Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(2), 665-670 | ISSN:2251-6727

Development of a Compact MBBR STP for Efficient Domestic Wastewater Treatment

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(Received: 04 February 2025 Revised: 21 March 2025 Accepted: 07 April 2025)

KEYWORDS

Wastewater, Sewage Treatment Plant (STP), Moving Bed Biofilm Reactor (MBBR) Environment, Organic Matter (OMs), Domestic Liquid Wastewater (DLW).

ABSTRACT:

Rapid urbanization has led to the continuous and excessive discharge of hospital wastewater into the environment, posing serious risks to both human and wildlife. Domestic liquid wastewater contains various organic compounds that can degrade water quality, pose risks to human health, and disrupt biodiversity in aquatic ecosystems. These pollutants significantly affect receiving water bodies, highlighting the importance of selecting effective treatment technologies to ensure the efficient removal of organic matter (OMs) from wastewater. Two common technologies used for the biological treatment of sewage are activated sludge and trickling filters. In contrast, the Moving Bed Biofilm Reactor (MBBR) is a more recent advancement in wastewater treatment. The MBBR system integrates key features of both activated sludge and trickling filters, offering an efficient and innovative approach to wastewater treatment. The required tank volume for an MBBR system is generally much smaller compared to that of an activated sludge process or trickling filter designed to handle the same wastewater flow. The MBBR process consists of a submerged biofilm reactor coupled with a liquid–solids separation unit. Taking all relevant application parameters into account, an MBBR tank has been designed specifically for the treatment of domestic liquid wastewater.

1. Introduction:

Hallvard (1980) degaard of the Norwegian University of Science and Technology devised and first developed the MBBR wastewater treatment technology in the late 1980s. The use of this wastewater treatment method has grown dramatically. A moving bed biological reactor (MBBR) mixes the two ways. The biomass in the MBBR arrives in 2 forms: suspended flocks and biofilm that sticks to carriers. It endures big organic loads and is less liable to hydraulic overloading. A MBBR process often requires a much smaller tank volume than an activated sludge process or a trickling filter intended to treat the same amount of wastewater. It is an associated growth process that shares a few traits to activated sludge. It uses plastic carriers to provide a surface on which biofilm can form. For an aerobic process, an aerator stops the plastic carriers in the aeration tank,

whereas for an anoxic or anaerobic process, mechanical mixing is used. A sieve located at the tank's outflow keeps the plastic carriers in the system. The MBBR process does not require sludge recycling, and the reactor size is often significantly smaller compared to an activated sludge system treating the same flow, or other conventional attached growth methods such as trickling filters and rotating biological contactors (RBCs). The MBBR technology is versatile and can be applied for BOD removal, nitrification, and denitrification. It is suitable for a wide range of applications, including municipal and industrial wastewater treatment, aquaculture systems, potable water denitrification, as well as roughing, secondary, tertiary, and sidestream treatment processes.

2. Objectives:

- The objective is to study domestic liquid wastewater and design a single-stage MBBR STP for efficient treatment and disposal.

3. Working of the MBBR:

The MBBR process is a type of attached-growth biological wastewater treatment system, where microorganisms responsible for treatment grow on a mobile solid medium. This concept is similar to other attached-growth systems, such as TF and RBCs, where microbes adhere to a fixed surface. In contrast, suspended growth systems like the Activated Sludge Process (ASP) rely on microorganisms suspended in the mixed liquor within the aeration tank. In conventional attached-growth systems, the wastewater flows over the surfaces of a fixed medium, allowing the attached biofilm to carry out treatment. In contrast, an MBBR method uses tiny plastic carrier media. MBBR treatment methods are often carried out in a tank similar to an activated sludge aeration tank. For aerobic processes, the carrier media are suspended using a diffused air aeration system, and for anoxic or anaerobic processes, a mechanical mixing system is used. A sieve is often employed at the tank outflow to keep the carrier medium within. Primary clarification is often utilized before the MBBR tank. Secondary clarification is also commonly utilized, although there is no recycling activated sludge returned to the process.

MBBR methods use plastic media support carriers similar to those, the carrier is often constructed to have a large surface area per unit volume, letting microorganisms to adhere and flourish. Numerous suppliers offer media support carriers. The process design calculations require two carrier qualities. They include specific surface area (m^2/m^3) and void ratio. The specific surface area of MBBR carriers can vary between 350 and 1200 m^2/m^3, with a void ratio of 60% to 90%.

The MBBR wastewater treatment process is highly adaptable, with several configuration options available. The MBBR process variations include:

✓ 1 stage BOD removal and tertiary nitrification

✓ 2 stage BOD removal and nitrification

✓ Pre-anoxic & Post-anoxic BOD removal, nitrification, and denitrification

4. Analysis and design calculations:

The surface area loading rate (SALR) in $g/m^2/d$ is the main empirical design parameter used to calculate the needed MBBR tank size. In SALR units, g/d refers to the g/d of the parameter being removed, while m^2 refers to the carrier's surface area for BOD removal in an MBBR system, the Surface Area Loading Rate (SALR) is expressed as grams of BOD per day per square meter of carrier surface area. In a nitrification reactor, SALR is defined as grams of NH_3-N per day per square meter, while for denitrification, it is measured in grams of NO_3-N per day per square meter of carrier surface. Using a selected SALR design value along with known parameters such as wastewater flow rate and concentrations of BOD, ammonia, or nitrate, the required carrier surface area in the MBBR tank can be calculated. Based on the specific surface area of the carriers (m^2/m^3), the required carrier volume can then be determined. Finally, applying the design carrier fill percentage allows for the calculation of the total tank volume needed. A single-stage MBBR process for BOD removal can function either as an independent secondary treatment system or as a roughing treatment step preceding another secondary process. In some cases, it is used to reduce the load on an existing secondary treatment system and prevent overloading. In any application, the primary design parameter for an MBBR (Moving Bed Biofilm Reactor) tank is the SALR, typically expressed in units of grams of BOD $g/m^2/day$. To begin the design process, the BOD load entering the MBBR tank is calculated using the influent flow rate and BOD concentration, yielding a value in grams of BOD per day. This BOD loading rate is then divided by the SALR to determine the total required surface area of the biofilm carriers (in m²). With this surface area, along with design parameters such as carrier fill percentage, specific surface area of the media, and the percentage of vacant space in the reactor, the required carrier volume, overall tank volume, and liquid volume in the reactor can be determined. Figure 1 illustrates a typical flow diagram of a single-stage MBBR process used for BOD/COD removal.

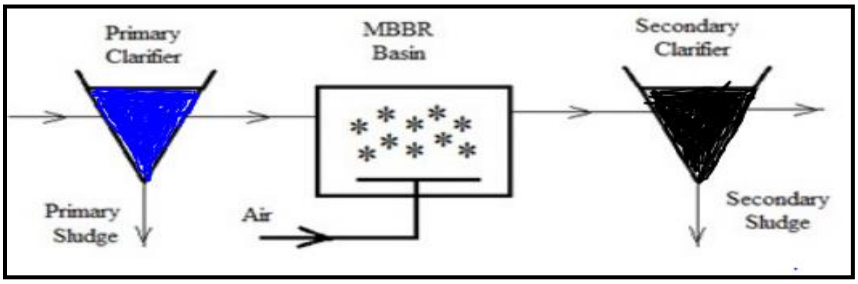


Figure 1. Single Stage BOD/COD Removal

The formulae for calculation are as follows

BOD rate loading = Q*So

Where: Q is the wastewater flow rate into the MBBR reactor in MGD So is the BOD concentration in that influent flow in mg/L, the calculated BOD loading rate will be in g/day.

Required carrier surface area = BOD Loading Rate/SALR

Where: BOD rate of loading is in grams per day.

SALR is the design surface area loading rate in g/m^2/day.

The estimated carrier surface area will be in m^2.

Necessary carrier volume equals

Where: the desired carrier surface area is in m^2.

Carrier-specific surface area is in m^2/m^3. The estimated carrier volume will be in m^3.

Required tank volume = necessary carrier volume / carrier fill %.

The needed tank volume will be in the same units as the required carrier volume.

Liquid volume in tank = required tank volume − [needed carrier volume (1 - carrier % empty space)].

Where: all three volumes will be in the same units.

Hydraulic retention time calculation formulae:

Although HRT is not usually a key design parameter for MBBR systems, it can be calculated using the design flow rate and the tank’s liquid volume. If a peak hour factor is specified, the HRT under peak flow conditions can also be determined. The following equations are used to perform these calculations.

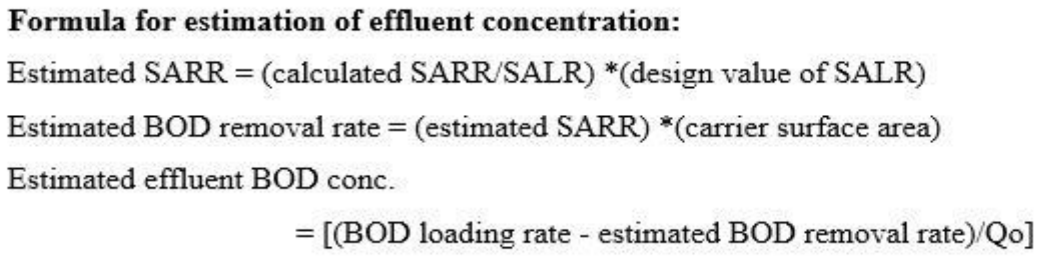
HRT des avg. = liquid vol. in tank)/ [Q], Where: liquid vol. in tank is in ft3 Q is in MGD

HRT peak hour = Ave. HRT des avg./Peak Hour Factor

Where: Ave. HRT peak hour will also be in min

Table 1- Design values of SALR

Typical Design values for MBBR reactor at 25-30^0C		
Purpose **BOD Removal**	**Treatment Target** **% Removal**	**Design SALR** **(g/m^2-d)**
1. Normal rate	85-90	15
2. Low rate	90-95	7.5
3. High rate	75-80	25



Formula for estimation of effluent concentration:

Estimated SARR = (calculated SARR/SALR) *(design value of SALR)

Estimated BOD removal rate = (estimated SARR) *(carrier surface area)

Estimated effluent BOD conc.

= [(BOD loading rate - estimated BOD removal rate)/Qo]

5. Design of Single Stage MBBR:

The Domestic liquid wastewater from the living communities including hospitals source is treated using the Moving bed biofilm reactor in which the design calculations are as follows. Design Calculations for Single Stage MBBR for Domestic Liquid Wastewater Calculation of Wastewater flow rate from the Domestic activity:

Let us assume that,

The no of households in the communities (Including Hospitals nearer by) = 1000

Water demand for Hospitals (>100 beds) = 450liters/bed (As per IS: 1172-1993)

Therefore,

The discharge from the hospital Q_O = 1000*450 = 450000 liters/day

The discharge of the waste water is 0.7 to 0.8 times the discharge of the total water Therefore

The Wastewater flow rate Q = 0.8*450000

= 360000 liters/day

= 360 m^3/day (where 1liter = 1/1000 m^3)

5.1. Design of the MBBR parameters:

The BOD concentration of the influent discharged from the hospital is collected and tested in the laboratory which is given as S_O = 225 mg/lit

a) BOD loading rate = Q*S_O

= 360*225

= 81000 g BOD/day

Based on Table 1, a suitable design SALR value for achieving a BOD removal efficiency of 90–95% is approximately 7.5 g/m²/day.

b) Required carrier surface area = BOD Loading Rate/SALR

= 81000/7.5

= 10800 m^2

Let the carrier surface area for the MBBR be = 500 m^2/m^3. Then,

c) Required carrier volume

= required carrier surface area/carrier specific surface area

= 10800/500

= 21.6 m^3

Let the carrier fill% of the tank is 30%. Then,

d) Required tank volume = required carrier volume/carrier fill %

= 21.6/0.4

= 54 m^3

e) Liquid volume in tank = required tank volume– [required carrier volume (1 – carrier % void space)].

= 54-[21.6(1-0.7)]

= 54-[21.6*0.3]

= 54-6.48

= 47.52 m^3

5.2. HRT Design Calculations:

a) HRT (des avg) = (liquid vol. in tank)/ [Q]

= 47.52/360

= 0.132 hrs.

= 0.132*24*60

= 190.08 min

≈ 190 min

Let peak hour factor be = 3. Then,

b) HRT peak hr = HRT des avg. /Peak Hour Factor

= 190/3

≈ 63 min

5.3. Estimation of Effluent Conc.:

SARR/SALR calculation

The SARR/SALR ratio of 0.925 for SALR = 7.5 $g/m^2/d$ was calculated from Table 1 above as the midpoint of the 90-95% projected BOD elimination for SALR = 7.5 $g/m^2/d$.

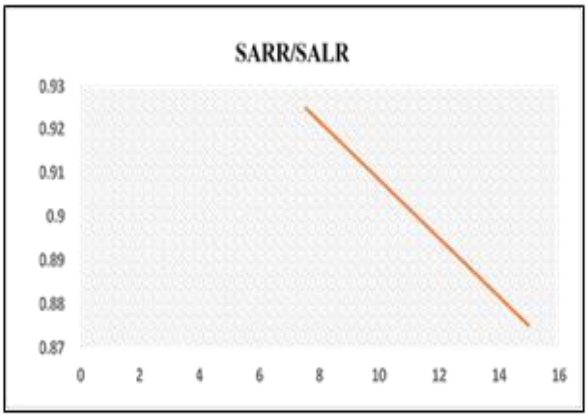
Similarly,

the SARR/SALR ratio of 0.875 at SALR = 15 g/m2/d was determined from Table 1 above as the midpoint of the expected BOD removal rate of 85-90% at SALR = 15 $g/m^2/d$.

Therefore, the graph was plotted between SARR/SALR vs SALR using Excel Data points for the graph to be plotted

Table 2- SARR/SALR for Single Stage

SALR($g/m^2/d$)	SARR/SALR
7.5	0.925
15	0.875



Graph 1 showing (SARR/SALR) vs SALR

Based on the graph above, the slope and intercept of the SARR/SALR versus SALR line are identified as –0.007 and 0.975, respectively. Therefore, the estimated SARR/SALR ratio for a given SALR value of 7.5 g/m²/day can be calculated using these values.

SARR/SALR = - (0.007) (7.5) + 0.975 = 0.925Therefore, Calculated SARR/SALR ratio = 0.925

Estimated SARR = (calculated SARR/SALR) *(design value of SALR)

= 0.925*7.5

= 6.375 $g/m^2/day$

≈ 6.4 $g/m^2/day$

Estimated BOD removal rate = (estimated SARR) *(carrier surface area)

= 6.4*10800

= 69120 g/day

Estimated effluent BOD conc.

= [(BOD loading rate - estimated BOD removal rate)/Q]

= [(81000-69120)/360]

= [11880/360]

= 32.78 mg/liter

≈ 33 mg/liter

5.4. Calculation of Tank Dimensions:

Let, Depth of the tank (H) = 2 m

The ratio of L: B = 1.5 m

Volume of the tank = L*B*H

Therefore, 3B2 = 54 m3 B2 = 54/3

= 18 m^2.

Therefore, B = 4.24m

≈ 4 m

Therefore, L = 1.5*B

= 1.5*4

= 6 m

Hence, Tank dimensions of single stage MBBR reactor = 6x5x2 m^3

6. Conclusion:

The performance of the Moving Bed Biofilm Reactor (MBBR) was assessed for the treatment of domestic

liquid wastewater. The single-stage MBBR system achieved a BOD removal efficiency of approximately 85%. In comparison to conventional treatment methods like the Activated Sludge Process and Trickling Filters, the MBBR system offers a more space-efficient and compact design, making it a practical and effective alternative for wastewater treatment.

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