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Municipal Wastewater Treatment Technologies: A Short Review

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ABSTRACT: The aim of this study was to evaluate different municipal wastewater treatment technologies for commercial use and develop an optimized system for a case study plant and future plant designs. Municipal wastewater, classified as a low-strength waste stream, can be treated using aerobic and anaerobic reactor systems or a combination of both. Aerobic systems are suitable for low-strength wastewaters, while anaerobic systems are suitable for high-strength wastewaters. Malaysia has actively implemented various wastewater treatment technologies to address the increasing demand for clean water and reduce environmental pollution. Some commonly used technologies in Malaysia include Activated Sludge Process (ASP), Membrane Bioreactor (MBR), and Moving Bed Biofilm Reactor (MBBR). These technologies show promise in removing emerging pollutants, such as pharmaceuticals and personal care products, which are not effectively eliminated by conventional treatment methods. Additionally, Malaysia could consider investing in renewable energy sources like solar and wind to power wastewater treatment plants, thereby reducing reliance on non-renewable energy and supporting sustainable development. It is also important to emphasize continued public awareness and education initiatives to promote responsible wastewater disposal practices and environmental stewardship.

KEYWORDS: Activated sludge process; membrane bioreactor, moving bed biofilm reactor; municipal wastewater

1. Introduction

Water scarcity, resource depletion, and global warming pose significant challenges on a global scale, emphasizing the critical importance of developing technologies that can address these issues by providing clean water and clean energy. With increasing populations and growing demands, access to clean water has become limited, while natural resources are being depleted at an alarming rate. Additionally, global warming and climate change exacerbate these challenges, further straining water supplies and energy sources [1]. Therefore, there is an urgent need to explore and implement innovative technologies that can ensure the sustainable production of clean water and renewable energy, mitigating the impacts of these global challenges and fostering a more sustainable future [2]. In this context, municipal wastewater treatment plant effluents have emerged as a potential source of renewable energy. These effluents contain significant chemically bound energy within the organic pollutants, which can be harnessed to generate useful energy carriers, such as biogas, while simultaneously producing recyclable and reusable by-products [3]. Municipal wastewater, categorized as a low-strength waste stream, represents a substantial portion of wastewater worldwide. These waste streams are characterized by low organic strength and high particulate organic matter content. As governments tighten regulations on pollution discharge, industries that achieve compliance can also benefit from additional revenue streams [4].

Municipal wastewater treatment is a vital process that can be achieved through various methods, including the utilization of aerobic and anaerobic reactor system setups, or a combination of the two. Aerobic systems involve the use of oxygen to facilitate the breakdown of organic matter in the wastewater, while anaerobic systems operate in the absence of oxygen, relying on specialized microorganisms to break down organic substances. Aerobic systems are suitable for the treatment of low-strength wastewaters, while anaerobic systems are suitable for high-strength wastewaters. Anaerobic treatment requires less energy and has the potential for bioenergy and nutrient recovery, but aerobic treatment achieves higher removal of soluble biodegradable organic matter, resulting in lower effluent suspended solids concentration and generally higher effluent quality [5, 6]. The combination of these two approaches offers the potential for enhanced treatment efficiency and improved removal of pollutants. By employing these diverse wastewater treatment technologies, municipalities can effectively address the challenges associated with wastewater management, safeguard public health, and protect the environment from the harmful effects of untreated wastewater discharge. The choice of technology to implement for municipal wastewater treatment is highly dependent on the desired product and the quality of the feed. The desired product can be effluent, biogas, or other products. The quality of the feed is dependent on the influent, i.e., municipal wastewater [5, 7]. Thus, it is essential to review the available municipal wastewater treatment technologies in Malaysia, which can help in developing an optimized municipal wastewater treatment system for a case study plant and future plant designs.

2. Municipal Wastewater Treatment Technologies

In developing countries, wastewater treatment technologies often face unique challenges due to limited resources, infrastructure constraints, and financial limitations. However, several common wastewater treatment technologies are implemented in these regions to address the pressing need for effective sanitation and pollution control [8]. Septic tanks are commonly used in rural and peri-urban areas. They provide basic treatment by separating solids from wastewater and allowing microbial degradation to occur in the anaerobic environment. Although septic tanks are relatively simple and cost-effective, they require regular maintenance and proper emptying to prevent groundwater contamination [8, 9]. Constructed wetlands have gained popularity in developing countries as a natural and low-cost treatment option. Wetlands mimic the natural purification processes by utilizing plants, microorganisms, and soil to remove pollutants. They are particularly suitable for decentralized wastewater treatment and can be integrated into agricultural and urban landscapes [9]. Malaysia has been actively implementing various municipal wastewater treatment technologies to address the increasing demand for clean water and the need to reduce environmental pollution. Some of the most commonly used municipal wastewater treatment technologies are Activated Sludge Process (ASP), Membrane Bioreactor (MBR), and Moving Bed Biofilm Reactor (MBBR) [10, 11].

2.1.Conventional Activated Sludge Process (ASP).

One of the major municipal wastewater treatment technologies implemented in Malaysia is the Conventional Activated Sludge Process (ASP). It is a biological process that uses microorganisms to break down organic matter in wastewater, resulting in clean water that can be safely discharged into the environment. This process is widely used because of its simplicity, efficiency, and effectiveness in removing pollutants from wastewater. The ASP process involves the use of a biological reactor, which is a large tank that contains microorganisms, oxygen, and wastewater. The microorganisms in the reactor consume the organic matter in the wastewater and convert it into carbon dioxide, water, and new microbial cells. The oxygen is provided to the reactor by aerating the wastewater, which creates a turbulent environment that promotes mixing and allows the microorganisms to thrive [12, 13].

Conventional activated sludge process in municipal wastewater treatment is shown in Figure 1**.** The ASP is divided into two stages: the biological stage and the settling stage. In the biological stage, the microorganisms consume the organic matter in the wastewater, producing carbon dioxide, water, and new microbial cells. This stage usually lasts for a few hours, depending on the quality of the wastewater and the efficiency of the system. In the settling stage, the wastewater is allowed to settle, and the suspended solids and microorganisms settle to the bottom of the tank. This stage usually lasts for several hours, allowing the solids to settle and separate from the treated water. The treated water is then discharged into the environment, while the settled solids are removed and disposed of appropriately [14].

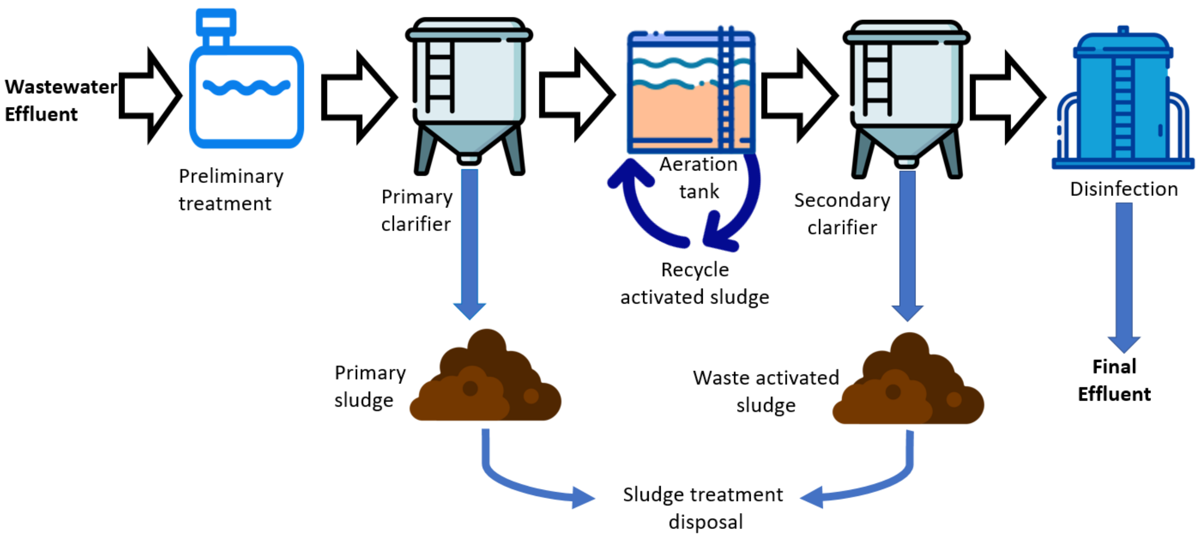

Figure 1. Conventional activated sludge process in municipal wastewater treatment [Icon from Flaticon Basic License CC3.0 (Creative Commons)].

One of the advantages of the ASP is its ability to remove a wide range of pollutants from wastewater, including organic matter, nitrogen, and phosphorus. It is also a relatively low-cost technology that requires minimal equipment and maintenance. Additionally, the ASP can be modified and optimized to meet specific treatment goals, such as increased nutrient removal or reduced sludge production [12, 14]. The effectiveness of the conventional ASP in removing contaminants from wastewater is dependent on various factors, including the quality of the influent wastewater, the operational parameters of the ASP system, and the efficiency of the sludge settling process. In general, the ASP is capable of achieving high removal rates for biodegradable organic matter, suspended solids, and nutrients from wastewater [15].

2.2.Membrane Bioreactor (MBR) Process.

The Membrane Bioreactor (MBR) process is an advanced wastewater treatment technology that combines conventional biological treatment with membrane filtration. It has gained significant attention in recent years due to its effectiveness in producing high-quality treated effluent. The MBR process utilizes a membrane barrier, typically made of microfiltration or ultrafiltration membranes, to separate the suspended solids and microorganisms from the treated wastewater. This results in a more efficient removal of contaminants, including suspended solids, bacteria, viruses, and some dissolved substances. MBR Process for municipal wastewater treatment is a relatively new and innovative technology that combines the traditional activated sludge process (ASP) with membrane filtration. In the MBR process, the wastewater is treated by a biological reactor that uses microorganisms to break down organic matter, and then the water is filtered through a membrane to remove suspended solids and other impurities. The MBR process has several advantages over traditional wastewater treatment methods, including a smaller footprint, higher treatment efficiency, and better water quality [4]. The MBR process is highly effective in removing contaminants from municipal wastewater. The process can remove up to 99% of organic matter, suspended solids, and pathogens, which makes it an excellent choice for areas with strict water quality standards. The MBR process also removes nutrients such as nitrogen and phosphorus, which can cause eutrophication in water bodies if discharged untreated [16, 17].

One of the key advantages of the MBR process is its ability to operate at higher MLSS concentrations than the conventional ASP. This allows for a smaller footprint of the treatment plant, which is especially important in urban areas where land is at a premium. The smaller footprint also reduces the environmental impact of the treatment plant and makes it more aesthetically pleasing. Another advantage of the MBR process is its ability to produce high-quality effluent, which can be used for non-potable purposes such as irrigation or industrial processes. The effluent produced by the MBR process is free from suspended solids, bacteria, and viruses, which makes it suitable for a wide range of uses. In addition, the MBR process can produce effluent with low nutrient concentrations, which can be beneficial for certain industrial processes [16, 18]. The MBR process is also highly flexible and can be easily adapted to different treatment requirements. The process can be designed to handle a wide range of wastewater characteristics, including high-strength and low-strength wastewater. This flexibility allows the MBR process to be used in a wide range of applications, from small-scale decentralized systems to large municipal wastewater treatment plants [16, 19]. MBR has been shown to achieve high removal rates for suspended solids, biological oxygen demand (BOD), total nitrogen (TN), and total phosphorus (TP). Studies have reported that MBR can achieve up to 99% removal of suspended solids and BOD, and up to 90% removal of TN and TP. These high removal rates are attributed to the filtration properties of the membrane, which allows for finer filtration of particles and microorganisms [20, 21]. Membrane Bioreactor (MBR) Process for municipal wastewater treatment is shown in Figure 2.

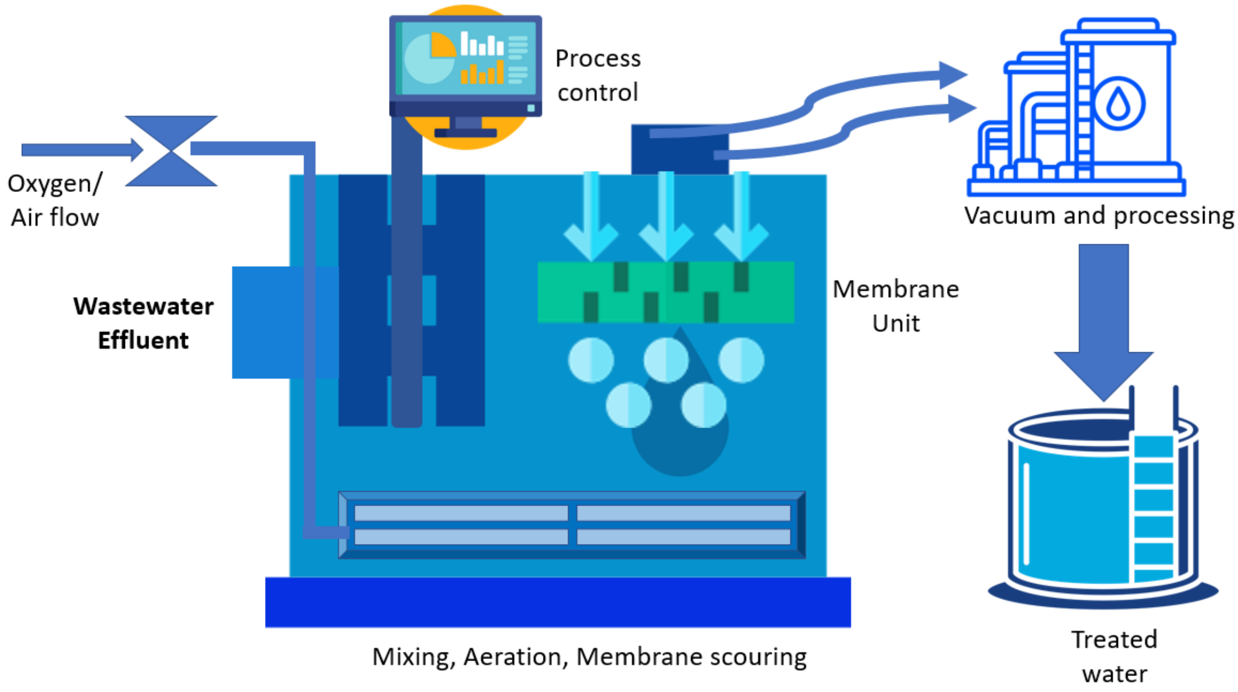

Figure 2. Membrane Bioreactor (MBR) Process for municipal wastewater treatment [Icon from Flaticon Basic License CC3.0 (Creative Commons)]..

2.3.*Moving Bed Biofilm Reactor (MBBR) Process*.

Moving Bed Biofilm Reactor (MBBR) process is an innovative technology that has been adopted for municipal wastewater treatment in recent years [22]. This process utilizes biofilm growth on mobile plastic carriers that move freely within the reactor. The plastic carriers have a large surface area for bacterial growth, allowing for the establishment of a robust microbial community that effectively removes organic pollutants from the wastewater [23]. The MBBR process is a cost-effective and efficient method for the treatment of low-strength municipal wastewater [24, 25]. In the MBBR process, wastewater is introduced into the reactor, where the plastic carriers move freely and come into contact with the wastewater. The biofilm attached to the plastic carriers breaks down the organic matter present in the wastewater, converting it into carbon dioxide, water, and biomass. The biomass is then separated from the treated water through a secondary sedimentation tank. The treated water can then be discharged or reused [27, 28]. Moving Bed Biofilm Reactor (MBBR) for municipal wastewater treatment is shown in Figure 3**.**

One of the significant advantages of the MBBR process is its high removal efficiency of organic pollutants. Studies have shown that this process can remove up to 95% of organic matter from municipal wastewater [24, 29]. Furthermore, the process is highly adaptable and can handle fluctuations in flow and organic loading. The MBBR process can also be used in conjunction with other treatment processes, such as activated sludge or anaerobic digestion, to further enhance its efficiency [30, 31]. The MBBR process is also highly cost-effective, as it requires lower capital investment and maintenance costs than other treatment processes. The system has a small footprint, which allows for easy installation and operation, making it an ideal choice for small to medium-sized wastewater treatment plants [25, 32].

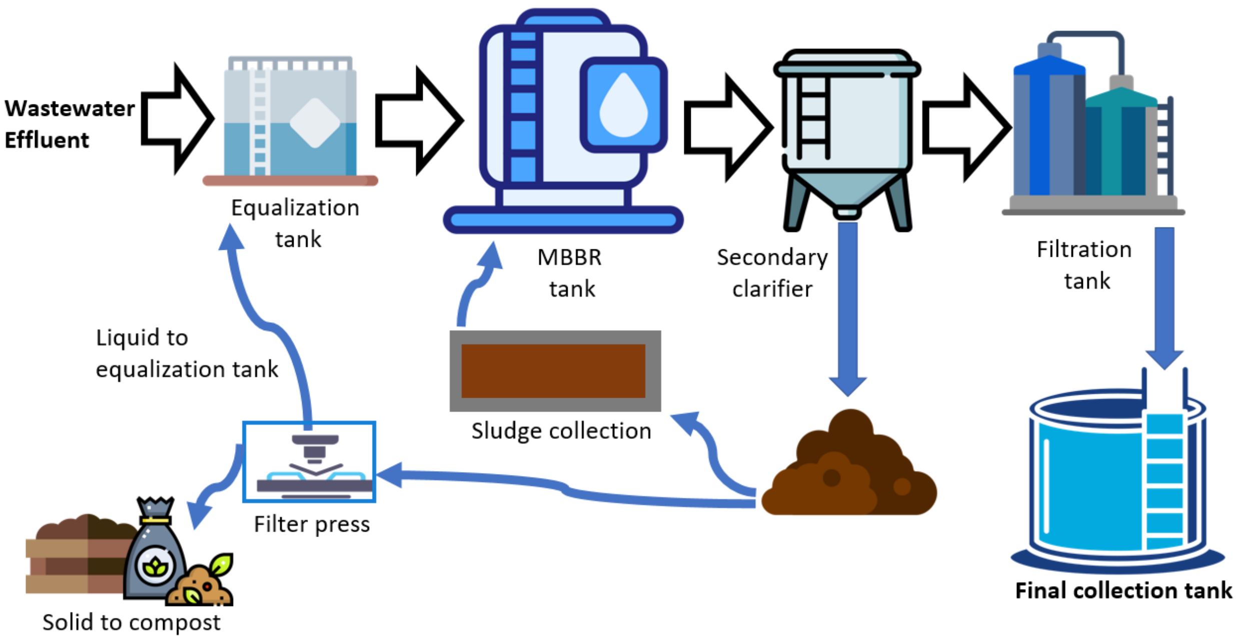

Figure 3. Moving Bed Biofilm Reactor (MBBR) for municipal wastewater treatment [Icon from Flaticon Basic License CC3.0 (Creative Commons)].

3. Conclusion

Over the past few decades, Malaysia has made significant advancements in municipal wastewater treatment technologies, resulting in several advanced technologies being widely implemented throughout the country. ASP, MBR, and MBBR are among the most widely used technologies, which have been effective in removing pollutants from wastewater and reducing the environmental impact of untreated wastewater discharge. The ASP technology has been successful in removing nutrients like nitrogen and phosphorus from wastewater when BNR is included. The use of microorganisms in BNR can convert nitrogen and phosphorus into forms that can be removed from the wastewater through the settling process, resulting in a removal efficiency of 70% to 90%. MBR technology is highly effective in removing contaminants from municipal wastewater, and can remove up to 99% of organic matter, suspended solids, and pathogens. It is an excellent choice for areas with strict water quality standards as it can remove nutrients like nitrogen and phosphorus, which can cause eutrophication in water bodies if discharged untreated. MBBR is an innovative technology that has been adopted for municipal wastewater treatment in recent years. It uses biofilm growth on mobile plastic carriers that move freely within the reactor, providing a large surface area for bacterial growth. This allows for the establishment of a robust microbial community that effectively removes organic pollutants from the wastewater. For future directions, Malaysia could explore the integration of advanced technologies like electrocoagulation and membrane distillation into their wastewater treatment processes. These technologies have shown promise in the removal of emerging pollutants such as pharmaceuticals and personal care products, which are not effectively removed by conventional treatment processes. Additionally, Malaysia could invest in the use of renewable energy sources such as solar and wind to power their wastewater treatment plants, reducing reliance on non-renewable energy sources and contributing to sustainable development. Finally, there should be a continued emphasis on public awareness and education programs to encourage responsible wastewater disposal practices and promote environmental stewardship.

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