# MOVING BED BIOFILM MEMBRANE REACTOR (MBB-M-R): CHARACTERISTICS AND POTENTIALS OF A HYBRID PROCESS DESIGN FOR COMPACT WASTEWATER TREATMENT PLANTS

TorOve Leiknes, Hallvard Ødegaard

NTNU- Norwegian University of Science and Technology
Department of Hydraulic and Environmental Engineering
S.P. Andersensvei 5
N-7491 Trondheim
Norway

Phn: +47 73 59 47 58
Fax: +47 73 59 12 98
E-mail: torove.leiknes@bygg.ntnu.no

## ABSTRACT

The potential of a moving-bed-biofilm membrane reactor (MBB-M-R) hybrid process has been investigated as an alternative design for compact wastewater treatment plants. Pilot studies of a high-rate moving-bed-biofilm process demonstrated that 85-90% COD removal is achievable at bioreactor loading as high as up to 100-150 g COD/$m^2 \cdot$d (30-45 kg COD/$m^3 \cdot$d) with hydraulic retention times of 20-30 min if the biomass and particulate COD downstream the bioreactor is completely removed. Membrane separation of the biomass and particulate COD was maintained with a steady flux of 60 l/$m^2 \cdot$h with consistently high permeate quality, SS < 5 mg/l and turbidity < 1 NTU. Compared to other membrane bioreactors this represents operating with 10-15 times higher volumetric loading at 10-30 times shorter HRT combined with flux rates that are 3-4 times greater, and thus the potential of a high-rate MBB-M-R hybrid process.

## KEYWORDS

membrane bioreactor, membrane filtration, moving bed biofilm reactor, submerged membrane module, high-rate process, hybrid process

## INTRODUCTION

The need for compact wastewater treatment plants is increasingly becoming a global concern, particularly in densely populated regions where the environmental impact by the population also sets high demands to the treatment of waste produced by the community. Both the cost and availability of land combined with implementation of secondary treatment standards sets demands for wastewater treatment plants that have a small footprint, produce an effluent of high standard and also comply with waste minimization. Biological processes are an economical alternative, where biofilm reactors in particular offer alternatives for compact treatment plant designs. Although efficient in removing soluble organic matter, biofilm reactors designed as trickling filters or submerged filters using granular media are prone to clogging when the wastewater contains high loads of particulate matter. Consequently there is a limit to the loading rate that can be applied to such processes, often necessitating a pretreatment step for particle removal prior to the biofilm unit.

In the moving bed biofilm reactor, biomass grows on carriers that move freely in the water volume by aeration or a mechanical mixer and are kept within the reactor volume by a sieve arrangement at the reactor outlet [1][2]. The biofilm carriers are made of high-density polyethylene (density 0,95 g/cm$^3$) and shaped as small cylinders with a cross on the inside of the cylinder and “fins” on the outside. The size of the carrier varies from lengths of 7-15 mm and diameters of 10-15 mm. The carrier filling-fraction (% of reactor volume occupied with carriers in empty tank) is normally 60-70%. An important advantage is, however, that the filling fraction may be subject to preferences and design criteria [2]. The process can therefore accept both a high particulate load as well as a high soluble organic load.

For BOD-removal only, the moving-bed-biofilm process is commonly designed with a 67 % carrier filling fraction (effective specific surface area: 210-335 m$^2$/m$^3$ depending on carrier size) and a volumetric loading rate of 4-5 kg $BOD_7$/m$^3$d at 15$^o$C. The fate of particles in a biofilm reactor is not clear since the characteristics of both the soluble and the particulate organic matter change through the reactor by hydrolysis, assimilation etc. However, there is reason to expect that particulate matter is to a far less extent degraded in a high-rate moving-bed-biofilm reactor than in a standard activate sludge process (AS) [3]. In such a high-rate situation it has been shown that the particulate matter moves more or less untouched through the reactor and only the soluble biodegradable matter is removed. A draw back of such a high-rate biofilm process is that the settling property of the biomass is very poor and coagulation or direct filtration is needed in order to achieve acceptable effluent qualities. If, however, one could use membrane separation of the biomass and particulate matter, one could expect a high removal of COD (85-90%) even at high loading rates of the bioreactor.

Therefore, the objective of this study has been to investigate the potential of a membrane separation unit combined with a high-rate moving-bed-biofilm reactor for the design of compact wastewater treatment plants.

## EXPERIMENTAL

The concept of the MBB-M-R process is shown in Figure 1. In the biological process the biofilm removes the soluble organic matter from the wastewater, while the membrane process, combined with coagulant if required, separates the biomass, particulate and colloidal matter from the effluent. Pre-treatment can consist of pre-sieving (3-4 mm sieve) if a larger biofilm carrier is used [2]. This concept has a potential for an extremely compact wastewater treatment plant design.

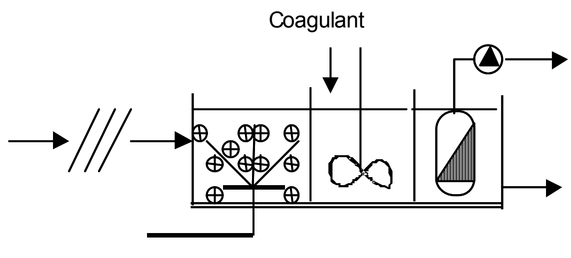


**Figure 1.** Flow sheet of the MBB-M-R process

Studies have been conducted to investigate the efficiency of the moving-bed-biofilm process for high-rate loadings and the efficiency of membrane separation of the biomass, particulate and colloidal matter in the effluent from the moving-bed-biofilm process.

*The high-rate moving-bed-biofilm process*

The experiments to investigate the high-rate performance were conducted in pilot plants in two parallel lines. Each bioreactor had a volume of 20 liters with filling fractions of the media set from 60-70%. Organic loads in the range of 10-120 g COD/$m^2$d and 5-45 g SCOD/$m^2$d were applied during the high-rate study [3]. The two lines with the respective media were operated in four sub-periods at close to constant flow and volumetric loading rate in each period, corresponding to average hydraulic residence times (HRT) of 380, 52, 27 and 18 minutes. Table 1 shows the wastewater characteristics of the influent for the experimental period.

*Membrane separation for the removal of particles from a moving-bed-biofilm reactor effluent*

Figure 2 shows a schematic of the pilot plant that was designed to investigate the efficiency of microfiltration for the clarification of effluent from a moving bed biofilm reactor. The pilot plant consisted of pre-treatment of raw municipal wastewater in a primary settling tank (volume 9 $m^3$) based on mechanical separation with no chemicals added. Next a moving-bed-biofilm reactor (volume 200 liters) with ~70% filling of the larger media, followed by a submerged hollow fiber membrane module in a downstream process tank (volume 190 liters, membrane surface area 0,93 $m^2$).

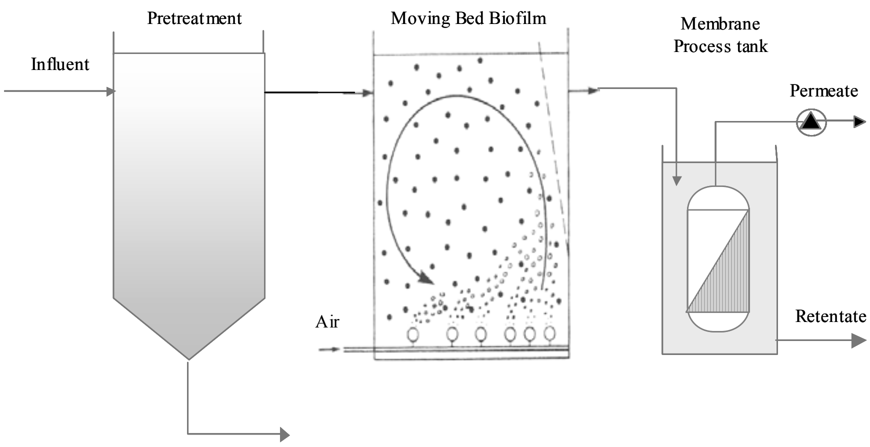


**Figure 2.** Experimental configuration for membrane separation study

Operation and loading rate of the pilot plant was defined to maintain only BOD removal without nitrification and denitrification, and an average load of 3 kg COD/$m^3$·d was applied. The moving-bed-biofilm reactor was operated at a flow rate of 2 l/min giving a hydraulic retention time of ~100 min. Effluent from the reactor was then collected in the membrane process tank operating at a 50-60% recovery. Average influent concentrations of the wastewater are given in Table 1.

The submerged membrane module was operated with constant flux using a suction pump (flow rate 1 l/min) and the performance of the unit was determined by monitoring the development of the trans-membrane pressure over time. A 10-minute cycle (9min 30sec suction and 30sec backwash) was applied for periodic backwashing and cleaning of the membrane and fouling was investigated by operating the unit with no air scouring, air scouring in pulses (2 minutes on/off) and continuous air scouring respectively.

The overall performance of the pilot plant was determined by analyzing the following parameters; suspended solids, COD and SCOD, turbidity, particle size and distribution, pH, dissolved oxygen (DO), temperature and ammonia nitrogen. Samples were collected from the respective stages in the pilot plant, the influent to the moving-bed-biofilm reactor, the biofilm reactor, the membrane process tank and the permeate. On average the influent DO was 2 mg/l, 6 mg/l in the moving-bed-biofilm reactor, 8-10 mg/l in the membrane process tank and permeate. SS, COD/SCOD and turbidity varied as a function of variations in the influent quality and recovery in the membrane process tank.

**Table 1** Average concentrations for influent wastewater for the respective studies

| | SS mg/l | COD mg/l | SCOD mg/l | $NH_4$-N mg/l | DO mg/l | pH | Temp. °C |
|---|---|---|---|---|---|---|---|
| *High-rate biofilm study* | 88±18 | 219±66 | 100±38 | - | 4-6 | 7.5±0.1 | 10-15 |
| *Membrane clarification* | 79±45 | 204±100 | 56±11 | 21±5 | 2.0 | 7.4±0.2 | 14 |

## RESULTS AND DISCUSSION

*Biodegradation results in a high-rate moving-bed-biofilm process*

An evaluation of the biofilm reactor was done independent of the biomass, particulate and colloidal separation step by comparing the removal of soluble organic matter (SCOD) as a function of the loading rate. A maximum removal rate around 30 g SCOD/m$^2$d was found at a loading of around 60 g SCOD/m$^2$d. The degradation rate was found to be limited by the availability of biodegradable organic matter up to this point [3]. The influent DO was 4-6 mg/l and within this range, variations in DO concentration are not expected to have any influence on the rate of COD-removal. The results shown in Figure 3 demonstrate there is little difference in the performance of the reactor at hydraulic retention times of 18, 27 and 52 minutes indicating that the removal of the biodegradable COD is rapid. However, at long retention times (380 minutes) the removal rate to loading rate is significantly higher suggesting that hydrolysis of the particulate COD takes place if retention times are sufficiently long.

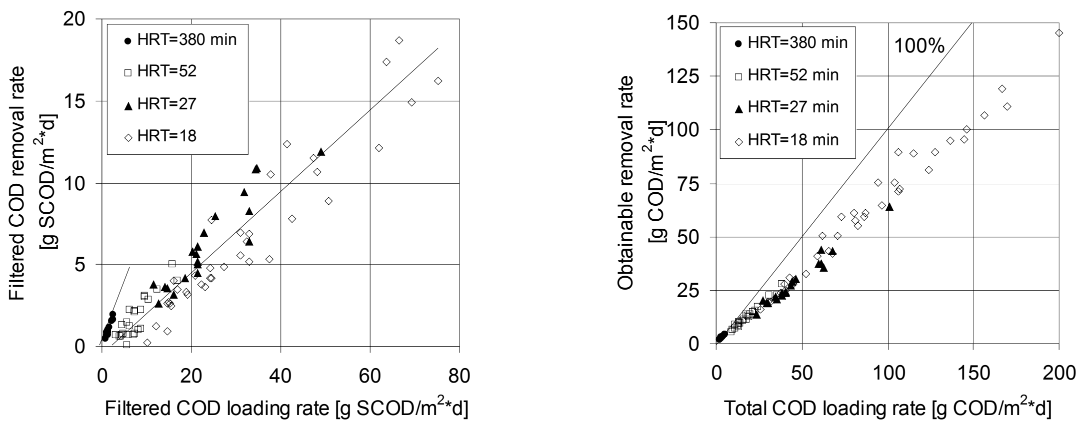


**Figure 3** Removal rates as a function of loading rates

Analysis of the process is made difficult in that the characteristics of both the soluble and the particulate organic matter change through the reactor by hydrolysis, assimilation etc. A total

COD removal rate was determined by including the particulate matter by defining an obtainable COD removal rate as $(COD_{influent}-SCOD_{effluent})*Q/A$, where Q is the flow and A is the effective surface area of the carrier [3]. This defines a removal rate of organic matter if all particulate matter is removed in a downstream separation step. Results of the analysis are shown in Figure 3, right graph.

The results demonstrate that a much higher design load than normally used for secondary treatment may be accepted if efficient biomass, particulate and colloidal separation is assured. A high removal of COD (85-90%) is achievable even at bioreactor loading as high as up to 100-150 g $COD/m^{2}\cdot d$ (30-45 kg $COD/m^{3}\cdot d$) if the biomass and particulate COD downstream the bioreactor is completely removed. Further more, the hydraulic retention time in the bioreactor is only 20-30 min to obtain a 85-90 % COD removal.

*Membrane separation of biomass from the moving-bed-biofilm reactor effluent*

The membrane performance was investigated by varying operating conditions for the membrane unit. An average permeate flux of 60 $l/m^{2}\cdot h$ was maintained for all tests with a trans-membrane pressure (TMP) range of 0-0,7 bar. A cleaning procedure using an extended backwash and low concentrations of NaOCl was applied when the limiting TMP of ~0,6 bar was reached. Initial TMP values (~0,1 bar) were recovered by the cleaning procedure applied.

The overall temperature of the wastewater remained consistently around 14°C for the duration of this study. An average of approximately 21,4 mg/l $NH_4$-N was measured throughout the pilot plant and no nitrification was observed in the process. DO concentrations varied in each section of the pilot plant as a function of the aeration in the moving-bed-biofilm reactor and the air scouring in the membrane process tank. On average the influent DO was 2 mg/l increasing to 6 mg/l and between 8-10 mg/l in succeeding stages. The effluent from the pilot plant showed a consistent high quality irrespective of operating conditions with average treatment efficiencies reported in Table 2 [5]. In effect, the biodegradable constituents are removed in the moving-bed-biofilm reactor while the particulate matter is removed in the membrane process where the permeate quality showed consistently SS < 5mg/l and turbidity < 1 NTU.

**Table 2** Average treatment efficiencies of measured parameters.

| *Quality Parameter* | SS mg/l | Turbidity NTU | COD mg/l | SCOD mg/l |
|---|---|---|---|---|
| *Treatment efficiency. %* | 99,5 | 99,5 | 84,0 | 24,6 |

Performance of the membrane unit was investigated with three modes of operation. Without air scouring the system had run cycles up to 3 hours before cleaning was required. With air scouring in pulses and continuous air scouring, cycles of 25-30 hours and >150 hours respectively were achieved before extended cleaning was required, in some cases with the cycle terminated at a TMP ~0,35 bars [5]. Representative results of the trans-membrane pressure devolvement for the three operating conditions are shown in Figure 4

Optimization of the operating conditions for the membrane separation unit was not investigated. Under the conditions investigated in this study a steady flux of 60 $l/m^{2}\cdot h$ was maintained for more than 6 days without reaching the maximum TMP of 0,6 bars which would dictate a more extensive cleaning cycle of the membrane module. If phosphate removal is required as well to meet the secondary treatment requirements, precipitation with a low dosage metal coagulant can be used [4]. Combining this with the membrane separation, particle size distributions in the wastewater can be engineered to optimize the membrane process thereby having the potential of increasing the permeate flux and controlling membrane fouling to a greater extent.

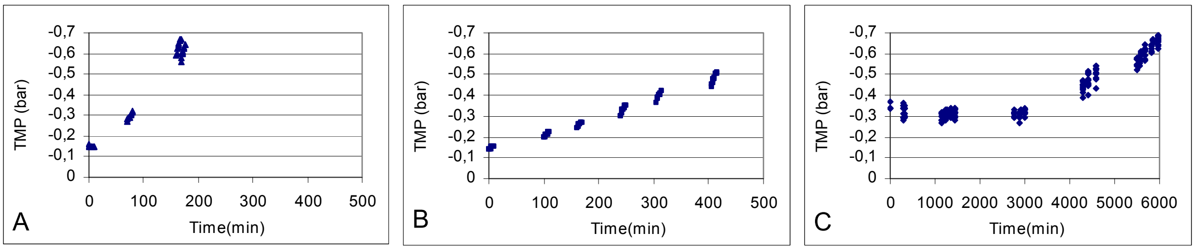


**Figure 4**. Representative development of trans membrane pressure for operating conditions; A – no air scouring, B – air scouring in cycles, C – continuous air scouring

*Comparing the MBB-M-R solution with activated sludge membrane reactors*

Typical operating conditions for membrane activated sludge (AS-M) configurations are reported to have volumetric loading rates of 1-3 kg COD/$m^3$·d, HRT 4-10 hours, fluxes of 15-25 l/$m^2$·h [6][7][8][9]. Treatment efficiencies compare well with those found in this study. A high-rate MBB reactor operating with 10-15 times higher volumetric loading at 10-30 times shorter HRT combined with flux rates that are 3-4 times greater shows the potential of a high-rate MBB-M-R hybrid process

## CONCLUSIONS

The combination of a high-rate moving-bed-biofilm reactor and membrane separation of the biomass, particulate and colloidal matter has the potential of making extremely compact wastewater treatment plants. The potential advantages are also apparent when the process is compared to membrane bioreactors based on activated sludge configurations.

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