Conversion of a biological SBR process into a Membrane Bioreactor A sustainable technical alternative

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October 2020

Energy Technology · Environmental Technology · Manufacturing

ABSTRACT

The **SBR** process (Sequencing Batch Reactor) is a discontinuous and sequential biological process for wastewater treatment widely used for decades.

In some cases, due to different reasons usually associated with the typology of the wastewater, the discharge requirements or the process design itself, this type of technology presents significant limitations for a safe and effective treatment. In these cases, the alternative of upgrading the SBR into an **MBR process** (Membrane Bioreactor) is a technically feasible, quick and economic solution, making it possible to increase the daily load of COD and nitrogen to be treated by up to five times and substantially improve the quality of the effluent, without increasing the biological volume or requiring large additional space.

This article presents the basic characteristics of both SBR and MBR processes, the differences between them that may be helpful in the selection of the appropriate treatment technology as well as the general considerations to be taken into account for the conversion of an SBR into an MBR, completed by three case studies carried out by the German company WEHRLE Umwelt GmbH.

KEYWORDS

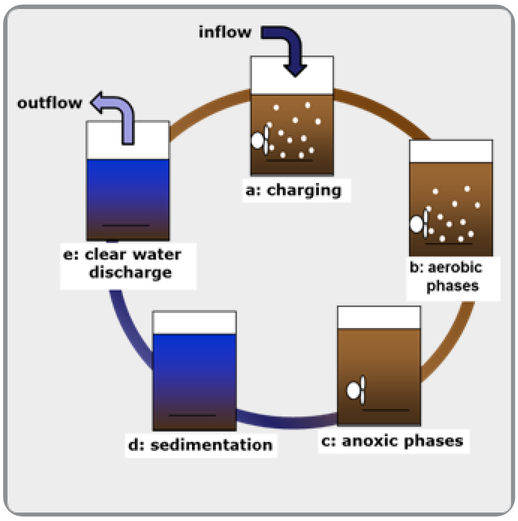
Water treatment, SBR, MBR, Membrane Bioreactor, Leachate, BIOMEMBRAT, Ultrafiltration, BAT, highly loaded wastewater.

SBR PROCESS

A Sequencing Batch Reactor (**SBR**) is a biological wastewater treatment system using activated sludge, whose main characteristic is that all processes required for the treatment are carried out sequentially in the same reactor.

The SBR system basically consists of 4 cyclic stages or phases:

- CHARGING PHASE: Feed of the wastewater to be purified into the SBR reactor.
- REACTION PHASE: Biological treatment of the wastewater with the help of microorganisms present in the activated sludge. Usually alternation of aerobic and anoxic phases.
- SEDIMENTATION PHASE: Sedimentation of the activated sludge in the reactor in order to separate the sludge from the purified water.
- DISCHARGING PHASE: Discharge of a certain quantity of the biologically treated water. Following the discharge, return to the charging phase of the SBR.



Picture 1: Typical SBR process scheme

This type of process has certain advantages, which is why it has been implemented in many industrial plants for decades. One of the main advantages of those processes is that they do not require high investments and have moderately low operating costs. Yet an SBR has several limitations, such as its discontinuity requiring a previous storage tank, the inability to achieve a sufficiently high effluent quality to keep discharge limits and the low stability of operation which is very sensitive to load and flow variations.

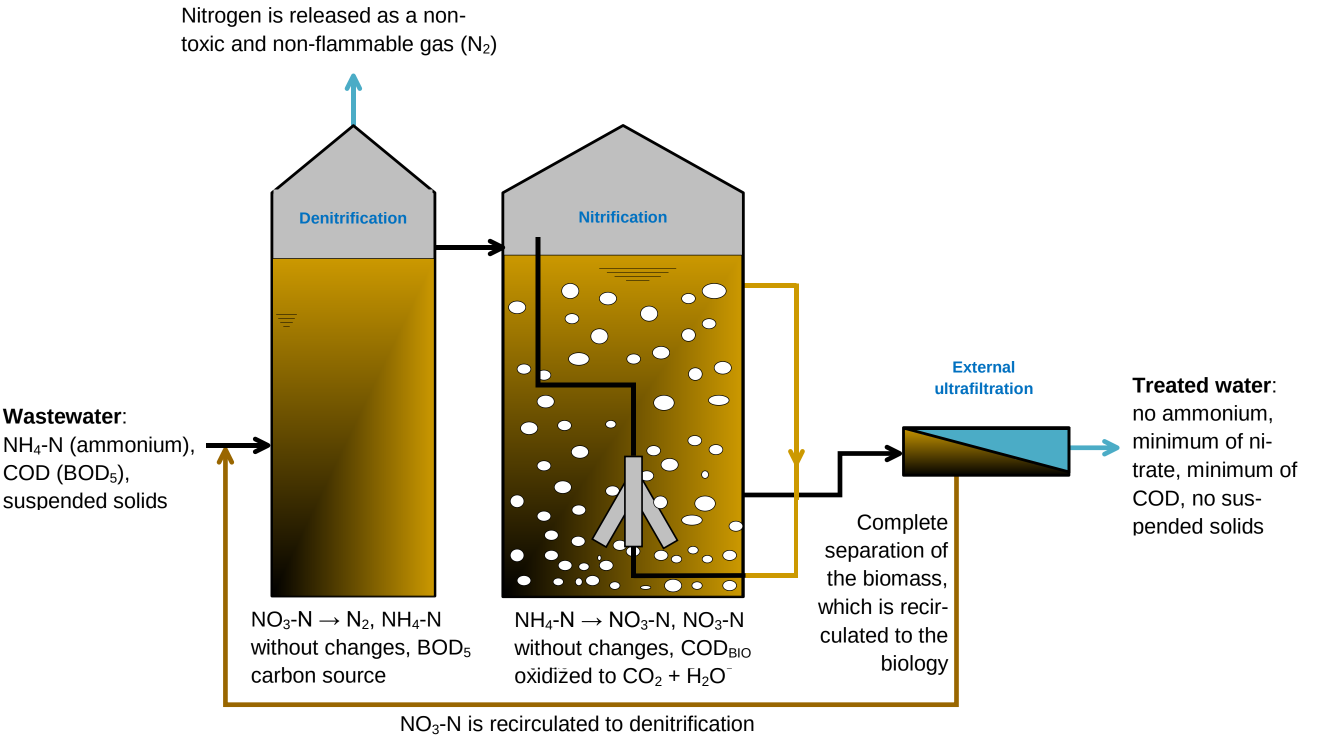
Another essential characteristic of this kind of process is the fact that the sludge is separated from the purified water by sedimentation in the reactor itself, so the process depends to a great extent on the sedimentability of the biological sludge. There is thus a high risk of bulking, producing a loss of active biomass and having negative effects on the discharge quality.

MBR PROCESS

The Membrane Bioreactor (MBR) biological treatment process is a biological process with activated sludge, in which the separation of the biomass is carried out by ultrafiltration modules and not by sedimentation. Due to the use of membranes, the MBR has specific characteristics which make it the BAT (best available technology) for biological wastewater treatment. There are basically two types of MBR: the ones using **submerged membranes** in the biological sludge and the ones using **external membranes**. In this article, we focus on MBR technologies with external membranes.

The main advantages of the MBR are its compact design, the simple and highly automated operation, its small footprint and the small biological volumes required. The plants offer high process stability, even in case of load variations, due to highly specialized microorganisms and a high, solid-free discharge quality. The reason for this is the safe retention of the active biomass with the help of ultrafiltration modules.

In contrast, MBR processes usually require higher investments than other water treatment technologies.



Picture 2: Simplified flow diagram of an MBR process with external membranes

The MBR process is particularly suitable for the treatment of landfill leachate or complex industrial effluents with high concentrations of organics and nitrogen, making it possible to obtain treatment results which other technologies are not able to achieve.

COMPARISON OF SBR AND MBR

When choosing a certain treatment technology, different factors must be taken into account, such as the inlet characteristics of the wastewater, the required discharge quality, the space available and the investment costs the client can accept.

Based on these considerations, each technology has its corresponding applications and market niches.

The main technical differences between SBR and MBR, which allow the selection of the appropriate technology, are as follows:

- **Process characteristics**: The SBR system is a discontinuous process (batch process), working with biomass concentrations below 5 g/l MLSS to ensure a proper sedimentation and usual tank heights of up to 6 m. The MBR, on the contrary, is a continuous process (operation 24/7) and works with concentrations of up to 25 g/l MLSS and tank heights of up to 10 m, since the separation is carried out by membranes and not by sedimentation. Due to these differences, MBR processes require smaller biological volumes and footprints than SBR processes.

- **Effluent quality**: The effluent of an MBR is completely free of suspended solids since the ultrafiltration represents a physical barrier. Due to this fact, the microorganisms are also more specialized (higher sludge age), making it possible to achieve high COD and nitrogen elimination rates. In general, MBR processes achieve significantly higher effluent qualities than SBR processes (COD 50-60 % lower than in SBR processes under the same circumstances and nitrogen concentrations below 10 mg/l). As for the denitrification rates, although the nitrate concentration of the effluent is comparable in both technologies, the SBR has a higher risk of inhibition of the biological process than the MBR due to the combination of high ammonium concentrations and high pH values during the anoxic denitrification phase.

- **Production of surplus sludge:** Due to the higher biomass concentration and sludge age, the quantity of surplus sludge produced in an MBR is significantly lower than the one of an SBR process.

Picture 3: Qualitative comparison of surplus sludge generated in MBR and SBR processes

- **Process stability**: SBR processes are much more sensitive to variations in the wastewater composition, which often cause changes in the biomass, affecting sedimentation and consequently lead to a loss of biomass and deterioration of the discharge quality. The MBR biomass separation system with membranes is less influenced by the rheological characteristics of the sludge, allowing a high degree of adaptation to changes in the inlet without affecting the process. On the other hand, by the MBR being a continuous process, the setup of the operating parameters (pH, dissolved oxygen, temperature, chemical dosing) is stable and continuous over time, which makes the plant control and operation easier than in an SBR.

- **Energy consumption**: For the same wastewater, the energy consumption of an MBR is generally higher than in an SBR, largely due to the high energy requirements of the MBR ultrafiltration pumps. Yet this is partly compensated by the higher energy efficiency of the MBR aeration.

- **Combination with post-treatment steps**: Due to the high effluent quality obtained in an MBR and the fact that the effluent is completely free of solids, the combination with refining post-treatment steps (salt reduction, recycling) is simpler and more efficient in case of an MBR process than in case of an SBR process.

Table 1: Comparison of SBR and MBR

	MBR	SBR
Feed	Continuous (24/7)	Discontinuous (batch)
Buffer tank needed	Optional	Indispensable
Aerobic/anaerobic reactors	In independent N/DN reactors	All in the same SBR reactor
Sludge concentration in the reactor (MLSS)	15-20 g/l	4-5 g/l
Aeration system	Ejectors	Diffusor plates
Separation of activated sludge	By UF membranes	By sedimentation in the SBR reactor
Risk of blocking	Non-existent	High
Effluent turbidity	< 0.2 NTU	> 0.2 NTU
COD elimination	++	+
NH4-N elimination	++	+
Retention of suspended solids	++	-
Retention of salts	o	o
CAPEX	-	+
OPEX	+	++

	MBR	SBR
Modular design (simple extensions / upgrades)	++	-
Space requirements	++	-
Process stability	++	-
Suitable for leachate treatment	++	o
Suitable for highly loaded effluents	++	o
Suitable for effluents with low loads and without limitations of space	o	++
Interface with post-treatment stages	++	-

CONVERSION OF AN SBR INTO AN MBR

In some cases, the installed SBR process does not suffice to achieve the required treatment objectives. There is a variety of possible reasons: changes in the characteristics of the actual wastewater compared to the ones considered in the design (concentrations, flow rate), modification of the discharge requirements, incorrect process design, etc.

In this case, a technological alternative for improvement is the **upgrade of an SBR to an MBR**, which allows to **reuse** most of **the existing plant** while achieving the discharge requirements **reliably, quickly and economically**.

The technical study of the requirements for the conversion of an SBR into an MBR is specific and individual for each specific plant, yet there is a series of general common criteria to be taken into account:

1. **Analysis of actual conditions**: The client must provide detailed information about the actual situation of the plant:
    - Detailed characteristics of the existing wastewater, present and/or future discharge requirements, specific project limitations (space, heights, location, noise, future change of regulations, other technical considerations)
    - Detailed data of the current SBR plant (engineering, design, equipment dimensioning, operating data)
    - Reasons why the client thinks that the SBR does not meet the expectations and requirements (insufficient treatment capacity, non-compliance with discharge limit values, non-compliance with other specific regulations, operating problems and difficulties, high costs, etc.)

2. **Analysis of the reasons for non-compliance**: With all data collected, a detailed and justified study must be carried out on the specific technical reasons for the inadequate functioning of the SBR, among which are typically the incorrect design or dimensioning of different units of the system (biological volume, aeration, cooling, nutrients, programming, …), the systematic failure to comply with the discharge requirements or operating problems (bulking, foaming, etc.).

3. **Study of alternatives and suggestions for improvement**: Based on the previous analysis, the interventions required for the conversion of an SBR into an MBR reusing most of the existing SBR plant are presented.

One of the essential actions to convert an SBR into an MBR is the installation of an **ultrafiltration** unit with external membranes for the separation of activated sludge connected to the existing biological SBR reactor, which will be basically operated continuously as **aerated nitrification reactor for the elimination of COD**. Moreover, the adaption of the rest of the equipment (aeration, cooling, anoxia zones, reagent dosing, post-treatment steps, etc.) to the new process must be analyzed and the operation system must be updated with a **new PLC/SCADA program**.

The external membrane ultrafiltration systems are very compact and usually delivered "fit for purpose" pre-installed on racks or in standard sea freight containers. For this reason, the conversion of an SBR into an MBR is usually a quick and simple project with minimal interface to the existing SBR system.

An external ultrafiltration unit requires very little space. Depending on the application, it is possible to install a complete ultrafiltration system with hydraulic capacity of up to **500 m^3/d** in a commercial 40' container (length 12 m, width 2.5 m).

Picture 4: Inside of two UF containers. Left: two lines; right: one line

CONCLUSIONS

The conversion of an SBR into an MBR is a sustainable technical alternative with the following advantages and improvements compared to the existing SBR:

- Reuse of most of the existing SBR system
- Increase of the COD and nitrogen load to be treated by up to 5 times without having to increase the biological volume
- High effluent quality (free of suspended solids, low COD load, ammonium practically zero) to comply with very strict discharge limits and possibility of water reuse
- Direct, economic and efficient combination with post-treatment steps
- Very compact solutions with very small footprints
- Simple and quick installation with minimal interface between the SBR and the new units
- Economic solution with improved treatment capacity and discharge quality at low investment costs

CASE STUDIES

The following are cases studies of three plants constructed by WEHRLE Umwelt GmbH, in which an SBR process was successfully transformed into an MBR process:

- CTR ECOPARC, Barcelona, Spain
- IGORRE Landfill, Vizcaya, Spain
- LILLYHALL Landfill, United Kingdom

All in all, WEHRLE built over 200 MBR leachate treatment plants in the world, some already in successful operation for over 20 years, being a proof of robustness and reliability of the technology as well as stable low operating costs throughout all phases of a landfill life cycle.

CTR ECOPARC, Barcelona, Spain

Before:

After:

COMPARISON TABLE:

	SBR	MBR + RO
Flow rate [m^3/d]	150	**300**
COD load [Kg COD/d]	2,400	**4,800**
Nitrogen load [Kg N/d]	420	**840**
Volumetric load [Kg COD/m^3.d]	1.2	**2.4**
Discharge	indirect	**direct**

IGORRE Landfill, Vizcaya, Spain

Before:

After:

COMPARISON TABLE:

	SBR	MBR
Flow rate [m^3/d]	100	**300**
COD load [Kg COD/d]	200	**1,500**
Nitrogen load [Kg N/d]	90	**165**
Volumetric load [Kg COD/m^3.d]	0.55	**3.35**

LILLYHALL Landfill, United Kingdom

Before:

After:

COMPARISON TABLE:

	SBR	MBR
Flow rate [m^3/d]	100	**100**
Footprint [m^2]	1,500	**900**
Volumetric load [Kg COD/m^3.d]	0.14	**1.4**
OPEX	> 10 £/m^3	**< 2.5 £/m^3**