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# Moving bed biofilm reactor (MBBR) for dairy wastewater treatment

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**Abstract**

The Moving Bed Biofilm Reactor (MBBR) system is considered an Advanced Wastewater Treatment (AWT), which combines the best of Conventional Activated Sludge (CAS) and biofilter processes, making use of suspended biomass and attached biomass. This system requires less space than CAS to process the same amount of wastewater and can be adapted to the existing structures of CAS. The dairy wastewater obtained during the milk transformation and cleaning operations is a residue characterized by a high content of organic matter and hydrocarbon compounds which contribute to its biodegradability, normally allowing the use of biological processes for the treatment of these effluents. In this study, the performance of the MBBR at a lab-scale during batch and continuous operations was addressed while changing the Organic Load (OL), the Filling Ratio (FR) and the Hydraulic Retention Time (HRT). The MBBR shows to be more stable when a FR of 40% is used, which allows a reduction of the HRT from 8 to 4 h, reaching a COD removal of 95%, allowing a reduction on the energy consumption, compared to the conventional processes.


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*Keywords:* Advanced biological wastewater treatment; Dairy wastewater; Moving Bed Biofilm Reactor

## 1. Main text

The Moving Bed Biofilm Reactor (MBBR) came up for the first time during the late 1980 and in early 1990 in Norway [1] when the biofilm systems were not sufficient to process successfully the nitrogen removal from an effluent [2]. This process uses suspended biomass, similar to Conventional Activated Sludge (CAS), and attached biomass, as a biofilter. To promote the adherence of the biomass, small pieces of High Density Polyethylene (HDPE), known as carriers, are added into the tank, where the biofilm will be formed and will further grow [1], allowing elimination of sludge recycling, typically required in conventional systems. This reactor can be used for aerobic, anoxic, or anaerobic processes [1,3]. One of the MBBR drawbacks, when compared to the CAS are the energetic cost due to the aeration need to promote the carriers' movement.

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The efficiency of the MBBR process is conditioned by operational conditions as the Filling Ratio (FR), and Dissolved Oxygen (DO). FR is the ratio between the volume occupied by the supports and the total volume of the reactor — VS/VR. This value can be changed and adapted to the desired conditions with an optimal range between 20 and 70% [4]

Rusten et al. [5] used a MBBR pilot plant to treat dairy wastewater, reaching COD removal efficiencies above 85% for organic loads up to 500 g CQO/$m^3$ h and a hydraulic retention time (HRT) of 7 h. A MBBR was also used to treat paper mill wastewater [6] with an organic matter removal efficiency of 98.7%. Vaidhegi [7] analyzed the same type of effluent and observed a maximum degradation when using 50% of FR in 8 h, pointing out that the filling ratio is an important factor because the organic removal depends on the biomass attached to the biocarriers. De Oliveira et al. [8] also studied pulp and paper mill wastewater in a MBBR pilot plant with 20 $m^3$, an average hydraulic retention time (HRT) of 3.3 h and a FR of 10%, is possible to observe high levels of biomass adherence. Regarding urban wastewater, Calderón et al. [9], concluded that for FR = 50% a more mature and better colonized biofilm on the carrier surface would be obtained.

The dairy industry is responsible to process and transform milk into yogurts, cheese, ice-cream, butter and other sub-products. The residues produced during these transformation processes, combined with large water consumption, make the dairy industry one of the most polluting of the food industries [10]. Indeed, from 4 up to 15 L of water can be used per litter of milk processed [11]. This wastewater is produced during the cleaning process of the milking equipment and pipelines that are usually made in four cycles: first rinsing where about 92% of the suspended solids are removed; detergent wash to eliminate the attached organic material; acid rinsing to remove the inorganic deposits from the piping and neutralize the alkaline detergent residue; sanitize rinsing to ensure that the milk lines are free of any microorganisms [12]. The effluents from dairy industries are characterized by their highly biodegradable nature and presence of soluble organics, suspended solids and trace organics [13], presenting high values of chemical oxygen demand, COD (1000–12 000 mg $O_2$/L,), biochemical oxygen demand, $BOD_5$ (500–2600 mg $O_2$/L).

## 2. Materials and methods

### 2.1. Wastewater and activated sludge

A synthetic wastewater composed by low fat milk and water was analyzed with four different organic loads; the initial biological sludge was obtained from a conventional activated sludge (CAS) domestic wastewater treatment station.

### 2.2. Experimental setup

For this study, a Beaker glass of 1 L with an operable volume of 900 mL was used and the carriers were "Kaldnes Evolution Aqua K1" with 12 mm diameter, 7 mm height, 836 $m^2/m^3$ of filter area, 494 $m^2/m^3$ of a protected area and 0.84 kg/$dm^3$ density.

### 2.3. Analytical methods

Chemical Oxygen Demand (COD) was determined by the 5220 D method (Closed Reflux), whereas the Total Solids (TS), Volatile Solids (VS), Total Suspend Solids (TSS), and Volatile Suspend Solids (VSS) were analyzed using the 2540 B, D, and E, methods, respectively [14]. The Biochemical Oxygen Demand (BOD) was carried out as established in the Standard Method 5210 B. 5-Day Test [14].

## 3. Results and discussion

This study was divided into two different assays: assay 1 for the batch experiment and assay 2 for the continuous operation.

In the assay 1 the MBBR operating in batch regime, was charged once a day, and samples were collected every hour during an experimental time of 8 h. Four different initial COD concentration (600, 800, 1100, 1200 mg $O_2$/L) were tested at a FR of 20%, called Test 1, and 40%, referred to as Test 2.

Fig. 1 shows a graphic representation of the normalized COD ($COD/COD_0$) during the batch operation. Both tests presented a similar behavior during the 8 h of experiment even though Test 2 tends to stabilize after hour 6, and Test 1 has a tendency for removal efficiency of 100% if the test was carried during more time. After the 8 h tests, it was reaching a COD removal efficiency of 98%.

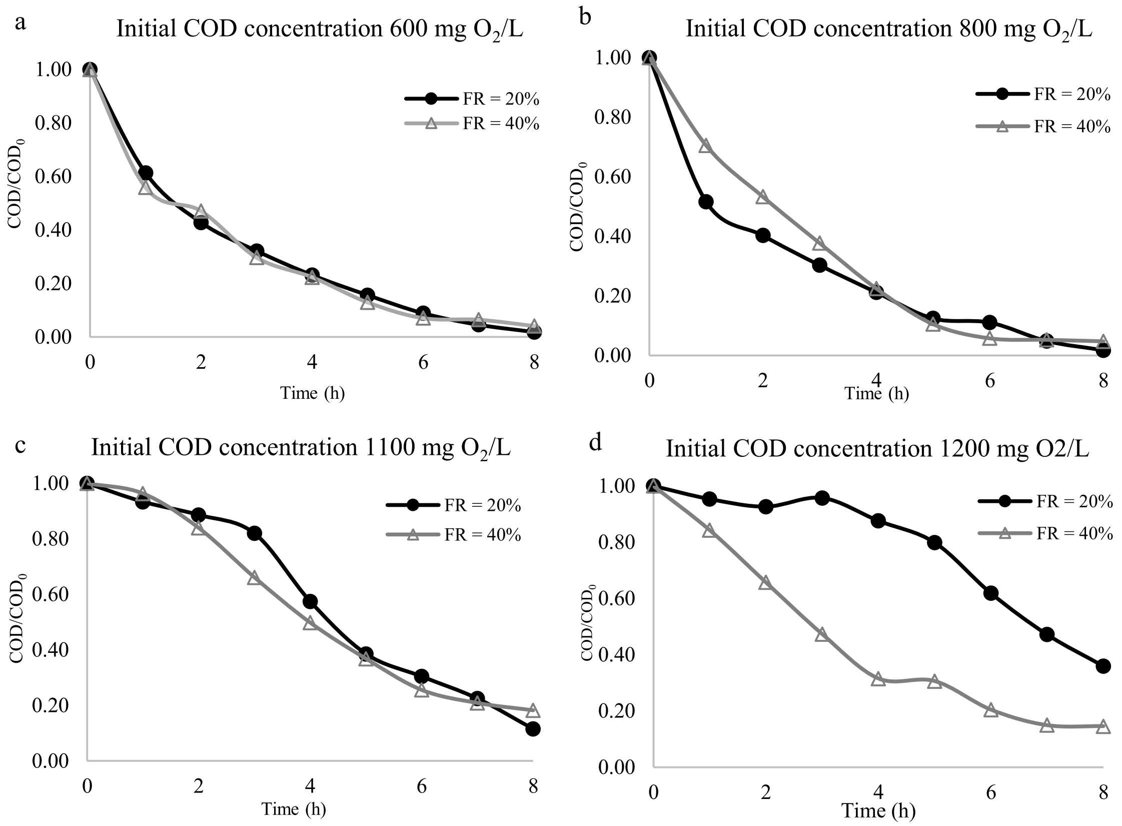


**Fig. 1.** Comparison of $COD/COD_0$ for both tests, at different OL. (a) Initial COD concentration 600 mg $O_2$/L, (b) Initial COD concentration 800 mg $O_2$/L, (c) Initial COD concentration 1100 mg $O_2$/L and (d) Initial COD concentration 1200 mg $O_2$/L.

When the initial concentration was increased to 800 mg $O_2$/L, the Test 1 shows to be more unstable when compared with Test 2; however, Test 2 behavior tends to stabilize after the 6 h of reaction, by the other side, the Test 1 starts to remove the COD faster than Test 2 but only after 7 h of reaction it reaches the same removal as the Test 2 had achieved 1 h before. Both tests achieved a COD removal efficiency of 98% as when used an initial concentration of 600 mg $O_2$/L.

The initial concentration was increased to 1100 mg $O_2$/L, and the effect on the MBBR behavior was noticeable, once Test 2 starts to remove COD faster than Test 1. In the middle of the assay, hour 4, Test 2 had removed more COD than Test 2, but at the end of the assay, both tests reach a COD removal near 80%.

For the last assay, the initial concentration was set at 1200 mg $O_2$/L. As shown previously Test 1 was getting unstable with an initial concentration higher than 1000 mg $O_2$/L. When it increases to 1200 mg $O_2$/L, the reactor gets very unstable and was able to remove only 60% of the initial COD in the 8 h. Regarding Test 2, does not remove COD as faster as in the previous assay but follows an almost linear profile after 1 h of reaction, reaching 80% of COD removal efficiency at the end of the assay.

For assay 2, the MBBR system was feed continuously with fresh wastewater. It was studied the effect of the HRT using a FR = 20%. First, it was evaluated the MBBR using a HRT of 6 h. After, the feed flow was increased to reduce the HRT to 4 h. During the assay, samples from the reactor were taken to evaluate the COD removal until the steady-state was achieved, as presented in Fig. 2.

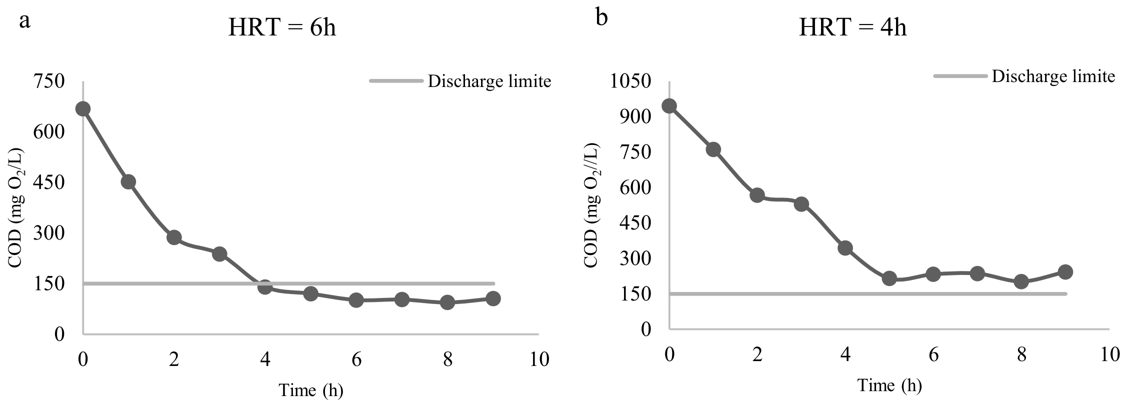


**Fig. 2.** COD evaluation of the MBBR with different HRT. (a) 6 and (b) 4 h.

Both systems had reached a stationary state between 4 and 6 h of reaction, but only for a HRT of 6 h, it was possible to discharge the treated wastewater in the aquatic environment, according to the Portuguese Decree-Law, number 236/98 of August 1 (Limit Emission Value of 150 mg $O_2$/L for COD).

Using a FR = 20% the system the was not able to operate with HRT lower than 6 h, otherwise, the limit value will not be achieved.

As concluded in the batch operation experiments, the use of a FR of 40% proved to be more efficient than FR of 20%, so the increase of the FR for the continuous operation was also studied. For this assay, the initial organic load was the same as in the previous case, as well as the HRT, but the FR was increased from 20 to 40%, as shown in Fig. 3.

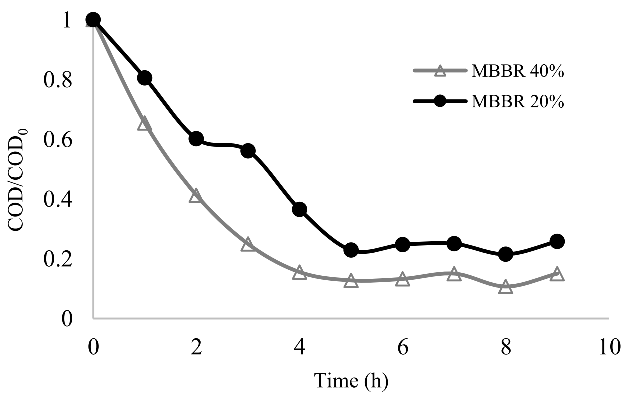


**Fig. 3.** Normalized COD (COD in the effluent divided for the COD in affluent) for the MBBR operated in continuous, with a FR of 20 and 40%.

Using a FR of 40% the process shows to be more efficient than using 20%, with both systems achieving constant values of COD after about 5 h, but the increase of the FR demonstrates an improvement of the COD removal efficiency from 80 to 95%. With a FR of 40%, the treated wastewater has a COD concentration that allows its discharge in the aquatic environment, according to the Portuguese Decree-Law, number 236/98 of 1 of August.

This increase of the FR does not require more space, once the reactor was the same in all experiments, so it could be a good alternative to the CAS since it requires less space and appears to be more efficient.

## 4. Conclusions

The MBBR shows to have a good performance to treat dairy wastewater, reaching a removal efficiency of 98% after 8 h of treatment, using a FR of 20% for a lower COD concentration of 600–800 mg $O_2$/L.

When the initial COD concentration was increased to 1100–1200 mg $O_2$/L. The FR of 20% shows not to be enough to reduce de desired amount of COD, confirming that a higher FR was needed.

Regarding the continuous operation, once again the FR of 20% was not enough to treat the wastewater in order to allow its discharge in the aquatic media, for HRT lower than 6 h.

After the tests carried out along this work, it is possible to conclude that a Filling Ratio of 40% reproduced better results in the COD removal efficiency in less reaction time and allows the discharge in the water environment according to the Portuguese law.

Using a FR of 40% there was achieved a great cod removal efficiency using a lower number of carriers inside the reactor, once the optimal FR can reach 70%, leading to higher energy costs. Using a FR lower than 70% and reaching a COD removal of 80% in less time than the conventional wastewaters treatments, this can be translated in lower energy requirement, consequentially the energy costs will be reduced.

## CRediT authorship contribution statement

**Andreia D. Santos:** Investigation, Formal analysis, Validation, Writing - original draft. **Rui C. Martins:** Data curation, Writing - review & editing. **Rosa M. Quinta-Ferreira:** Conceptualization, Supervision, Writing - review & editing, Project administration, Funding acquisition. **Luis M. Castro:** Conceptualization, Supervision, Writing - review & editing, Project administration, Funding acquisition.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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