Journal of Ecological Engineering
Volume 21, Issue 5, July 2020, pages 1–8
https://doi.org/10.12911/22998993/119798

Received: 2020.01.15
Revised: 2020.03.26
Accepted: 2020.04.27
Available online: 2020.05.25

Development of Malaysian Wastewater Polishing Index: Case Study on a Moving Bed Biofilm Reactor

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ABSTRACT

Currently, extra treatment of secondary effluent to remove nitrogen and phosphorous may be required for its unrestricted reuse. This can be achieved by installing the wastewater polishing systems (or tertiary treatment). The wastewater polishing solutions are environmentally friendly, cheap and effective. The experiments were conducted on a pilot scale using a Moving Bed Biofilm Reactor (MBBR) with a capacity of 500 L to polish the municipal effluent from organic pollutant, undesirable nutrients and bacteria without the use of disinfectants. The major purpose was to define and apply a model for evaluating polishing of secondary effluent and implement the optimal technology for unrestricted use. Wastewater Polishing Index (WWPI) is a new tool that has been employed for rapidly evaluating of water quality improvement. It can be implemented into any surface water effluent treatment system or for reuse. WWPI can be an important tool designed for decision makers. The total average weight of six parameters (COD, BOD_5, SS, Ammonia nitrogen, Total Phosphorus and *Escherichia coli*) are defined as the index, each one converted to sub-index which is scaled from zero to one hundred. If none of six parameters exist in the effluent WWPI, it is equal to zero, while if the parameters match the Malaysian's effluent Standard B, It amounts to one hundred. In turn, WWPI is ninety when all six of them are equal to their corresponding Malaysian National Water Quality Standard (IV) for re-use. The index of wastewater polishing was validated and approved for the pilot MBBR study.

Keywords: wastewater polishing index, moving bed biofilm reactor, effluent polishing, water reuse, quick assessment.

INTRODUCTION

There are no common indices specified for monitoring regulatory standards or for quick evaluation of the obtained results during the wastewater recovery in Malaysia, only water quality index (WQI). Discharge of wastewater to surface water body or to any other final destinations should respect all the regulations set by local, national and regional quality standards (Morales-Garcia et al. 2011). In almost all countries, the trend towards concentration limits for the purpose of water reuse in several qualitative parameters was established, even without determining the more suitable treatment.

The objective of a wastewater polishing index (WWPI) is a rapid evaluation whether the polished effluent is suitable for agriculture or has the recreational potential. It has great benefits according to the managers and the people making the water planning decisions, also to compare different wastewater treatment technologies. WWPI is known as the average weighted of the following six parameters: COD, BOD_5, SS, Ammonia nitrogen, Total Phosphorus, and *Escherichia coli* (Bhavin 2012). Each of these parameters was converted to a sub-index scaled from zero to a hundred.. If none of six parameters exist in the effluent WWPI, it is equal to zero, while if the parameters match the Malaysian's effluent standard B, it amounts to one hundred. However, in a number of cases, WWPI will exceed 100 because of high concentrations of suspended solids and *E. coli* within the secondary discharge. The value of WWPI is 36 in Italy where each of the six parameters is equivalent to the Italy legal restrictions on reuse (Bhavin 2012).

The increasing coverage of the domestic water supply resulted in a substantial increase in the wastewater production and combined with natural scarcity of water, increased the amount of wastewater to be treated (Al-Baldawi et al. 2013). The heavy usage of underground aquifers and continuous drop in, especially in dry regions, which has encouraged the reuse of domestic wastewater as substitute sources of water and tools of polishing (Palese et al. 2009). Effluent polishing has attracted extensive attention for wastewater treatment (Ustun et al. 2011; Md Yusoff et al. 2019; Hanafiah et al. 2019). The moving bed biofilm reactor (MBBR) is a well-known development technology (Lariyah et al. 2016). It is used to remove turbidity, particulars, microorganisms as well as cysts (Oron et al. 2008) without any disinfectant usage in order to build up sustainable water supply. The advantages of MBBR are very promising by combining an integrated system (Bick et al. 2009; Drioli et al. 2011). The investigation focused primarily on the system of polishing using MBBR, as it is widely adopted worldwide for large, medium and small WWTP effluent (Tang et al. 2017). The MBBR technology is considered the most suitable biological and physical treatment for producing high effluent quality and consistency, which is sufficient for its reuse (Piechna & Żubrowska-Sudoł 2017; Lin 2018).

The pilot plant has been made on the treatment plant of the UKM Bangi engineering building, located in the city of Kajang, Malaysia, to evaluate the efficiency of MBBR system for secondary effluent polishing. The feeding water was taken straight from the WWTP secondary effluent of urban municipal clarifier. The three objectives of the current study were as follows: (i) to offer rapid tool evaluation for improving the water quality; ii) provide sufficient technical information and aid in understanding the performance of secondary supplementary effluent polishing using MBBR; iii) provide a reliable and sustainable recovered effluent, suitable for agricultural irrigation and reuse without restrictions.

METHODOLOGY TO DETERMINE WWPI

Malaysian Treated Effluent Discharge Standards

In Malaysia, the standards of wastewater are provided in the environmental quality regulations of 2009 (sewage and industrial effluents). These standards cover not only the industrial waste water, but also apply the limit values to the domestic wastewater. The standards on wastewater are prescribed as a series of national standard uniform which is divided into two classes: the standard A is applicable to the areas upstream of the drinking water intake points, while the standard B is applicable to the downstream areas of the drinking water intake points. Every standard covered 23 parameters, including common parameters, for instance BOD_5, COD, SS, pH, temperature, pH, CFU/100 ml and various types of heavy metals. The standard A is stricter than the standard B (Environmental Quality 2009).

The water quality standards (WQI) in Malaysia were set for the quality of the river waters. The water quality is divided to six categories (Department of Environment 2010), from the level where it retains the natural environment in which aquatic organisms are sensitive to environmental changes, through the level that the water can be used for drinking after tertiary treatment, to the level usable for irrigation in agriculture. The water quality standards are determined for about seventy parameters, including the ammonia nitrogen, COD, BOD_5 and bacteria coliform number of groups, as well as a large number of pesticide and heavy metals. There is no specified environmental standard for ponds and lakes, but an interim standard is currently proposed to be applied for coastal waters.

Development of Wastewater Polishing Index WWPI

Wastewater is polished in order to further improve the water quality via decreasing the concentrations of the essential parameters of pollution, until the level needed for their destination is reached (released into the body of surface water, reuse or recycling). The water quality improvement depends on the selected treatment of various polishing technologies and evaluates their purification performance. A modern indicator named wastewater polishing index has been invented. The main parameters are the very important toward the effluent into final destination or reuse of the recovered municipal wastewater. The parameters are COD, BOD_5, SS, NH_3-N, P_{Total} and *E. coli* (Asano 1998; Metcalf & Eddy 2014).

Generally, the influent flow to the polishing stage is a secondary discharge, the quality is illustrated via the variety ranges of subsequent main parameters: BOD_5 10–20 mg/l, SS 10–30 mg/l, COD 30–60 mg/l, P_{Total} 0.8–1.5 mg/l, NH_4 5–10 mg/l and *E. coli* 103–105 CFU/100 ml (Metcalf & Eddy 2014). Since these ranges are expressed with varied units and different sizes, a normalization step is needed in order for the corresponding sub-indices to be used in the same interval scale. The rating curve is recruited by two key points for all indicators matching the estimated limits for each specific scope (Table 1).

For the six parameters, the normalizing curve assumed a linear graph between the two extreme points, as illustrated in Figure 1. In this way, the matching of six sub-indices was identified. If the value of analyzed concentrations is greater than the value of the concentrations allowed by law, the corresponding linear correlation will over range which a normalized sub index value higher than 100.

The Eq. (1) defined the wastewater polishing index, where Ii is sub-index matching the essential parameters i, whereas i of COD, BOD_5, SS, P_{Total}, NH_3N and E. coli is to 1 for all parameters, except for *E. coli*, which is equivalent to 1.4. Instead of the sub-index value, the WWPI will be calculated by the following equation:

$$WWPI = \left(\frac{\sum_i I_i^{ni}}{\sum_i 100^{ni}}\right) x100 \quad (1)$$

$$WWPI = \frac{I_{BOD5} + I_{COD} + I_{SS} + I_{NH3N} + I_P + I_{E.coli}^{1.4}}{(5x100) + 100^{1.4}} x100 \quad (2)$$

where: *WWP*I is wastewater polishing index,
I_{BOD5} is normalized value sub-index of BOD_5,
I_{COD} is normalized value sub-index of COD,
I_{NH3N} is normalized value sub-index of NH_3N,
I_P is normalized value sub-index of phosphorous,
I_{SS} is normalized value sub-index of SS,
$I^{1.4}{}_{E.coli}$ is normalized value sub-index of *E. coli*.

The highest value provided to the peak *E. coli* sub index to improve the experimental ability of polishing disinfection. WWPI shows that a macroscopic achieved quality of effluent is lower than the level permitted by Malaysian regulations for discharge to surface water body, where the WWPI value is 100. If the effluent quality meets the specific legal requirements, the recovered wastewater can be reused for industrial, agricultural or civil purposes. The Malaysian regulations were introduced by [Department of Environment 2010], referring to 23 parameters. However, the main problem for the domestic wastewater reuse usually occurs because of the high concentration of six parameters that have been selected to determine WWPI. These requirements are listed in column IV of Table 2.

If the six key indicators approximate appropriate national standards for water quality Malaysia (IV) limits for the reuse of recovered wastewater, the index is 90.

EXPERIMENTAL VALIDATION BASED ON TREATED EFFLUENT FROM MBBR

The pilot plant moving bed biofilm reactor MBBR was experimentally investigated in the WWTP, at a new engineering building of UKM for validating the new indicator. The inlet water (tertiary effluent) was taken immediately from the secondary clarifier effluent of the municipal WWTP. The experimental investigation

Table 1. Various parameters range for rating curve

BOD_5 mg/l	COD mg/l	SS mg/l	NH_3-N mg/l	P_{Total} mg/l	*E. Coli* CFU/100 ml
50	200	100	20	10	5000

Source: Environmental Quality (Sewage and Industrial Effluents) Regulations, 2013.
Minimum amount equal zero,
Maximum amount equal to Malaysian's effluent Standard B.

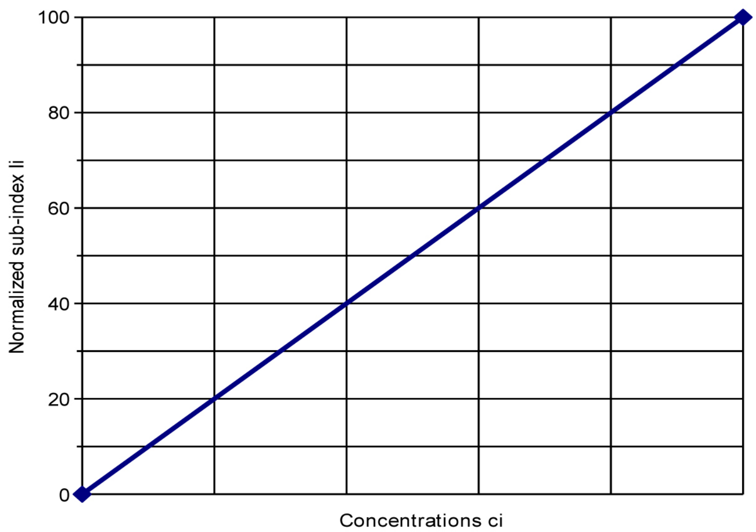

Figure 1. Normalized curve for the six parameters
ci law, with i = BOD_5, COD, P_{Total}, NH_3N, SS, and *Escherichia coli*

focused on the actual domestic wastewater, because it is increasingly accepted as a polishing treatment for reuse in a lot of countries. The advantages of MBBRs, such as: i) non expendable chemicals needed, thus the prices are relatively low (Lin 2018); ii) generally, MBBR design is modular and easily modified (Kawan et al. 2016; Abu Bakar et al. 2018; Jasem et al. 2018). MBBR is very well adapted for use in smaller areas of natural and recreational facilities like sport centers, golf courses, bicycle paths and nature parks. It is highly reliable and may be easily extended.

In this pilot-scale study, experiments were conducted by designing, building, and operating a 500 L capacity moving bed biofilm reactor (MBBR) to polish the organic pollutant, undesirable nutrients and bacteria in the treated wastewater without the use of disinfectants. The 500 L MBBR includes a submerged clarifier designed with height and diameter dimensions of 120 and 75 cm, respectively, as shown in Figure 2. It has a down flow configuration and it is supplied with aeration from the bottom. The reactor was filled with 1250 pieces of fabricated Enviro Multi Media which is equal to 5% (v/v) of reactor volume.

All the samples of water were gathered on the same day and time in clean plastic bottles. The samples were directly analyzed chemically and physically in civil and environmental engineering laboratory. The analyses of essential parameters such as COD, BOD_5, NH_3N and P_{Total} were conducted according to the standard American method for wastewater and water analysis (APHA/AWWA/WPCF, 2005). Suspended solids were measured using the DR6000 HACH spectrophotometer. The membrane filtration method was used to carry out E. coli counting at the incubation temperature 37 ± 0.5 °C for 24 hours. The WWPI equation takes *E. coli* into consideration, because the enteric bacteria removal is higher than the percentage removal for *E. coli*, as shown in the experimental investigation (Vymazal 2005; Salgot et al. 2006).

Table 2. Malaysian Legal Restrictions with Sub-index for each parameter and WWPI

Parameters	Malaysian Legal Limited St. B	Class IV	Sub-index Class IV	Class I	Sub-index Class I
BOD_5	50	12	24	1	2
COD	200	100	50	10	5
NH_3-N	20	2.7	13.5	0.1	0.5
SS	100	300	300	25	25
P_{Total}	10	0.2	2	0.1	1
E.coli	5000	5000	100	10	0.2
WWPI	100		90		3

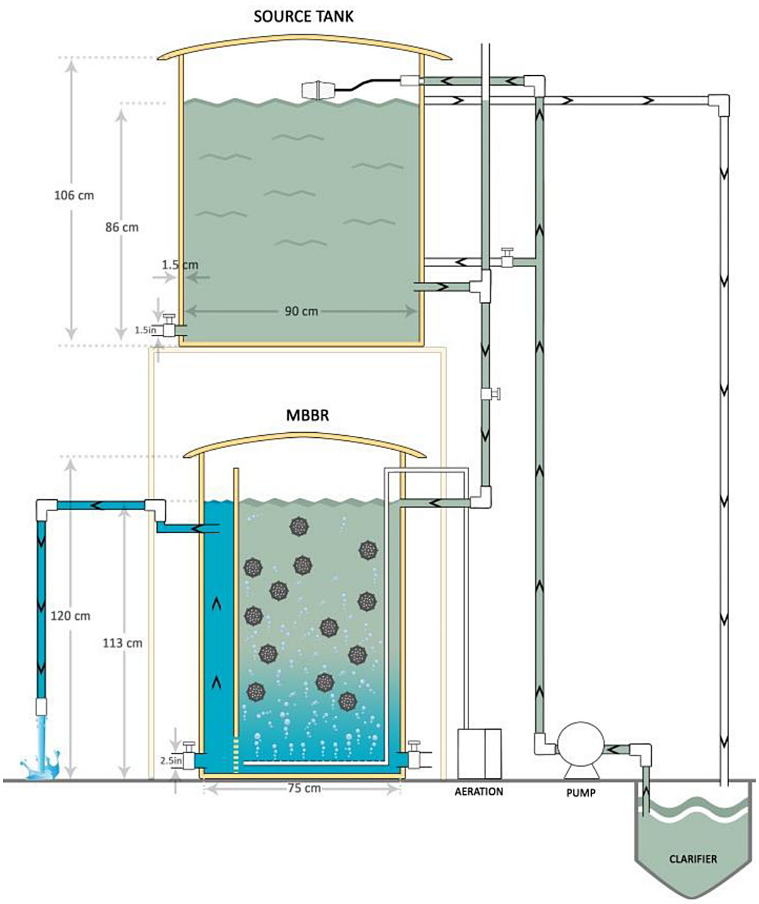

Figure 2. The structure of the MBBR polishing system consisting of the reactor and entire clarifier

RESULTS AND DISCUSSIONS

The methodology used to determine WWPI is based on the normalized graph of parameter values (Bhavin 2012). WWPI depends on a single result for each parameter and the result shows less variation in the index. Different WQI depends on a great number of replicated samples analyzed over long-term. WWPI is quicker, less labor-intensive and less time-consuming process, whereas WQI takes a long time to determine. WWPI is used for wastewater treatment, while the WQI is used only for the drinking water.

Table 3 shows in detail the averages and standard deviations of COD, BOD_5, P_{Total}, SS, NH_3N and *E. coli* for effluent and influent of the pilot plant during experiments, where the MBBR technology produces extra high quality water.

Commonly, WWPI for influent is always below the threshold value of 100, but in a few cases, it may be higher as a result of *E. coli* and SS high concentrations in secondary discharge (Verlicchi et al. 2011). Accordingly, a chemical disinfection must be added to ensure meeting the Malaysian legal limit of 5,000 CFU/100 mL for discharge into surface water bodies. In the current study on effluent polishing using MBBR, the chemical disinfection was not used due to low concentrations of *E. coli*.

No sludge was discharged from MBBR during all the experimental period. . The MBB reactor with HRT 24hrs enhances the final effluent quality, where WWPI always corresponds to 2 under or close to class I. Figure 3 confirms that a moving bed biofilm reactor is normally enough for producing the effluent corresponding to class (I) that WWPI is equal to 3 and sufficient for direct reuse. In turn, a study was conducted in Italy for comparison of the effluent water quality index. They used wastewater polishing index (WWPI) in different refining treatments including a rapid sand filter, horizontal subsurface flow system, lagoon and their combinations. The WWPI results were between 10.25 and 40.14 (Bhavin 2012).

The Malaysian WWPI indicates macroscopically to what extent is the effluent quality achieved below the level permitted by Malaysian regulations for discharge to surface water body, where

Table 3. WWPI with sub-index of average values of influent and effluent of MBBR

Parameters	Malaysian Legal Limited St. B	Influent MBBR	Sub-index Influent	Effluent MBBR	Sub-index Effuent
BOD_5	50	8±2	16	4±1.5	8
COD	200	23±2	11.5	11±0.5	5.5
NH_3-N	20	1.1±0.3	5.5	0.64±0.2	3.2
SS	100	13±2	13	2±1	2
P_{tot}	10	0.83±0.1	8.3	0.74±0.1	7.4
E. coli	5000	2400±700	48	40±28	0.8
WWPI	100		25		2

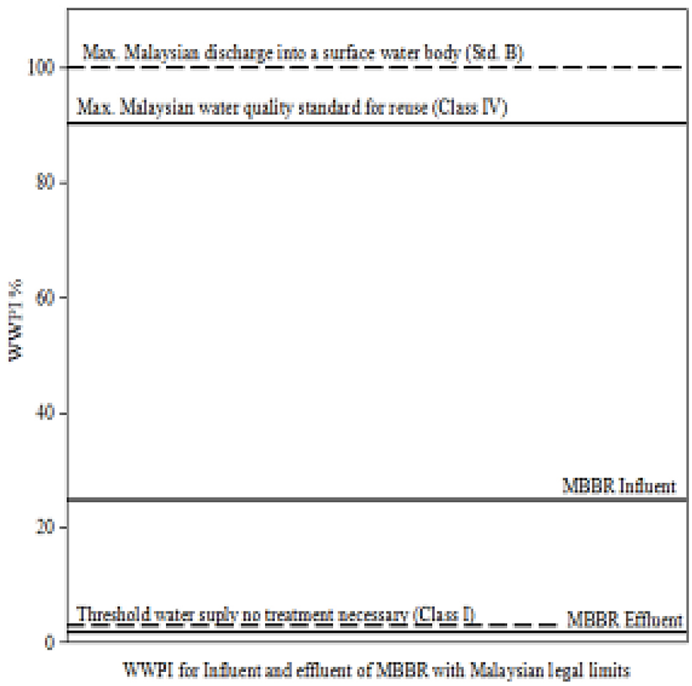

Figure 3. Normalized curve for the six parameters

the WWPI value is 100. If the six basic indicators assume the corresponding Malaysian legal limits for reuse of reclaimed wastewaters, the index becomes equal to 90. The value of WWPI in Italy is 36, where each of the six parameters was close to the legally restricted values for reuse (Bhavin 2012; Verlicchi et al. 2011).

Furthermore, WWPI is defined as a flexible indicator similar to the model in equation (1). It can be expanded to further chemical parameters or to further biological parameters for specified demands. As an example, if standard restrictions specify other bacteria, virus, or protozoa, the corresponding weight to the every new parameter must be determined (in equation 1 in is the exponent). In addition, the index can be utilized for any country. Every country has various legal restrictions established for wastewater treatment plants effluent discharge into surface water or reuse. Thus, the wastewater polishing index would lead to new thresholds.

CONCLUSION

The most critical pollutants in secondary effluent of domestic treatment plants are: COD, BOD_5, SS, P_{Total}, NH_3N, and first of all the *E. coli* bacteria. The water quality index (WQI) depends on a large amount of water samples analysed in the long term. Therefore, WQI takes a long time to identify and can be used only for drinking water. On the contrary, Wastewater Polishing Index (WWPI) is a new index proposed for an effluent polishing to give quick and more accurate results of the water quality level. The technique is based on a chart, thus simple to understand and easy to implement. The wastewater polishing index can be a great support for those who make decisions and environmental management in the water resources planning. Therefore, WWPI could help them to make a quick assessment for a number of scenarios including different polishing treatment systems when necessary. MBBR with HRT of 24 hours can improve the effluent quality where WWPI corresponds with class (I) and can be employed for direct reuse. No sludge was generated during the experiment. Model simulation results were verified and approved. This model can be used for the design of a pioneer MBBR plant for simultaneous removal of organic carbon and nutrient from a wastewater treatment plant (WWTP).

Acknowledgement

The authors would like to thank the Universiti Kebangsaan Malaysia (Grant no: GUP-2018–022) for supporting this research project.

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