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Challenges of Moving Bed Biofilm Reactor and Integrated Fixed-Film Activated Sludge Implementation for Wastewater Treatment in Indonesia

Firdaus Ali[a,*], Chris Salim[b], Dwi Lintang Lestari[c], Khalidah Nurul Azmi[c]

[a]Universitas Indonesia, Depok, 16424, Indonesia
[b]Podomoro University, Jakarta, 11470, Indonesia
[c]Indonesia Water Institute, Tanjung Barat, South Jakarta, 12530, Indonesia
firdausali@ymail.com

Environmental damage caused by improper wastewater treatment is a global problem, especially in developing countries such as Indonesia. With limited land availability, cost, and human resources, one of the potential technologies that excels in terms of cost-effectiveness is biological treatment technology. Moving Bed Biofilm Reactor (MBBR) and Integrated Fixed-Film Activated Sludge (IFAS), as modifications to conventional activated sludge, utilize solid media that are either suspended or fixed in the reactor to enhance the biological growth of microorganisms to improve the treatment efficiency. Despite the common researches and practices of MBBR and IFAS for the treatment of wastewater in many countries, the implementations of these technologies in Indonesia are still minimal due to lack of understanding of the principles of these methods, particularly IFAS. The aim of this study is to present a review of MBBR and IFAS and to analyze the challenges of implementing both technologies in Indonesia for better understanding of the principles and a more balance use of these technologies according to their advantages in different cases of wastewater treatment. The application of MBBR technology using small-size suspended media distributed in the reactor is more commonly found in Indonesia due to ease of implementation, especially when it is applied as improvement to the existing wastewater treatment systems. IFAS technology using a fixed media introduced into the reactor requires more modifications and redesign compared to MBBR when applied to an existing system. Comparison of both technologies as designs for a new wastewater treatment plant showed that IFAS requires shorter hydraulic retention time and less energy to operate than MBBR. The costs for both systems are roughly the same. In conclusion, MBBR and IFAS have their own advantages that can be applied to wastewater treatment in Indonesia with MBBR suitable for improving existing activated sludge system and implementation of IFAS in new facility design to achieve a more efficient and economical operation. The review in this study can be used to broaden the perspective of wastewater treatment practitioners, facility owners and government officials in choosing and applying MBBR and IFAS technologies in specific cases of wastewater treatment.

1. Introduction

Environmental pollution, specifically the one caused by wastewater disposal, is gaining attention both in the developed and developing countries (Kamyab et al., 2018). As a developing country, the water pollution is still an important issue in Indonesia. One of the major causes is the lack of proper facilities to treat large quantities of wastewater. Due to high economy and population growths, the demand of clean water resources in every sector continues to rise. Many largely populated cities in Indonesia have already started undertaking remediation projects and implementing stricter control on wastewater treatment efforts to increase the availability of clean water resources. Suitable wastewater treatment technologies are also introduced to help improve the effluent quality from the treatment facilities.

Biological treatment that relies on biochemical activities of microorganisms and/or larger water organisms in neutralizing and removing pollutants is an effective method to treat wastewater containing organics pollutants.

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According to Bhunia (2014), biological treatment is more cost-effective that other treatment processes, e.g. chemical treatment, thermal treatment or advanced oxidation, in terms of initial and operating/maintenance costs, making this method preferable in an integrated wastewater treatment plant.
Conventional activated sludge (CAS) as one of the biological treatment methods was used extensively due to its simplicity and cost-effectiveness. This method requires a relatively large area and space due to long hydraulic retention time (HRT), a value that determines how long the wastewater remains in the treatment system. In order to meet with increasingly stricter policies on wastewater quality and to cope with the diminishing land availability, a more efficient technology such as Moving Bed Biofilm Reactor (MBBR) or Integrated Fixed-Film Activated Sludge (IFAS) was introduced to improve CAS by overcoming these obstacles and provide sufficient treatment performance (Lariyah et al., 2016). IFAS has been widely used in other countries, for example wastewater treatment plant (WWTP) in Hopedale replaced CAS with IFAS to meet the wastewater quality standard for ammonia in wastewater (Ye et al., 2010). WWTP of Cocalico Valley Poultry Farms was also retrofitted with a submerged structured sheet media IFAS system in 2010 to treat the poultry wastewater (Zhu et al., 2012). Christensson et al. (2011) reported the use of MBBR to treat municipal wastewater and also to provide anammox bacteria seeds that are grown inside MBBR media in Sweden. MBBR is also used as secondary treatment at City Center treatment plant in Isfahan, Iran (Hadei et al., 2015). Despite the common researches and practices of MBBR and IFAS for the treatment of wastewater in many countries, the implementations of these technologies in Indonesia are still minimal due to lack of understanding of the principles of these methods, particularly IFAS.
The aim of this study is to present a review of MBBR and IFAS technologies and to analyze the challenges of implementing both technologies in Indonesia for better understanding of the principles and a more balance use of these technologies according to their advantages in different cases of wastewater treatment.

2. Principles of MBBR and IFAS

CAS is an aerobic biological treatment method that utilizes biomass in the form of suspended flocs to mainly treat and remove organic pollutants in wastewater. In this method a part of sludge separated from treated wastewater is recirculated back to the aeration tank to maintain a certain biomass concentration required in the system.
Both MBBR and IFAS can be considered as improved versions of CAS method, with MBBR designed without recirculation of sludge, while IFAS has the sludge recirculation system similar to CAS as shown in Figure 1. The porous solid media, whether suspended or fixed, improves the treatment performance of CAS by increasing the specific surface area for attached-growth biomass in the form of biofilm which contributes directly to the pollutant removal. Börner and Trübenbach (2017) recommended using pollutant removal rate per volumetric unit of solid media instead of surface area of the porous media for a more accurate performance evaluation. The study also highlighted the risk in comparing the performance of media based on the surface area alone. It is very important for the media supplier or manufacturer to provide the performance data of media in details as assumptions and estimations in designing the system could cause discrepancies between design and actual operation in the field.

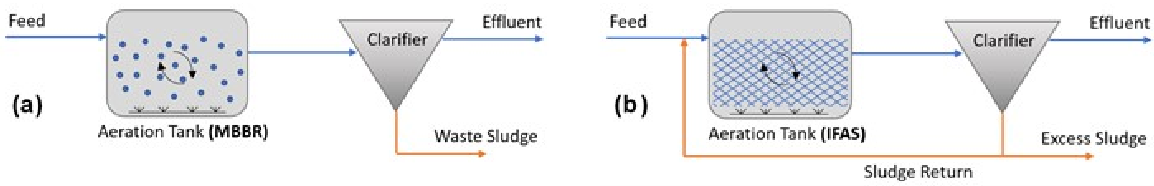


Figure 1: The schematic diagrams of (a) MBBR with suspended media and (b) IFAS with fixed media

Huang et al (2016) suggested that biomasses flocs contribute more to chemical oxygen demand (COD) removal compared to biomass attached to MBBR or IFAS solid media. The results could also lead to an indication that a synergy between suspended flocs and biofilms on solid media as nitrification and denitrification platforms exists. This could lead to an improved nitrogen removal performance in the combination of MBBR or IFAS with suspended flocs which is achieved by applying recirculation of sludge collected in the clarifier.
In MBBR process, small plastic media (Figure 2a) distributed and suspended in wastewater using continuously mixed reactors is commonly used as support for biofilm growth. This media containing attached-growth biomasses has several advantages that cannot be found in conventional system, e.g. improving nitrification process and creating local anoxic condition suitable for denitrification process. Based on research

conducted by Zimmerman et al. (2005), MBBR showed flexibility to be used in almost all tank of sizes or shapes.

The amount of media used in MBBR can be adjusted easily depending on reactor size and wastewater loading rate as proven in WWTP of Soekarno-Hatta airport, a project of Indonesia Water Institute (IWI), where a MBBR system with adjustable media filling capacity was successfully applied to cope with the difficulty of wide range in daily wastewater discharge rate. With rigorous mixing in MBBR to suspend the solid media, the dead space, where wastewater and solids are stagnant, is almost non-existing. With this mechanism, MBBR helps eliminate bad odor that could be produced by localized anaerobic condition (Water Online, 2012). MBBR can also be used to upgrade overloaded activated sludge, trickling filter, or other processes. Based on the study conducted by Hadei et al. (2015), application of MBBR on optimizing wastewater treatment system, followed by a rapid sand filter produces a more effective treatment system to remove high level of suspended solids and organic matters. The small porous or perforated media of MBBR can achieve higher specific surface area compared to IFAS with fixed bulky media. Since the solid media is suspended continuously, MBBR is also not affected by clogging that can reduce performance of the treatment system. Improper installation of IFAS media has been known to cause clogging problems in real practice in Indonesia according to practitioners in wastewater treatment. MBBR could be adapted to various combinations of processes or be used in a single system (Ødegaard et al., 2000). This is due to the high concentration of biofilms that help protect the system from failures during the process.

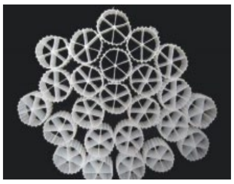
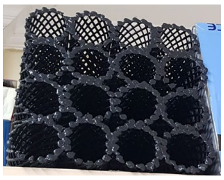
a)  b)  c) 

Figure 2: (a) MBBR media, (b) and (c) IFAS media used in projects of Indonesia Water Institute

IFAS system has been introduced to overcome the problem of land availability and the high construction cost of wastewater treatment facility. A primary advantage of IFAS compared to CAS is the ability to provide higher amount of biomass in the aeration tank that increase the treatment capacity and performance of the system (Saknenko et al., 2015). The fixed-film phase combined with the biomass floc in returned sludge could allow IFAS to be operated at low solid retention time (SRT) and still achieve nitrification (Kowtarapu and Katoch, 2016). Figure 2b and 2c shows one of the fixed media types for IFAS that is currently recommended in design of municipal wastewater treatment in Pekanbaru City. One of the main obstacles faced by CAS system is the separation of biological solids from effluents after processing. IFAS and MBBR could solve this problem due to attached-growth biomass on solid media which size could be controlled better by sloughing mechanism which is the detachment of biofilm when it reaches a certain thickness and mass. The result is sludge with good settling characteristics. Choi et al. (2012) reported a better performance for IFAS in nitrogen and phosphorus removal compared to MBBR. Table 1 provides the comparison of MBBR and IFAS in terms of initial cost, energy consumption, and criteria design based on a project design by IWI and relevant research results of Ma (2012).

Table 1: Comparison of MBBR and IFAS

Parameter	MBBR	IFAS
Initial cost[a]	IDR 77.24 billion for an average wastewater discharge of 0.09 m^3/s	IDR 77.58 billion for an average wastewater discharge of 0.09 m^3/s
Energy consumption[a]	about 6,880 kWh/d for an average wastewater discharge of 0.09 m^3/s	about 6,507 kWh/d for an average wastewater discharge of 0.09 m^3/s
Criteria design		
- HRT[b]	6.2 h	4.2 h
- Biological media	Dispersed type (polypropylene fined cylinders)	Fixed in place (submerged fixed film, structured sheet media, fabric web type);

[a]based on WWTP Design Project of Pekanbaru City conducted by Indonesia Water Institute
[b]Ma (2012)

The initial costs to construct WWTP using MBBR and IFAS are roughly the same, with IFAS slightly higher due to requirement of additional pump for sludge recirculation. As for energy consumption, MBBR requires more energy than IFAS because this system relies on continuous and more rigorous mixing of liquid in the reactor to maintain suspension of solid media. This is supported by research results of Gu et al. (2017) showing that MBBR system required higher energy in nitrogen removal from wastewater compared to IFAS. Ma (2012) compared the HRT required in MBBR and IFAS to achieve the same performance in terms of wastewater quantity and effluent quality. The results showed that IFAS required a shorter HRT compared to MBBR. In the case of biological treatment, HRT could be interpreted also as the contact time between biomass and organic pollutants, and a longer HRT will usually result in better removal efficiency of organic pollutants, although the required volume for the system will also increase as larger volume of wastewater will be retained in the process. With shorter HRT, IFAS requires less facility footprint than MBBR.

Both MBBR and IFAS systems requires aeration to maintain sufficient dissolved oxygen (DO) concentration for aerobic treatment and also provide mechanical stirring inside the reactor for the suspension of biomedia and flocs. For both economic and technical reasons, it is important to control the DO level in the aerobic reactor (Man et al., 2017), since the aeration rate is directly proportional to the energy consumption. Ødegaard (2014) explained that energy consumption after converted from MBBR to IFAS was lower (1.2 kWh/kg NH_4-N removed). Sen et al. (2008) identified the blower power requirements for the MBBR and IFAS systems, where the results were obtained that the MLE (Modified Ludzack Ettinger) and ENR (Enhanced Nutrient Removal) IFAS were smaller than the MBBR.

3. Challenges of MBBR and IFAS implementations in Indonesia

In Indonesia, planning and designing of wastewater treatment facilities are done roughly without accuracy and details due to many factors. This has caused many difficulties and obstacles during the actual operation and maintenance of the treatment system. The lack of capable human resources is also another problem that needs to be solved. Some wastewater treatment facilities have already introduced automation in the operation and maintenance using control technologies such as supervisory control and data acquisition system to reduce the requirement of human resources and the probability of human errors, which in turn reducing operational costs in the long run. In order to follow the progress of wastewater treatment technologies, to understand the types of treatment process required and their performances, computer-based training system will be helpful to educate and train system operators or managers in designing an efficient wastewater treatment (Avramenko et al., 2009).

Most of industries in Indonesia that produce wastewater with high organic content use biological treatment processes to remove pollutants. This type of technology is energy-intensive with electricity consumption reaching 50-60 % of the total usage in the wastewater treatment system. Other issues that also arise in the application are large facility footprint and treatment of large amount of sludge by-product. Integration of biological treatment systems could enhance the treatment performance and enable the reuse of treated wastewater as raw water for clean water production.

One of the main challenges faced in this kind of systems is the sludge disposal. Long-term and sustainable solutions are a necessity for treatment facilities to operate properly without causing secondary pollution from sludge. The produced sludge contains organic material and nutrients that are high enough for agricultural needs. High demand of fertilizer in Indonesian agricultural industries can be a sustainable solution providing the sludge is safe from toxic and hazardous materials, the conversion system of sludge to fertilizer is already well-established, and the logistics can be planned properly between wastewater treatment plant and the agricultural sites. According to Sidek et al. (2015), MBBR system is also a promising technology in sludge reduction when compared to conventional system. In Indonesia, the application of MBBR technology has generally been carried out for some areas, including urban and airport. This might be due to the implementation of MBBR as an improvement to existing system is much easier than other technology such as IFAS. In MBBR, the suspended media can just be added to enhance the treatment performance without much modification, while in IFAS, more modifications and redesigns are required for the implementation.

In Jakarta, MBBR technology has been successfully used to increase the volume of raw water. The deficit of raw water in 2015 was overcome by operating the Water Intake Installation of West Flood Canal equipped with MBBR technology. Another application of MBBR technology in Jakarta is at Setiabudi WWTP where the effluent is reuse for plant watering as the first step in water reclamation of MBBR technology in Indonesia. A vertically designed MBBR has also been developed in Krukut area which designed as an edutainment facility to learn about the treatment processes. The treated wastewater was also reclaimed fully for community activities in this area with a clean water production capacity of 100 L/s. In the WWTP of Jakarta International Airport (Soekarno-Hatta), MBBR technology has been implemented (Figure 3), which followed by water recycle process and sludge treatment. Research on MBBR using a combination of aerobic-anoxic processes that can reduce organic pollutants together with nitrogen content has also been carried out. The system can reduce COD of 92.15 %, ammonia of 76.81 %, and nitrate of 69.82 %. The research was aimed at full-scale application to treat leachate at landfilling sites (Rosidi et al., 2015). For the full-scale application, effluent from MBBR can be further treated using wetland to meet the wastewater effluent standard in Indonesia.

Figure 3: MBBR technology implemented in WWTP of Soekarno-Hatta Airport

For IFAS system, some large scale of this system has been designed and planned for several municipalities in Indonesia such as Jakarta and Pekanbaru. Based on the feasibility study of Jakarta sewerage system zone 6, IFAS technology will be implemented in Duri Kosambi, Jakarta, which will be replacing the existing sewage treatment plant. This project is still in the stage of planning and supervision, and will be implemented in the beginning of next year. Another IFAS system has been proposed in WWTP Design Project of Pekanbaru City conducted by Indonesia Water Institute. Upon implementations as actual WWTPs, the data from these projects can then be included in further study of IFAS application and improvement in Indonesia. The IFAS system that has been implemented in Indonesia is in industrial area such as the industrial WWTP in Karawang that used FBAS system developed by Hungarian WWTP company Organica Technologies (Surya Internusa, 2018). In this system, a fixed-bed reactor was achieved using plants where the plant roots serve as support for microbial growth to enhance the decomposition of organic pollutants.
Key considerations in planning, designing and implementing WWTP in Indonesia including land availability; wastewater standards and regulations; the quality of receiving water body for the treated effluent; operational and maintenance cost, and system reliability; track records of designers; and constructors and operators (DKI Jakarta Local Government, 2011). Each region has own different characteristics and considerations. For example, in Jakarta, the major obstacle is the land availability. This is one of the reasons the master plan for municipal wastewater treatment that has been developed still could not work out until now. In planning, designing, and implementing WWTP of the city or region, the ongoing and possible issues should be considered carefully.

4. Conclusion

Wastewater treatment can be done with variety of technologies that can be adjusted to the current availability of local and international markets and limited by land availability and construction and operational costs. Some previous studies have proven that the application of MBBR and IFAS system in wastewater treatment is feasible and can be combined with other treatments. These systems can overcome the problem of wastewater treatment whether an existing one or a newly designed one. In the long term, MBBR can be a suitable alternative to improve the existing wastewater treatment plant, because it can be retrofitted flexibly according to reactor tank size and wastewater loading rate, and IFAS can be used as a primary technology in new facility design, especially the one requiring nitrogen and phosphorus removal. With increase applications of IFAS in Indonesia, the performance and flexibility of this technology can be better understood and studied. The obstacles commonly found of using MBBR or IFAS technology in Indonesia are the inadequate and unintegrated sanitation services and effluent regulation to be complied regionally and nationally. Management institutions of wastewater infrastructure in each region should be arranged and strongly supported by the regional and central governments.

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