life, and facilitate disinfection processes.

Activated sludge treatment can achieve effluent turbidity levels below 5 NTU (Nephelometric Turbidity Units). For high-quality treatment plants, turbidity values can be as low as 1 NTU or even less.

B. Biological Oxygen Demand

BOD is a measure of the amount of oxygen consumed by microorganisms during the biological degradation of organic matter in water. A decrease in BOD indicates improved effluent quality. Lower BOD levels signify that a significant portion of the organic pollutants in wastewater has been broken down by bacteria and other microorganisms during treatment. Lower BOD values in the effluent suggest a reduced oxygen demand on the receiving water body, preventing oxygen depletion and minimizing adverse impacts on aquatic ecosystems.

Effluent BOD concentrations after activated sludge treatment typically range from 5 mg/L to 30 mg/L. Well-designed and well-operated activated sludge systems can achieve BOD levels as low as 5 mg/L or even lower.

C. Chemical Oxygen Demand

COD measures the amount of oxygen required to chemically oxidize both biodegradable and non-biodegradable organic compounds in water. A decrease in COD indicates improved effluent quality. Lower COD levels signify a reduction in the concentration of organic pollutants, including complex compounds that may be resistant to biological degradation. Decreasing COD values indicate a lower risk of oxygen depletion, improved water quality, and reduced environmental impact upon effluent discharge.

COD values in the effluent of activated sludge treatment usually range from 10 mg/L to 50 mg/L. Advanced activated sludge systems with additional treatment stages, such as tertiary filtration, can achieve COD levels below 10 mg/L.

D. Total Suspended Solids:

TSS refers to the concentration of solid particles that are retained on a filter when a known volume of water is passed through it. A decrease in TSS indicates improved effluent quality. Lower TSS levels indicate the effective removal of suspended solids, such as sediment, organic matter, and other particulate contaminants. Reducing TSS concentrations in the effluent helps maintain water clarity, prevents sedimentation and clogging of waterways, and supports healthy aquatic ecosystems.

Effluent TSS concentrations from activated sludge treatment commonly range from 5 mg/L to 30 mg/L. Effective solids separation and settling processes in activated sludge systems can produce TSS values as low as 5 mg/L or less.

E. Nutrient Concentrations

Nutrients such as nitrogen and phosphorus are essential for biological growth but can cause water quality issues when present in excessive amounts. Effluent quality is assessed by monitoring the concentrations of nutrients, including total nitrogen (TN), ammonia nitrogen (NH3-N), nitrate-nitrogen (NO3-N), total phosphorus (TP), and orthophosphate (PO4-P). Effective treatment processes aim to reduce nutrient concentrations in the effluent to prevent eutrophication and maintain ecological balance in receiving water bodies.

Activated sludge treatment can significantly reduce nutrient concentrations in the effluent. For example, total nitrogen (TN) concentrations can range from 5 mg/L to 15 mg/L, ammonia nitrogen (NH3-N) concentrations can be below 2 mg/L, and total phosphorus (TP) concentrations can range from 0.5 mg/L to 5 mg/L.

It is important to note that the specific values may vary depending on factors such as the influent wastewater characteristics, treatment plant design, and operational conditions. Effluent quality requirements can also vary based on local regulations and the intended receiving water body or reuse application. These sample values represent typical ranges, but actual values may differ based on site-specific factors and treatment objectives. Regular monitoring and compliance with regulatory standards are necessary to ensure the desired effluent quality is achieved.

In order to evaluate the efficiency and effectiveness of the system, several parameters of the wastewater were measured.

We continuously monitor the effluent temperature, pH, and flow rate. The turbidity values of the wastewater were measured (Fig. 2). These indicators, including turbidity, provide quantitative measurements that help assess the quality of the treated wastewater and ensure compliance with regulatory standards and environmental guidelines. Decreased turbidity levels serve as an essential indicator of the effectiveness of treatment processes in removing suspended particles, enhancing water clarity, and producing high-quality effluent suitable for discharge or reuse.

From Fig. 2, it is evident that the turbidity of the raw sewage was initially measured at 21.5 NTU (nephelometric turbidity units). During the first 80 minutes of the experiment, there was a slight decrease in turbidity. Subsequently, at the 100-minute mark, the turbidity dropped to 16 NTU. After an additional 160 minutes, totaling 260 minutes from the start of the experiment, the turbidity further decreased to 12 NTU. The observed decrease in turbidity indicates an improvement in the quality of the wastewater being treated. Turbidity is a measure of the cloudiness or haziness of water caused by suspended particles such as proteins, minerals, bacteria, algae, dirt, and oil. Higher turbidity values indicate a greater presence of these suspended particles, while lower values suggest clearer and cleaner water. Therefore, the decreasing turbidity observed in the wastewater throughout the experiment implies an enhancement in its quality.

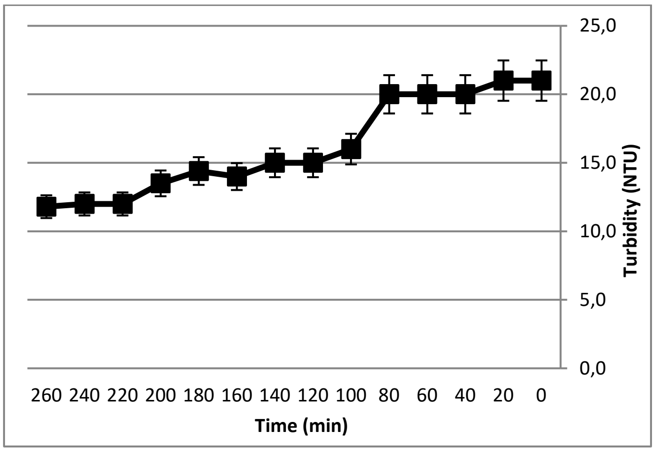

Fig. 2 Turbidity (NTU)

IV. Conclusion

In this research, we propose an approach for treating wastewater by utilizing renewable energy sources. These facilities can serve as small-scale, local treatment plants in areas lacking access to energy and infrastructure. The focus of our work goes beyond the energy source and aims to design an efficient treatment process that yields effluent suitable for various applications. By integrating renewable energy into wastewater treatment, we aim to address the challenges faced by regions with limited resources and contribute to sustainable water management [10]. Conventional wastewater treatment methods often struggle to effectively and economically treat complex and high-strength wastewaters. These wastewaters, such as swine wastewater, pulp wastewater, and dyeing wastewater, contain organic compounds at concentrations much higher than domestic wastewater. However, these high concentrations of organics present an untapped resource of chemical energy that can be recovered as valuable products, including biogas and medium-chain fatty acids. Wastewater generated from biorefineries, in particular, exhibits high organic content but is typically managed using practices that raise safety concerns and require significant energy usage. Our research aims to address the limitations of conventional treatment approaches and explore high-rate technologies that can improve the economic and environmental sustainability of biorefineries by recovering energy and water resources from wastewater [9]. Furthermore, there is a growing recognition of the wastewater industry's potential to contribute to carbon capture and utilization (CCU) efforts. Wastewater treatment plants (WWTPs) are significant energy consumers, accounting for up to 3% of global electricity usage. By re-envisioning wastewater treatment processes, it becomes possible to capture and utilize carbon dioxide (CO_2) simultaneously. Microbial electrochemical and phototrophic processes are among the alternative pathways that can achieve this dual objective, offering environmental and economic benefits. By incorporating CCU capabilities into wastewater treatment, the industry can potentially offset its greenhouse gas emissions and become a significant contributor to negative carbon emissions. To achieve our objectives, further research and development are necessary to design and optimize wastewater treatment processes that harness renewable energy sources effectively. These innovative approaches have the potential to revolutionize the wastewater industry, making it more sustainable, cost-effective, and environmentally friendly. By adopting renewable energy-based treatment methods, we can create self-sufficient and decentralized wastewater treatment systems that provide valuable resources while addressing the water and energy needs of underserved regions [11].

References

[1] A Mojiri, JKB Mohammed (2022)"Wastewater Treatment: Current and Future Techniques", Water 14, no. 3: 448. https://doi.org/10.3390/w14030448

[2] SO Nti, R Buamah, J Atebiya (2021) "Polyaluminium chloride dosing effects on coagulation performance: case study", Barekese, Ghana. Water Practice and Technology, no. 16 (4), pp. 1215–1223. https://doi.org/10.2166/wpt.2021.069

[3] MD Roman, C Sava, DA Iluțiu-Varvara, R Mare, LL Pruteanu, EM Pică, L Jäntschi (2022) "Biological Activated Sludge from Wastewater Treatment Plant before and during the COVID-19 Pandemic", Int J Environ Res Public Health., no.19(18):11323. doi: 10.3390/ijerph191811323

[4] Z Yang, Y Zhou, Z Feng, X Rui, T Zhang, Z Zhang (2019) "A Review on Reverse Osmosis and Nanofiltration Membranes for Water Purification". Polymers (Basel)., no. 11(8):1252. doi: 10.3390/polym11081252

[5] M Kaltschmitt, W Streicher, A Wiese (2007) "Renewable Energy Technology and Environment", Springer-Verlag Berlin Heidelberg.

[6] S Bilgen, K Kaygusuz, A Sari (2004) "Renewable energy for a clean and sustainable future". Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, Vol. 26, no. 12, pp. 1119–1129.

[7] ML Tuballa, ML Abundo (2016) "Renewable and Sustainable Energy Reviews", Vol. 59, pp. 710–725.

[8] H Friman (2017) "New Trends in the Higher Education: Renewable Energy at the Faculty of Electrical Engineering" DOI: 10.1016/j.egypro.2017.05.003.

[9] A Keyhani, NM Mohammad, M Dai (2010) "Integration of Green and Renewable Energy in Electric Power Systems", Hoboken, NJ, USA: John Wiley & Sons, Inc.

[10] KS Krishna, KS Kumar (2015) "A review on hybrid renewable energy systems". Renewable and Sustainable Energy Reviews, Vol. 52, pp. 907-916.

[11] A Rani, SW Snyder, H Kim, et al. (2022) "Pathways to a net-zero-carbon water sector through energy-extracting wastewater technologies". npj Clean Water Vol. 5, no. 49. https://doi.org/10.1038/s41545-022-00197-8

[12] https://www.oecd.org/israel/Water-Resources-Allocation-Israel.pdf