CHEMICAL ENGINEERING TRANSACTIONS
VOL. 105, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: David Bogle, Flavio Manenti, Piero Salatino
Copyright © 2023, AIDIC Servizi S.r.l.
ISBN 979-12-81206-04-5; **ISSN** 2283-9216

DOI: 10.3303/CET231050

Exploring Ways of Making Self-Sustenance in Wastewater Treatment Plants

Zikhona Tshemese*, Nirmala Deenadayalu

Department of Chemistry, Durban University of Technology, Steve Biko Campus, KwaZulu-Natal Province, Republic of South Africa
tshemesez@gmail.com

The increase in population and urbanization have resulted in an increase in the number of wastewater treatment plants in South Africa. Although wastewater treatment plants serve a great purpose in the reduction of environmentally threatening contaminants from wastewater, the increase in energy consumption by these plants raises concerns about climate change. Thus, there has been a rise in literature attempting to map the energy consumption of wastewater treatment plants to help decision-making in the search for alternative energy sources to promote self-sufficient wastewater treatment plants. There has been a proposition of capturing energy from sewers to mitigate the greenhouse gas emanating from energy consumption by wastewater treatment plants. Literature has proven that sewers can produce 10 times the energy required to operate wastewater treatment plants with the correct factors considered including the characteristics of the wastewater being treated, the technology used, and the management practices employed. This has resulted in a rise in the number of studies investigating biogas production from wastewater treatment plants. Although sewage has been proven to be able to produce sufficient biogas to support the energy requirements of wastewater treatment plants to go off-grid. There are still challenges in the implementation of self-sufficient wastewater treatment plants especially in developing countries such as technological barriers and capital investments. Therefore, this paper will investigate possible ways of making wastewater treatment plants more energy sustainable. Out of many approaches of making WWTP sustainable (resource recovery and energy efficiency improvements); energy generation is the main focus of this mini review.

1. Introduction

Water is one of the basic needs for survival and life activities. As much as water is a naturally available resource, there are inadequate amounts of available clean water in most developing nations. On the other hand, industrialized countries are faced with worrying states of water quality (Vasileva et al., 2021). The “not so good” water quality exists due to high levels of pollution as a result of either organic or inorganic pollutants which spread out in different sectors such as agriculture and industry. Commonly found contaminants are heavy metals, carbon compounds, microplastics, phosphates, high levels of nitrates, etc pose a danger to the food chain and life in general (Eerkes-Medrano et al., 2019, Farmer, 2018). Since this is a common issue in many nations, there can never be a single solution to address it, different technologies are therefore required. The existence of wastewater treatment plants (WWTP) looks at addressing this issue, for example, conventional WWTPs are focused on removing suspended solids and reducing biochemical oxygen demand through activated sludge (Wang et al., 2017, Guillossou et al., 2019). This is done by using physical and biological processes where wastewater is treated according to different steps viz preliminary, primary and secondary, tertiary and advanced treatment (Jasim, 2020).
Biological processes focus on secondary treatment where sewage and activated sludge are treated through using mixed microorganisms in a controlled environment aerobically and anaerobically. About 85 % of organic compounds can be removed through secondary treatment while advanced treatment eradicates approximately 90 % of organic matter from water (Jasim, 2020). Wastewater treatment aims to resolve water pollutants by looking at different characteristics as highlighted in Table 1.

3DSHU5HFHLYHG -XO 5HYLVHG 6HSWHPEHU FFHSWHG 2FWREHU
3OHDVHFLWHWKLVDUWLFOHDV7VKHPHVH= 'HHQDGDOX1 ([SORULQJ:DVRI0DNLQJ6HOI6XVWHQDQFHLQ:DVWHZDWHU7UHDWPHQW3ODQWV
&KHPLFDO(QJLQHHULQJ7UDQVDFWLRQV '2,&(7

Table 1: some of the parameters checked during wastewater treatment (Jasim, 2020, Tshemese et al., 2022, Adedeji and Chetty, 2021)

Physical attributes	Chemical attributes	Biological attributes
Temperature		Pathogenic organisms
Colour	Inorganic contents (alkalinity, pH, heavy metals, chloride etc)	
Suspended and total solids	BOD, COD, phenols, surfactants etc	Plants
Odour	Gases (oxygen, carbon dioxide, methane etc)	Protista

2. Wastewater treatment processes

Wastewater treatment is a necessity in the modern world, this is caused by the increase in population which has risen the demand to more than the available supply in many countries. Also, as the population rises urbanization also increases resulting in high levels of pollution of different kinds including water pollution (Gračan and Agbaba, 2021). Since water is a basic need for human survival, therefore, its scarcity is regarded as a crisis which needs imperative intervention and prioritization from both government and private sector. Water pollution in simple terms occurs when one or more substances that negatively alter water are thrown into it (Crini and Lichtfouse, 2019). This alteration then causes problems to the quality of water which then affects humans, animals, and the environment (Ati et al., 2020). Water pollution has been classified into different types elsewhere, but the classifications all evolve from two main sources; the point and the nonpoint. The former refers to pollutants which come from a single source such as discharges from industries into water streams while the latter implies pollutants coming from various sources (Crini et al., 2019, Crini and Lichtfouse, 2019).
Several techniques have been explored for the removal of pollutants in wastewater depending on the contaminants available in each type of wastewater and its characteristics. These include the use of conventional and non-conventional methods which can be further divided into biological, mechanical as well as physicochemical approaches as illustrated in Figure 1. Each of these treatment methods has its advantages such as being cost-effective and ease of operation and disadvantages such as high costs of installation and operation for others (Fahad et al.). Organic and inorganic pollutants found in wastewater are treated by chemical methods such as advanced oxidation processes where purification occurs with an adequate amount of the hydroxyl generated (Vogelpohl and Kim, 2004). This method was later extended to oxidative derivatives with sulphate radicals. Although the method has also been studied for pathogens and pathogenic indicators inactivation, however that application has not been fully explored due to the lack of understanding on the exact mode of action for killing the microorganisms (Ikai et al., 2010, Cho et al., 2005).

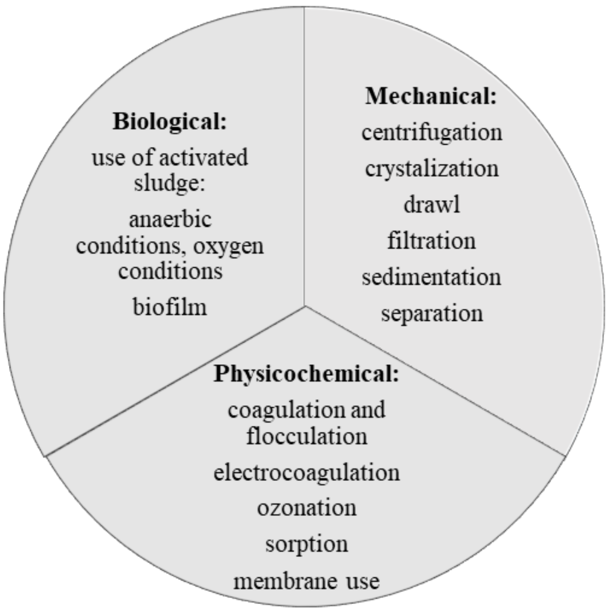

Figure 1: Wastewater treatment methods (Donkadokula et al., 2020, Zajda and Aleksander-Kwaterczak, 2019)

3. Anaerobic Digestion (Biogas) production for self-sustained wastewater treatment plant

Studying the self-sustainability of power in industrial and service facilities such as wastewater treatment plants is a necessity since water pollution is a naturally energy-intensive process. Over the past three decades, substantial increases in energy unit costs have caused an increase in the operating costs of WWTP (Tassou, 1988). Moreover, possibilities of continuous increases in fossil fuel prices and their depletion are a pressing factor which calls for proper management and conservation in WWTP. Wastewater treatment energy requirements are mainly for pumping, primary and secondary treatment, space heating, sludge heating, and disposal (Riley et al., 2020, Tassou, 1988). Use of renewable energy sources to power WWTP whether partially or fully has been deemed to significantly reduce operating costs (Helal et al., 2013). According to the US Environmental Protection Agency (EPA), WWTP with an influent flow rate of less than 19 000 m^3/day does not produce enough biogas to sustain the plant as a renewable source in some areas (Eastern Research Group, 2011). However, the biodegradability of wastewater plays a critical role in determining biogas production which proves to be economically reasonable in small-scale WWTP (Gu et al., 2017). There are added benefits of generating energy from WWTP such as the reduction of waste disposal costs due to minimum waste volume as well as the removal of hazardous contaminants in the wastewater (Mo and Zhang, 2013).

The best way to reduce energy consumption in WWTP is through full exploitation of the biogas from anaerobic digestion. About 50-65 % of energy is obtainable from biodegradable wastewater organics, this biogas is then combusted into thermal energy which can be used to power different components of the plant such as the engine-generator used to generate electricity, and the jacket water from internal combustion can be used in the heating of buildings (McCarty et al., 2011). Another 28-40 % of the initial energy potential can be converted to electricity which is beneficial to WWTP as the plants use electricity for their operations (Curtis, 2010). Electrical load management in wastewater treatment facilities plays a significant role in the conservation of energy where operational processes are transformed thereby reducing peak demands (Golodetz, 1980). The aforementioned data was based on domestic wastewater as a net energy producer study.

Biogas production from WWTP can help mitigate greenhouse gas emissions while contributing in energy sustainability. Greenhouse gas emissions can be classified as direct or indirect depending on where they are sourced from the wastewater treatment process. Direct emissions are associated to activities that emit greenhouse gases directly into the atmosphere, such gases are CO_2, CH_4, N_2O etc (Wang et al., 2023). Notably, greenhouse gas emissions may not be completely eliminated due to some inadequate anaerobic treatment causing some leakages of CH_4 or N_2O to the adjacent environment (Gu et al., 2017).

4. Status quo of biogas production in South African wastewater treatment

In South Africa, there are about 986 (with an increase of 36 plants from 2015) municipal water treatment plant facilities within all nine provinces as shown in Figure 2 (Igwaran et al., 2018, Ochieng et al., 2015). Biogas production in WWTP has been performed at some of these municipalities. As these studies have been conducted for the biogas potential in nine municipalities located in different provinces across the country, several challenges have been identified. These challenges include a lack of in-depth understanding of the exact operation processes at the different WWTP which is required to conduct a realistic analysis of the practical quantity of sludge available to serve as feedstock for digester individual WWTP. Biogas projects yet require a long-term investment with sustainable returns only feasible over a 7–10-year period. Most municipalities reviewed showed interest in these projects, and they saw them as options to gain some degree of independence from the national grid and reduce their energy costs while making their municipalities “green” (Ferry, 2015).

Literature studies have shown the potential of domestic wastewater through anaerobic treatment. However, there has been a concern around the conceptualization of energy production in the balance between input energy needed for the treatment and conversion process, and the output energy obtained from the treatment of waste process (Ramrathan, 2022). In investigating ways to address this concern, research has extended to incorporate efficiency in energy-producing processes (Kollmann et al., 2017, Mei et al., 2016). Some of the energy issues that need to be understood and conceptualized in the treatment of wastes for energy production are related to self-sufficiency (Gude, 2015). This means in an energy self-sufficient production, input energy needs to be lower than output energy, making the process of producing productive.

As mentioned in the article, the need for the augmentation of the energy efficiency of a WWTP is coupled with the optimization of the anaerobic digestion of the sludge. According to (Panepinto et al., 2016), some of the options could be concerning the sludge line and consideration of dynamic pre-thickening together with thermal pre-treatment. Concisely, sludge thickening encompasses conventional gravity settling whereas new dynamic thickening systems, which make use of centrifuges.

The latter has the ability to reduce the volume of the sludge which can lead to a consequent saving of the energy required to heat it inside the digesters. In a different study by the same research group, it was inveterate that centrifugation may lead to a sludge thickness improvement of approximately 3.5% total solids (TS), achieving the self-sufficiency of the plant with regards to thermal energy (Ruffino et al., 2014).

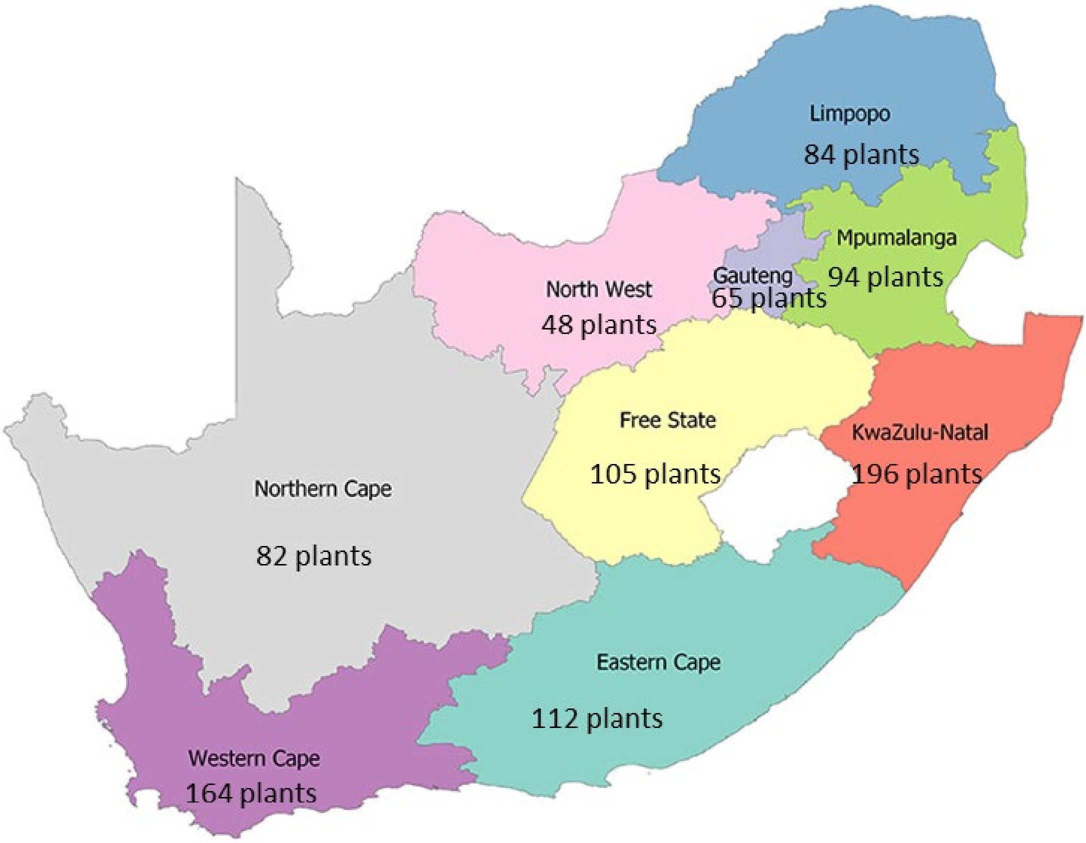

Figure 1: Wastewater treatment methods (Donkadokula et al., 2020, Zajda and Aleksander-Kwaterczak, 2019)

5. Conclusion

Biogas production in WWTP could contribute positively to energy sustainability while reducing greenhouse gas emissions. As much as there are a few challenges which are of concern with this process, there have been ways proposed solutions to aid these issues such as sludge thickening and pre-treatment. Sludge thickening could have the advantage of guaranteeing thermal sustainability of the AD process while TS content of higher than 4% could have negative effects such as rheological behavior. On the other hand, the thermal pre-treatment option has been proven to show advantages when done in shorter time intervals with lower temperatures as opposed to the likely outcome. The disadvantages are however that there is a need for supplementary fuel in these pre-treatment options. Looking at these, it is clear that complete self-sustenance is still far-off from being achieved.

Acknowledgments

The study was funded by the Durban University of Technology.

References

Ati, E. M., Jazar, Z. H., Ajmi, R. N. & Farooq, H. Z. 2020. Water pollution and its relationship to human health: A review, EurAsian Journal of Biosciences, 14.

Cho, M., Chung, H., Choi, W. & Yoon, J. 2005. Different inactivation behaviors of MS-2 phage and Escherichia coli in TiO2 photocatalytic disinfection, Applied and Environmental Microbiology, 71, 270-275.

Crini, G. & Lichtfouse, E. 2019. Advantages and disadvantages of techniques used for wastewater treatment, Environmental Chemistry Letters, 17, 145-155.

Crini, G., Lichtfouse, E., Wilson, L. D. & Morin-Crini, N. 2019. Conventional and non-conventional adsorbents for wastewater treatment, Environmental Chemistry Letters, 17, 195-213.

Curtis, T. P. 2010. Low-energy wastewater treatment: strategies and technologies, Environmental Microbiology, 2.

Donkadokula, N. Y., Kola, A. K., Naz, I. & Saroj, D. 2020. A review on advanced physico-chemical and biological textile dye wastewater treatment techniques, Reviews in Environmental Science and Bio/technology, 1-18.

Eastern Research Group, E. 2011. Inc.(ERG) and Resource Dynamics Corporation,"Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field," US Environmental Protection Agency (EPA) Combined Heat and Power Partnership (CHPP).

Eerkes-Medrano, D., Leslie, H. A. & Quinn, B. 2019. Microplastics in drinking water: A review and assessment, Current Opinion in Environmental Science & Health, 7, 69-75.

Fahad, A., Mohamed, R. M. S., Radhi, B. & Al-Sahari, M. Wastewater and its Treatment Techniques: An Ample, Indian Journal of Science and Technology, 12, 25.

Farmer, A. 2018. Phosphate pollution: A global overview of the problem. Phosphorus: Polluter and Resource of the Future—Removal and Recovery from Wastewater, Institute for European Environmental Policy, 35-55.

Ferry, A., Sofja, G 2015. Biogas potential in selected wastewater treatment plants, South Africa: South African-German Energy Programme (GIZ-SAGEN).

Golodetz, D. 1980. Energy cost conservation seen as future sludge trend, Pascal and Francis.

Gračan, D. & Agbaba, R. 2021. Analysis of crisis situations in nautical tourism, Pomorstvo, 35, 16-22.

Gu, Y., Li, Y., Li, X., Luo, P., Wang, H., Wang, X., Wu, J. & Li, F. 2017. Energy self-sufficient wastewater treatment plants: feasibilities and challenges, Energy Procedia, 105, 3741-3751.

Gude, V. G. 2015. Energy storage for desalination processes powered by renewable energy and waste heat sources, Applied Energy, 137, 877-898.

Guillossou, R., Le Roux, J., Mailler, R., Vulliet, E., Morlay, C., Nauleau, F., Gasperi, J. & Rocher, V. 2019. Organic micropollutants in a large wastewater treatment plant: what are the benefits of an advanced treatment by activated carbon adsorption in comparison to conventional treatment?, Chemosphere, 218, 1050-1060.

Helal, A., Ghoneim, W. & Halaby, A. 2013. Feasibility study for self-sustained wastewater treatment plants—using biogas CHP fuel cell, micro-turbine, PV and wind turbine systems, Smart Grid and Renewable Energy, 4, 227-235.

Igwaran, A., Iweriebor, B. C. & Okoh, A. I. 2018. Molecular characterization and antimicrobial resistance pattern of Escherichia coli recovered from wastewater treatment plants in Eastern Cape South Africa, International Journal of Environmental Research and Public Health, 15, 1237.

Ikai, H., Nakamura, K., Shirato, M., Kanno, T., Iwasawa, A., Sasaki, K., Niwano, Y. & Kohno, M. 2010. Photolysis of hydrogen peroxide, an effective disinfection system via hydroxyl radical formation, Antimicrobial Agents and Chemotherapy, 54, 5086-5091.

JASIM, N. A. 2020. The design for wastewater treatment plant (WWTP) with GPS X modelling, Cogent Engineering, 7, 1723782.

Kollmann, R., Neugebauer, G., Kretschmer, F., Truger, B., Kindermann, H., Stoeglehner, G., Ertl, T. & Narodoslawsky, M. 2017. Renewable energy from wastewater-Practical aspects of integrating a wastewater treatment plant into local energy supply concepts, Journal of Cleaner Production, 155, 119-129.

McCarty, P. L., Bae, J. & Kim, J. 2011. Domestic wastewater treatment as a net energy producer–can this be achieved?, ACS Publications.

Mei, X., Wang, Z., Miao, Y. & Wu, Z. 2016. Recover energy from domestic wastewater using anaerobic membrane bioreactor: Operating parameters optimization and energy balance analysis, Energy, 98, 146-154.

Mo, W. & Zhang, Q. 2013. Energy–nutrients–water nexus: Integrated resource recovery in municipal wastewater treatment plants, Journal of Environmental Management, 127, 255-267.

Ochieng, A., Onyango, M. S., Thokozani, M., Esmail, S., Leswifi, T., Sophia, R. & John, K. 2015. Water and Wastewater Management in Local Government: Skills Needs and Development, Chemical, Materials and Metallurgical Engineering, 127.

Panepinto, D., Fiore, S., Zappone, M., Genon, G. & Meucci, L. 2016. Evaluation of the energy efficiency of a large wastewater treatment plant in Italy, Applied Energy, 161, 404-411.

Ramrathan, Z. 2022. Evaluation and optimisation of biogas production in municipal wastewater treatment plant using computational intelligence approach: potential to generate electricity, M.Eng Thesis, Durban University of Technology, South Africa.

Riley, D. M., Tian, J., Güngör-Demirci, G., Phelan, P., Villalobos, J. R. & Milcarek, R. J. 2020. Techno-Economic Assessment of CHP Systems in Wastewater Treatment Plants, Environments, 7, 74.

Ruffino, B., Campo, G., Zanetti, M. & Genon, G. 2014. Improvement of the anaerobic digestion of activated sludge: thermal and economical perspectives, WIT Transactions on Ecology and the Environment, 190, 979-991.

Tassou, S. 1988. Energy conservation and resource utilisation in waste-water treatment plants. Applied Energy, 30, 113-129.

Vasileva, E., Parvanova-Mancheva, T. & Beschkov, V. 2021. Biological approaches in wastewater treatment, Journal of Chemical Technology & Metallurgy, 56.

Vogelpohl, A. & Kim, S.-M. 2004. Advanced oxidation processes (AOPs) in wastewater treatment, Journal of Industrial and Engineering Chemistry, 10, 33-40.

Wang, Q., Wei, W., Gong, Y., Yu, Q., Li, Q., Sun, J. & Yuan, Z. 2017. Technologies for reducing sludge production in wastewater treatment plants: State of the art, Science of the Total Environment, 587, 510-521.

Wang, Q., Li, X., Liu, W., Zhai, S., Xu, Q., Nie, S., Ouyang, Q., Wang, H. & Wang, A. 2023. Carbon source recovery from waste sludge reduces greenhouse gas emissions in a pilot-scale industrial wastewater treatment plant, *Environmental Science and Ecotechnology,* 14**,** 100235.

Zajda, M. & Aleksander-Kwaterczak, U. 2019. Wastewater Treatment Methods for Effluents from the Confectionery Industry–an Overview, Journal of Ecological Engineering, 20.