Self-supporting Wastewater Treatment Technology: A Review

Dr. Pushpendra Kumar Sharma[1], Deepak Kumar Gupta[2], Faizan Shafi Bhat[3], Kashif Shafi Mir[4], Md Ajijur Rahman[5], Mehwish Qayoom[6]

[1]*Professor, SCE, Lovely Professional University, Phagwara, 144411, Punjab, India*

[2,3,4,5,6]*UG Scholar, SCE, Lovely Professional University, Phagwara, 144411, Punjab, India*

***Abstract* - Wastewater treatment utilizes a huge amount of energy which we get from the grid. From last many years many research have been done to reduce or minimize the energy consumption and to increase the renewable energy from the wastewater treatment. This review presents the aspects which can guide technologists to move towards low energy or no energy wastewater treatment. This review is to present systematic approaches to achieve energy neutral condition in wastewater treatment. This review contains methods for reducing energy consumption and increasing the energy recovery to supplement with the extra external renewable energy.**

1.INTRODUCTION

Wastewater treatment requires an ample amount of energy and if the energy used is delivered from external grid running on fossil fuels, greenhouse gas emission is induced which increases the global temperature. The wastewater treatment industry is one of main energy consuming industry and has developed a lot of technologies to improve the efficiency but practically there is not a single prescribed scenario for self-wastewater treatment. Therefore, increasing the efficiency of wastewater treatment technologies to manage energy consumption ensures the sustainability [1].

There are many factors that influence the energy consumption in wastewater treatment like the process of treatment, treatment technologies knowledge and skill of treatment etc. The energy consumption can be as low as 0.25kWh/m3 and as high as 1kWh/m3 [1].

Energy from the sun which is considered as the most abundant source of renewable energy can be utilized in the wastewater treatment plant for increasing the temperature there by increasing the rate of reactions and for dewatering the sludge that results in volume reduction of sludge up to 50-60%. Solar energy can be used for many more activities in WWTP like it can provide electricity for biological treatment etc.

As far as energy utilization in wastewater treatment is concerned the transportation and treatment of wastewater consumes nearly 4% of the electricity produced by US [2], in Europe it is about 1% [3] and in Spain it is about 2-3 % [4]. It is forecasted that requirements of electricity will increase by 20% in the developed countries by the next 15 years [5].

Obviously, the utilization of wind energy has many limitations still it can be used as a renewable source of energy without emitting pollutants or releasing gases into the atmosphere [6].

Developing country face problem regarding wastewater treatment plant due to need of large area and high investment. Expanding energy expenses and worries about worldwide environmental change feature the need to acknowledge energy independence in WWTPs. The researchers practically build up energy independent WWTPs which indirectly contribute less carbon emission economically. Wastewater treatment plant plays a vital role to contribute a lot to our environment. It is difficult to degrade completely wastewater containing with having a toxin and contamination electrochemical technology has potential to treat sustained environmental and having high and cost efficiency [7]. Wastewater treatment plants (WWTPs) are generally actualized to lessen emission outflows to getting water bodies. In the ongoing years as both water and energy are basic components. Around 25-40% of working costs is ascribable to energy utilization. To decrease net energy utilization for wastewater treatment is a corresponding not an alternative objective to water reuse [8].

It is said that the environmental contamination with the rapid increase of the population and due to the poor sewage system affect the hygienic of the people and suffer illness. After making the sewage system brings life and everything back in the balance situation wastewater treatment plant needed 1 percentage of the total electricity consumption globally. To fulfill the requirement of the electricity consumption expected to increase 60 percentage to the total capacity within the year of 2040, because of the increase in the demand [9], 68% of the population will be settled in the urban areas as the urbanization is increasing rapidly. The energy consumption shares in wastewater plant is 84% of the electric energy and 15 % of the mechanical energy. in aeration process about 78% of the electric energy is consumes. The chemical oxygen demand, total nitrogen, biological oxygen demand, and total phosphorous, and total suspended solids are calculated for the effluent of the treatment plant. Due to the wastewater treatment 76-97% reduction occurs [10].

2. LITERATURE REVIEW

Biological wastewater treatment processes are using nowadays as compare to the chemical and the physical methods. Energy consumption plays a vital role in order to provide more energy efficiency. In order to make plant a self-energy driven and utilizing the minimum energy they introduced a modelling consist of, 107 thermal solar panels, 2.85-MW photovoltaic panel, and 99-m-deep geothermal heat pump. With the help of this modelling, they achieve annual electricity of 5,750,000 kWh of power and having a 7,300,300 L hot water at 50 °C. This hot water can be utilized to heat wastewater and used for the purpose of drying [11].

Wastewater treatment plants (WWTPs) are classical case of water-energy interactions. With the number of WWTPs increasing and the effluent quality requirements becoming more demanding, the issue of energy efficiency of WWTPs has been attracting increasing attention all over the globe. In this paper, we review how the electricity consumption in a WWTP located in eastern China was calculated, and the feasibility of energy self-sufficient was analyzed through scenario analysis. Two parallel paths, reducing energy consumption and increasing the conversion of wastewater to usable energy, and four scenarios that were studied were reviewed. The results showed that combined heat, power, and solar photovoltaic cells technology can generate energy for WWTP. Furthermore, energy self-sufficient WWTPs can be realized through energy saving technologies and application of renewable energy.

Water and energy are critical resources for global sustainable development. In today’s world, water-energy nexus has become a high-priority issue. The water sector is energy intensive, while energy sources require water supplies. Meanwhile, water supply and sanitation services provided by urban water and wastewater utilities consume considerable amount of energy. Wastewater treatment plants (WWTPs) are typical case of water-energy interactions, where the water quality is improved at the cost of energy consumption. As fundamental tools for improving urban water environment, WWTPs have increased dramatically during last few decades. The energy consumption of WWTPs is related with influent wastewater, treatment progress, effluent standard, etc. This paper reviews the influence from policy side over WWTP structure by use of scenario analysis. The paper focuses on the “energy for water”, offering evaluations of energy consumption in WWTPs. By analyzing the current efficiency of energy consumption of WWTPs, the paper explores the feasibility of energy self-sufficiency in WWTPs. The paper explores the water-energy nexus in WWTPs, providing the theoretical basis for improving energy management system of WWTPs, as well as formulation of energy policy.

Scenario analysis was conducted to provide information and alternative images for future development of WWTP under different external conditions. The analysis serves as a strategic support for policy makers in dealing with uncertainties. Different scenarios were calculated under the assumption of different treatment progress. Firstly, a baseline scenario was established. Then two alternative WWTP working scenarios focusing on energy reduction and reuse were identified. Finally, a combined scenario taking advantages of aforementioned three alternative cases together is set to find their contributions to energy efficiency improvement. The details and assumptions for each scenario are described as follows: 1) baseline scenario, WWTP will run as present; 2) alternative scenarios, WWTP takes technologies and better management to reduce energy consumption, including combined heat and power (CHP), and solar photovoltaic power (PV); 3) combined scenario, 4) WWTP takes the advantages of alternative scenarios [12].

The author puts forward four scenarios. Scenario A (Baseline) represents the ‘treatment as usual’ situation of the WWTP; Scenario B represents the WWTP that increases energy efficiency from wastewater through combined heat and power technology; Scenario C represents the WWTP that produces energy through solar photovoltaic cells; and Scenario D combined these two paths to produce energy in the WWTP system. In scenario A, it is assumed that the influent wastewater keeps increasing in a steady rate due to which the WWTP is expanding to its fourth phase, and the treatment capacity will double when finished. Thus, it is predicted that the daily influent wastewater of nearly 120,000 m3 in 2020 through linear extrapolation. And the electricity intensity is 0.30 kWh/m3, which is the average value with the technological process. Therefore, the electricity consumption of WWTP in 2020 will reach about 1.31 × 107 kWh. Besides, green energy from renewable and/or unused energy sources (e.g., thermal energy from wastewater) are available in WWTP [12].

WWTPs may have the potential of 20%-40% energy saving, and some WWTPs can even reach 75%. As the WWTP is newly built, thus the energy efficiency is considered high when compared to other WWTPs with the same technology. In the following three scenarios, energy savings are assumed by improving efficiency in unit processes, and the energy efficiency in primary treatment and advanced treatment are improved through technological innovation. Then, the electricity consumption comes out to be 1.23 × 107 kWh in 2020 [12].

In scenario B, CHP technologies can generate both electricity and heat from a single fuel source at the same time. Recent efforts in WWTPs were focused on the energy reduction of consumption and on the diversion of organic carbon to anaerobic digestion to produce energy through the combustion of biogas in a CHP system. And CHP system using the anaerobic digestion of sludge is the technology most adopted in existing energy efficient WWTPs, such as in Strass (Austria). An average of 1 kg COD can generate 3.5 m3 biogas, then produce electricity for 38.5 kWh of electricity. Here, the NZE WWTP Theoretical Model proposed by Yan et al. [20] was used to calculate the theoretically reclaimed electricity. The average ratio of theoretically reclaimed electricity to actual electricity consumption from 2012 to 2016 was 0.40, which means that nearly 40% of energy consumption can be reclaimed by CHP. The theoretical energy claim rate was lower than various WWTPs in the study by Yan et al. [20], and this is mainly due to the low COD of influent wastewater in this WWTP. Then, the energy reclaimed by CHP in 2020 will be 4.91 × 106 kWh [12].

In scenario C, the authors calculated the energy produced through solar photovoltaic power. In this scenario, energy production was simulated by PVsyst, which is a software package for the study, sizing, simulation, and data analysis of complete PV systems. Through importing basic data of the WWTP (e.g., site) and designed photovoltaic facilities (e.g., model type, technology, mounting disposition, ventilation property and other details of photovoltaic facilities). Authors designed the nominal power of 90 MWp, using monocrystalline cells. Then the WWTP can get nearly 1.04 × 107 kWh of electricity [12].

In scenario D, the authors combined energy saving and renewable energy (CHP, PV) together. In the WWTP, the electricity consumption in 2020 will be 1.23 × 107 kWh. And energy produced by CHP, PV will be 4.91 × 106 kWh, and1.04 × 107 kWh, respectively [12].

The energy self-sufficient WWTPs can be achieved by two parallel paths, reducing the energy required for the removal of solids, organics, and nutrients, and increasing the conversion of organics to usable energy. Both of these paths require innovative technologies to achieve the goal. In this study, the main energy consumption is electricity. The electricity produced by single renewable energy technology may not meet the electricity demand for wastewater treatment, hardly to reach energy balance. If useable heat and solar energy were taken into account, the solution would be energy positive, which is clear in scenario D. If more organic energy is captured from wastewater than is used for wastewater treatment, external energy input is not required; thus, an independent and self-sufficient energy recycling system may be established. In the scenario analysis, energy production by PV is remarkable. Authors simulated the PV system in the WWTP and found that the energy produced by PV is nearly equal to the electricity consumption. In other words, if the WWTP adopts PV of nearly 9,000 m2, and it can supply most of the electricity demand, although the land footprint and cost should not be ignored. In addition, the pursuit of energy self-sufficiency should not be achieved at the expense of effluent quality. Therefore, authors have not lowered the effluent wastewater standards, keeping it satisfy the first grade A of Discharge standard of pollutants for municipal wastewater treatment plant [12].

Enhancement of energy productivity is significant for wastewater treatment plants Increasing energy costs and concerns about global climate change highlight the need to realize energy self-wastewater treatment plants. Self-wastewater treatment plants have been studied to reduce operation costs, energy consumption and achieve carbon neutrality. In this paper, researchers analyzed the energy consumption and recovery in wastewater treatment plants and characterized the comprehensive influence factors of energy use in wastewater treatment plants including treatment techniques, treatment capacity and different regions. It is possible to establish self-wastewater treatment plants, although there are still challenges for the implementation of self-wastewater treatment plants [13]

A supply of clean water is an essential requirement for human activities. Nowadays many water resources are polluted by human and industrial activities wastewater treatment represents 0.1 to 0.3% of total energy consumption and within local city and community government Furthermore, energy for wastewater treatment is increase in the future due to increasing population [14] Wastewater can be considered various source of energy :biogas from anaerobic digestion, electrical energy from bio electrochemical wastewater treatment process, chemical energy and heat energy. Waste heat from wastewater is able to generate electrical energy via thermoelectric generator, self-wastewater treatment plants create other benefits for the environment, like a reducing greenhouse gas and it also creates jobs [15].

Generating electricity from waste water- A microbial fuel cell (MFC) is a gadget that utilizes microorganisms as biocatalysts to change substance energy into power Microbial fuel cells (MFCs) convert the energy available in biodegradable substrates such as glucose, sucrose, and starch; low sub-atomic weight natural acids, for example, acetic acid derivation, oxalate, and fumarate; and amino acids directly into power through the synergist action of electrochemically dynamic microbes joined to the terminal. These microscopic organisms can oxidize natural mixes to carbon dioxide and move electrons to the anode; at that point, electrons go through an outer circuit to the cathode to deliver current [16].

Benefits of self-Wastewater treatment plants are like; Energy production-as the world needs more energy to help growing populations and expanding cities utilizing waste for energy is an economical source, economic benefits- Sludge-to-energy systems reduce the need for more costly and polluting forms of power, for example petroleum, decrease greenhouse effect and increase employment [17].

[18] Studied the energy-self-sufficient biological municipal wastewater reclamation, its present status, challenges faced and the solution for the future. While studying the topic they first of all stated the art of the current biological process, which is that there are a lot many varieties of conventional activated sludge processes that aim for the removal of COD and nitrogen from the wastewater. Nitrification and oxidation of carbon is done in the aeration tanks wherein the effluent is recycled back to the anoxic tank for de-nitrification. The current biological municipal wastewater treatment has been challenged by the high amount of energy it takes to treat wastewater whereas it itself generates so much of energy. The Energy consumption by the plant is 0.3-0.6kWh per cubic meter [19]. Major consumers of energy in the WWTP are the aeration and the post treatment of the activated sludge which includes its dewatering and thickening [20]. According to a report energy consumption of 0.23kWh/m3 for both COD and nitrification while as only 0.14 kWh/m3 of electric consumption for only COD removal [21]. After the studies of the high energy consumption by the plant efforts are made to reduce the consumption of energy by improving the aeration efficiency. A study says that 50% to 30% of the total energy is consumed by the aeration and treatment of sludge [22], [23]. This energy consumption highly depends on the treatment capacity, effluent quality, configuration, characteristics of the influent, status of the instruments and equipment [24]. There are two main challenges faced i.e., the high energy consumption and the generation of waste activated sludge. The amount of sludge growth lies between 0.3-0.5 d dry biomass/g COD removed as a result a huge amount of wastewater sludge is inevitably generated in municipal wastewater reclamation. With no doubt these both will have a negative impact on the global wastewater sector in

terms of environmental and economic sustainability? As the saturation in terms of land use is increasing day by day due to the rapid urbanization, due to which landfill may no longer solve the problem of handling WAS, while incineration of WAS has been expensive as well as harms environment due to the toxic emissions. Therefore, handling of WAS is still a big challenge and requires more research and efforts.

After studying all the aspects of wastewater, it was found that it is a unique pool of energy in itself. A survey presents that unit energy consumption is average at about 0.45 kWh/m3 [20]. For municipal wastewater having 500 mg/L of COD, for one gram of COD energy consumed to oxidize is 1620 kJ m3 500 g COD m3 =3.20 kJ/g COD, while the potential energy ranges between 14.7 to 17.8 kJ free energy/g COD with an average of 16.2 kJ/g COD [25], [26] which indicated it is 5 times of the electrical energy needed for wastewater treatment, which means it is a great source to turn the plant into a self-sufficient if converted into electrical energy. The potential energy generally is recovered from anaerobic digestion of biosolids which also includes primary and secondary sludge. About 73% of total recoverable energy can be obtained from anaerobic treatment of wastewater [27]. The combined heat and power generation to improve the energy situation is to be implemented for maximizing the total methane conversion to useable electricity, which is almost impossible or highly challenging. Therefore, there has to be some technological solution that will be efficient to make the wastewater treatment self-efficient.

To attain the self-sufficiency of a WWTP, COD should be ideally captured for direct energy recovery before biological process. This novel process has the advantages of improved energy efficiency, low energy used for aeration, minimized WAS production., and reduced cost associated with posttreatment. A method of adsorption or bio-oxidation was first reported by [31] which introduced a concept of high loading A stage and low loading B-stage. Further the concept was modified. In this process A-stage is particularly specified for enhancing the COD capture from municipal wastewater with an aim for direct anaerobic digestion of captured COD before biological oxidation, while as B-stage is specified for particularly for removing nutrients [27]. Based on the above analysis on energy, the energy obtained from the process generated was expected to offset the energy used for wastewater reclamation i.e., 3.2 kJ per gram COD removed, if about 65% of total COD in municipal wastewater with 500 mg/L of COD can be retained at A-stage for direct anaerobic digestion. The energy obtained at stage a can be lowered at stage B. The principle is based basically on minimizing energy consumption, creating a situation where the energy recovery is comparatively larger than the energy consumption within the plant and is regarded as the feasible approach for making self-sufficient biological process.

An integrated A-B process towards energy self-sufficient municipal wastewater reclamation has two paths i.e., integrated high-rate activated sludge and mainstream de ammonification and Integrated. In which de ammonification provides a more efficient nitrogen removal pathway. The high COD/N ratio of municipal wastewater is a main hindrance as it triggers the over-competition of denitrifies against anammox bacteria [28]. To reduce it High rate activated sludge process operating a short sludge retention time and a short hydraulic retention time helps to reduce influent COD by 55-65% [29]. The captured COD is then ready for biogas generation [30]. The Strass WWTP adopted a two-stage biological treatment process in which it operated in the similar way as HRAS process. The COD balance in this plant shows that 74.3% of the COD was channeled to the digester for biogas production with 38.9% digest produced [29]. This shows 35.4% of COD ended up as methane gas, which was much lower than that achieved with anaerobic treatment as the lead a stage [32]. The difference in energy recovery efficiency might be because anaerobic process usually has higher COD removal efficiency compared with HRAS process [27]. Besides, in HRAS the efficiency of converting captured COD to biogas is comparatively low.

The wastewater should not be seen as a “waste” that is of no use but has sufficient energy and useful substances. By the process of time the reclamation of energy from wastewater should move a step further to the synergetic recovery of power. The primary wastewater treatment plant should be considered as water factory that is able to reclaim water for different uses. The modern design WWTP are largely based on the oxidation philosophy, as such a large amount of potential energy in wastewater is lost, but at the cost of ample amount of energy input to carry out biological oxidation of organic and nitrogenous compounds with production of greenhouse gases like carbon dioxide. China's municipal wastewater has been growing substantially in the past decade, and already reached 42.16 billion tons in 2012. Assuming 0.4 kWh of electrical energy is required for the treatment of 1 m3 of municipal wastewater, the total energy consumption would stand at 16.86 billion kWh of electrical energy in China. Despite the fact that municipal wastewater is full of energy with the averaged potential energy of 16.2 kJ/g COD, equivalent to 2.25 kWh/m3 at a COD concentration of 500 mg/L. If an anaerobic process is chosen as A-stage, the total energy recoverable from methane gas produced was about 0.51 kWh/m3, which is based on 500 mg/L of COD in wastewater and 35% of the conversion [32].

4. CONCLUSIONS

After reviewing all the existing and current research there is still some challenges that have to be overcome regarding self-sufficient wastewater treatment plants which is exactly the research gap identified. There is an urgent need of sustainable wastewater treatment process. Sustainable wastewater treatment processes must be developed to decrease energy consumption of WWTPs. Improvement of energy efficiency is the trend for WWTPs, as well as improvement of effluent quality. Therefore, through scenario analysis, it was found that energy self-sufficient WWTPs are possible through energy-saving technologies and renewable energy production. And the latter is the tendency of WWTPs' development. Besides, it is clear that the building of CHP and PV facilities will consume some energy as well as the chemicals (e.g. polyacrylamide, flocculants, hypochlorous acid and etc.), which was neglected in this study. For a real energy self-sufficient WWTP, the authors should have considered these factors.

REFERENCES

[1] Maktabifard, M., Zaborowska, E. & Makinia, J. Achieving energy neutrality in wastewater treatment plants through energy savings and enhancing renewable energy production. Rev Environ Sci Biotechnol 17, 655–689 (2018). https://doi.Org/10. 1007/s11157-018-9478-x

[2] U J, Li Y, Wang H et al (2017) Exploring the feasibility of energy self-sufficient wastewater treatment plants: a case study in eastern China. Energy Procedia 142:3055–3061. https://doi.Org /10.1016/ j.egypro.2017.12.444

[3] Hussmann M (2009) Improving energy efficiency in wastewater treatment: What emerging countries can learn from experience gained in the developed world. http://siteresources. worldbank .org/EXTWAT/Resources/4602122-1213366294 492/5106220-1234469721549/213_Energy_effic iency.pdf.

[4] Longo S, d'Antoni BM, Bongards M et al (2016) Monitoring and diagnosis of energy consumption in wastewater treatment plants. A state of the art and proposals for improvement. Appl Energy 179:1251–1268. https://doi.org/10.1016/j.apenergy.2016.07.043

[5] Yan P, Qin RC, Guo JS et al (2017) Net-zero-energy model for sustainable wastewater treatment. Environ Sci Technol 51:1017–1023. https://doi.org /10. 1021 /acs.est.6b04735

[6] Gu Y, Li Y, Li X et al (2017) The feasibility and challenges of energy self-sufficient wastewater treatment plants. Appl Energy 60:402–409. https://doi.org/10.1016/j.apenergy.2017.02.069R eturn to ref 2017 in article

[7] Tianlong Zheng et.a.l (2015) ," Research trends in electrochemical technology for water and wastewater treatment" springer link volume 7, 26 March 2015, Pages 13–30 DOI 10.1007/s13201-015-0280-4

[8] Yifan Gu et.al (2017) "Energy Self-sufficient Wastewater Treatment Plants: Feasibilities and Challenges" Energy Procedia Volume 105, May 2017, Pages 3741-3751 doi.org/10.1016/j. egypro. 2017. 03.868

[9] Henriques et.al (2020) "Leveraging logistics flows to improve the sludge management process of wastewater treatment plants" Journal of Cleaner Production 7 June 2020, doi.org/10.1016 /j.jclepro.2020.122720

[10] Sharawat et.al. (2020) "Analysis of a wastewater treatment plant for energy consumption and greenhouse gas emissions" International Journal of Environmental Science and Technology published on 9 August 2020 doi.org/10.1007 /s13762-

[11] Gürtekin.E. (2018) "Experimental and numerical design of renewable-energy-supported advanced biological wastewater treatment plant"

International Journal of Environmental Science and Technology Published online: 29 October 2018 doi.org/10.1007/s13762-018-2088-x

[12] Jin Xu, Yue Li, Hongtao Wang, Jiang Wu, Xin Wang, Fengting Li- Exploring the feasibility of energy self-sufficient wastewater treatment plants: a case study in eastern China.

[13] ifan Gua, Yue Lia, Xuyao Lia, Pengzhou Luoa, Hongtao Wanga*, Xin Wangb, JiangWub, Fengting Lia (2017) Energy self-sufficient wastewater treatment plants: feasibilities and challenges Energy Procedia 105 (2017)3741–3751 https: //www.sciencedirect.com/science/article/pii/S1876610217309530

[14] Ashlynn S. Stillwell 1, *, David C. Hoppock 2 and Michael E. Webber 3(2010) Energy Recovery from Wastewater Treatment Plants in the United States: A Case Study of the Energy-Water Nexus Sustainability 2010, 2, 945-962; doi: 10. 3390/su2040945 https://www.google. com/url?sa=t&source=web&rct=j&url=https://www.mdpi.com/2071-1050/2/4/945/pdf&ved= 2ahUKE wiGkaqM7MLsAhVZzjgGHR2TCRIQFjABegQICRAC&usg=AOvVaw2bqiPBzafb5INkuYKNPyUM&cshid=1603185956588

[15] Daniele Cecconet*, Jakub Racek, Arianna Callegari and Petr Hlavínek. Energy Recovery from Wastewater: 22 December 2019 https:// www. researchgate.net/publication/338108090_Energy_Recovery_from_Wastewater_A_Study_on_Heating_and_Cooling_of_a_Multipurpose_Building_with_SewageReclaimed_Heat_Energy/link/5dff160392851c8364909c6b/download

[16] Harshal D. Kawale*, Anil C. Ranveer, Abhijit R. Chavan. Electricity generation from wastewater using a microbial fuel cell by using mixed bacterial culture. September 2017 https://www.researchgate.net/publication/319981317_Electricity_generation_from_wastewater_using_a_microbial_fuel_cell_by_using_mixed_bacterial_culture.

[17] U.S. ENVIRONMENTAL PROTECTION AGENCY 2013 https://www.google.com/url?Sa=t& source=web&rct=j&url=https://www.epa.gov/sites/production/files/2015-08/documents/wastewater-guide. pdf&ved=2ahUKEwib_63futfsAhVywTgGHfiaAGAQFjAAegQIFBAB&usg=AOvVaw0-JVKm2aA35Lc 3yTG6z1yG

[18] Liu, Y-J., Gu, J., Liu, Y., "Energy-self-sufficient biological municipal wastewater reclamation: present status, challenges and solutions forward", Bioresource Technology (2018), Available at: https://doi.Org/10. 1016/j.biortech.2018.08.104

[19] McCarty, P.L., Bae, J., Kim, J., 2011. Domestic wastewater treatment as a net energy producer--can this be achieved? Environ. Sci. Technol. 45, 7100-6.

[20] Zhou, Y., Zhang, D.Q., Le, M.T., Puah, A.N., Ng, W.J., 2013. Energy utilization in sewage treatment – a review with comparisons. J. Water Clim. Change 4, 1-10.

[21] Goldstein, R., Smith, W., 2002. Water & sustainability (volume 4): US electricity consumption for water supply & treatment-the next half century. Electric Power Research Institute.

[22] Henderson, M., 2002. Energy reduction methods in the aeration process at Perth wastewater treatment plant. University of Strathclyde, renewable energy systems and the environment MSc individual thesis.

[23] Owen, W.F., 1982. Energy in wastewater treatment. Prentice-Hall, Inc.,Englewood Cliffs, NJ, United States.

[24] Jenkins, D., Wanner, J., 2014. Activated sludge-100 years and counting. IWA publishing.

[25] Heidrich, E.S., Curtis, T.P., Dolfing, J., 2011. Determination of the internal chemical energy of wastewater. Environ. Sci. Technol. 45, 827-32.

[26] Shizas, I., Bagley, D., 2004. Experimental Determination of Energy Content of Unknown Organics in Municipal Wastewater Streams. J. Environ. Eng. 130, 45-53.

[27] Wan, J., Gu, J., Zhao, Q., Liu, Y., 2016. COD capture: a feasible option towards energy self-sufficient domestic wastewater treatment. Sci. Rep. 6, 25054.

[28] Xu, G., Zhou, Y., Yang, Q., Lee, Z.M., Gu, J., Lay, W., Cao, Y., Liu, Y., 2015. The challenges of mainstream deammonification process for municipal used water treatment. Appl. Microbiol. Biotechnol. 99, 2485-90b

[29] Wett, B., Buchauer, K., Fimml, C., 2007. Energy self-sufficiency as a feasible concept for wastewater treatment systems. IWA Leading Edge Technology Conference. Singapore, pp. 21-24.

[30] Wett, B., Omari, A., Podmirseg, S.M., Han, M., Akintayo, O., Gomez Brandon, M.,

[31] Murthy, S., Bott, C., Hell, M., Takacs, I., Nyhuis, G., O'Shaughnessy, M., 2013. Going for mainstream deammonification from bench to full scale for maximized resource efficiency. Water Sci. Technol. 68, 283-9.

[32] Böhnke, B., 1977. Das adsorptions-belebungsverfahren. Korresp. Abwasser, 24, 33-

[33] Gu, J., Yang, Q., Liu, Y., 2018. Mainstream anammox in a novel A-2B process for energy-efficient municipal wastewater treatment with minimized sludge production Water Res.138, 1-6.