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AirLift MBR for municipal wastewater treatment: out of the box performance

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ABSTRACT

In recent years, Norit has developed and proven a totally new concept for treating domestic wastewater. The concept applies the side-stream AirLift principle using the robust and reliable side-stream cross-flow concept while incorporating all the advantages of the low energy consuming submerged systems. Based on this 'outside the box thinking', a new membrane bioreactor (MBR) concept was developed offering the solution, which is fully beneficial to the potential of ultrafiltration (UF) membranes. The biological box can be designed and operated optimally, while the UF installation can be handled as a separate unit, performing cleanly, safely and efficiently, while producing bacteria and virus-free water for recycling or ecological discharge. Recently, the first full-scale installations have been commissioned successfully, while currently larger installations are under construction and will be commissioned soon. This article presents the development of the AirLift MBR concept from the proof of concept till commercial installations.

Keywords: Wastewater treatment; Membrane bioreactor; Ultrafiltration; Side-stream; Airlift; Cross-flow

1. Introduction

World-wide the demand for fresh water grows, while the availability decreases. Emerging technologies can offer an important contribution to future water treatment. It is fully recognised nowadays that membrane filtration has conquered a mature place in the production of drinking and industrial water. Especially, desalination by means of reverse osmosis has proven to be a technically feasible and economically viable technique.

However, the closure of the water loop by recycling is another alternative of importance to cope with the world water challenges. The expenses for the disposal of industrial and municipal wastewater are increasing strongly due to more stringent governmental legislation ordering lower discharge limits and higher discharge taxes. Moreover, the intake of ground water is being limited to prevent a dehydration of the soil having a destructive influence on nature's flora and fauna. The call for a closed water cycle is becoming louder and more efficient wastewater treatment techniques have been developed, such as the membrane bioreactor (MBR).

A MBR is a compact-built purification system combining the biological degradation step with a membrane separation step instead of with a clarification tank. The

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influent is fed to the aerated bioreactor where the organic components are oxidised by the activated sludge. Next, the aqueous activated sludge solution passes through an ultrafiltration (UF) membrane filtration unit separating the water from the sludge. The latter returns to the bioreactor, while the permeate is discharged or re-used as particle-free effluent.

Although membrane filtration is applied in hundreds of different applications, Norit UF technology for water treatment focuses on:

- bacteria- and virus-free drinking water production;
- surface water treatment;
- seawater reverse osmosis pre-treatment;
- industrial wastewater effluent recycling;
- industrial wastewater influent treatment (MBR);
- municipal wastewater effluent recycling;
- municipal wastewater influent treatment (MBR);
- recovery of sand filter backwash water.

The Norit UF knowledge and expertise is based on the application of membrane technology for more than 25 years. All this experience is concentrated in the following product market combinations covering the complete water market depending on the total suspended solid contents of the sources:

- Norit XIGA™ — for low suspended solids (0–50 mg/l);
- Norit AquaFlex™ LowSolids — for medium suspended solids (50–200 mg/l);
- Norit AquaFlex™ HighSolids — for high suspended solids (200–1,000 mg/l);
- Norit AirLift MBR — for very high suspended solids (1,000–15,000 mg/l).
- Norit CrossFlow MBR — for extremely high suspended solids (1,000–40,000 mg/l).

Some membrane suppliers choose to submerge their membranes into the activated sludge, while Norit has always viewed this as a suboptimal configuration. Norit's systems are exclusively designed in side-stream configuration, i.e. with the membrane section next to the bioreactor ("out-of-basin") in a clean and safe place, and easily accessible for the operators.

This article summarises two side-stream MBR systems which are based on two different operating philosophies in order to optimise the system performance in relation to the application.

2. Technologies

2.1. Norit CrossFlow MBR

The cross-flow mode is used most generally for industrial wastewater treatment applications. The main characteristic of cross-flow is that a part of the feed is withdrawn as permeate, while the other part is forced to flow along the membrane surface (Fig. 1a). The pressure pump pressurises the feed, while the circulation pump recirculates the concentrate; part of the concentrate is purged to the bioreactor. The advantage is a better control of the cake layer build-up resulting in a long time constant flux without any backwashing or cleaning-in-place. Typically, a system consists of several modules in-series (one street) and several streets in-parallel. Norit CrossFlow MBR systems are available as standardised, modular skids. The modules are placed horizontally resulting in very reliable and compact installations (Fig. 1b). Generally, the capacity of a cross-flow system is maximised to 100 m^3/h due to energy consumption, which is on the order of 2.5–3 kWh/m^3.

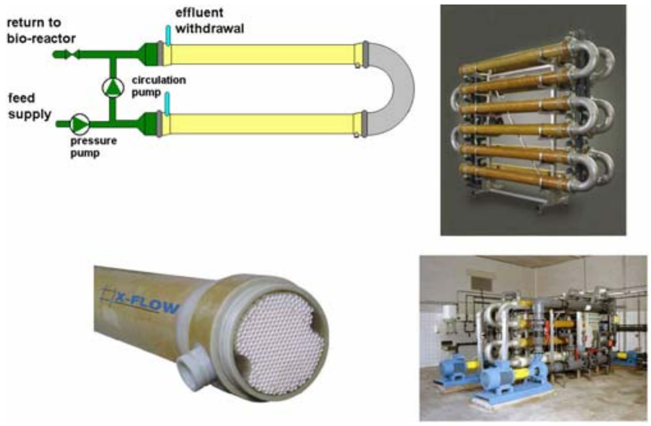

Fig. 1. Norit CrossFlow MBR based on 8" modules: (a) basic configuration; (b) standard street; (c) 8" GFR module; (d) typical full-scale installation.

The heart of the cross-flow membrane installations is the 8" GPR module with Compact UF membranes with an inner diameter of 5 or 8 mm (Fig. 1c). Norit X-Flow has developed especially for the Norit CrossFlow MBR application high flux membranes with excellent anti-fouling behaviour. Together with an optimal cleaning-in-place (CIP) procedure, the Norit CrossFlow MBR process is an efficient solution for industrial wastewater treatment. Fig. 1d shows an example of a full-scale cross-flow UF installation being part of a MBR at a tank cleaning company. In all the MBR projects Norit Membrane Technology can supply from the standardised skids to turnkey projects.

Typical references are found in:

- paper and pulp industry;
- food, beverage and dairy industry;
- chemical (process) industry;
- tank cleaning water recycling;
- leachate water treatment.

2.2. Norit AirLift MBR

The principle of the AirLift MBR is based on the same basics as used for the cross-flow principle; however, the turbulence within the tubular shaped membranes is achieved by sparging air into the vertically mounted membranes [1].

As shown in Fig. 2, the recycling flow propelled from the activated sludge tank at a velocity ranging from 0.3–0.5 m/s is enhanced in turbulence by adding air underneath the module with an additional 0.3–0.5 m/s. The permeate output can be controlled by a simple control valve for adapting the 'gravitational flow' or by a dedicated pump. A regular back-pulse is executed to maintain the membranes performing at a steady state.

The airlift system is built modularly as well, as can be seen in Fig. 3. A typical system consists of multiple skids. The major advantage of the airlift system is its low energy consumption being lower than 0.25 kWh/m^3, which is currently the lowest available in the market. Although airlift systems were originally aimed at municipal markets, these systems are becoming very attractive to industrial customers as well.

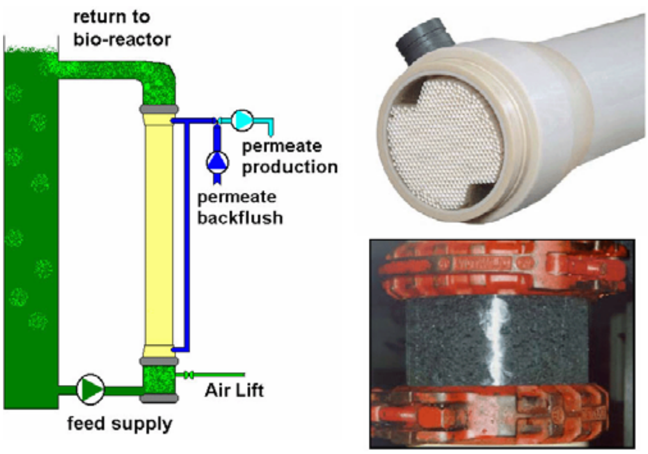

Fig. 2. Norit AirLift MBR: (a) basic principle; (b) 8" Compact membrane module; (c) and continuous aeration.

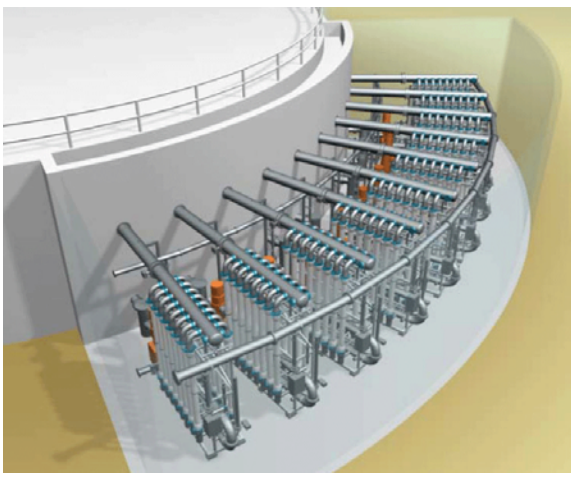

Fig. 3: Norit AirLift MBR: standard, modular skids.

3. Applications

3.1. Norit CrossFlow MBR

Holland Malt has erected one of the world's largest and most innovative maltaries at Eemshaven (in the Northern province Groningen, The Netherlands) having a malt production capacity of 130,000 metric tons (Fig. 4). The feed stock of this plant is around 165,000 metric tons of barley, which grows on 30,000 ha of agricultural land. Holland Malt is a joint company of the Dutch brewery Bavaria (Lieshout), the Dutch agricultural cooperation Agrifirm (Meppel), and around 600 farmers of brewer's barley combining the quality of Dutch barley with the knowledge and expertise of leading producers of malt and beer. The first steps in the malt process are the intensive washing of the barley, followed by a soaking step in large tubs. During these steps the water is polluted with dust

(a)

(b)

Fig. 4. Norit CrossFlow MBR: Holland Malt plant: (a) bioreactor; (b) UF system.

particles, sugar and starch. In currently operated malteries the wastewater is biologically treated in a large bioreactor, converting the organic components into carbon dioxide and nitrogen gas. After a rough clarification to remove the insoluble particles, the water is discharged on the surface water. This commonly used treatment is no longer allowed for new malteries, and better treatment of the wastewater is required by the local authorities.

In order to cope with the strict water discharge requirements, Holland Malt has decided to use an advanced membrane bioreactor/activated carbon and ultraviolet disinfection water recycling plant. The malt washing water is discharged 3 times a day and is collected in a large buffer. From this buffer a constant flow of wastewater passes a drum filter and flows into the biological treatment tank. The bioreactor is an intensive activated sludge (aerobic) process converting the organic components into carbon dioxide and nitrogen. Next, the activated sludge is pumped to a four-stage UF system to separate the water from the biomass. The latter is recycled to the bioreactor, while the particle and bacteria-free treated water is polished. First, the remaining odour is removed by Norit activated carbon filtration, after which the water is disinfected by ultraviolet disinfection before it is reused as process water. The quality of the produced process water is according to the Dutch drinking water requirements. This water recycling plant enables Holland Malt to reduce dramatically its effluent sewer volume to 20%, enabling a fivefold reuse of the potable water.

Norit Membrane Technology has delivered the project turn-key. Comparable water treatment systems are under investigation for several breweries in Europe.

3.2. Norit AirLift MBR

The Ootmarsum wastewater treatment plant (WWTP) is owned by the water authority, Regge & Dinkel (WRD), and is situated in the municipality of Dinkelland (eastern part of the Netherlands). The WWTP must be modernised because it discharges treated wastewater into a water system with considerable ecological vulnerability. A design study resulted in the choice for a so-called hybrid system. Such a system combines a conventional system followed by a sand filter with a MBR. With a hybrid MBR, the costs can be reduced relatively to those of a complete MBR plant without making concessions in terms of effluent quality [2].

The hybrid system consists of a MBR alongside a conventional system (Fig. 5). The MBR has a limited hydraulic capacity. The idea is that a relatively large part of the dry weather flow (DWF) will be treated with the membranes. During periods of rain weather flow (RWF) the excess rainwater will be channelled via the intermediate buffer to the conventional active sludge system

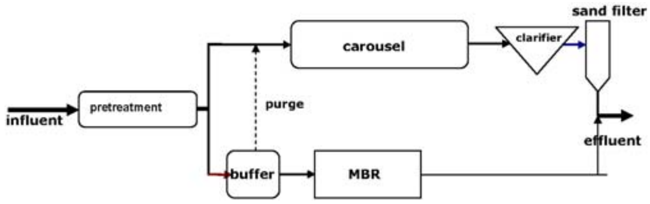

Fig. 5. Schematic presentation of the Ootmarsum hybrid configuration.

and the final settling tank. In this way, the surface area of the membranes can be considerably reduced in comparison with a complete MBR plant, and the membranes can be used at their optimum. With a hybrid MBR, the costs can be reduced relative to those of a complete MBR plant, without making many concessions in terms of effluent quality. There are a number of possible hybrid solutions. No experience has yet been gained with any of these options in the Dutch situation.

The MBR at the Ootmarsum WWTP treats 50% of the total amount of sewage in periods of DWF, when the hydraulic capacity is only 23% of the RWF. The maximum hydraulic capacity of the MBR is 150 m^3/h, while the total sewage inflow to the WWTP under RWF conditions is 650 m^3/h. The intermediate buffer serves as a preliminary settling tank. During prolonged periods of RWF the buffer has insufficient capacity and will therefore overflow. The overflow water (max. 175 m^3/h) is treated in the conventional system. In this situation, the conventional system has to treat a maximum of 500 m^3/h. A notable aspect of this configuration is the large variation in the hydraulic load of the conventional system.

The Ootmarsum WWTP is configured for a biological capacity of 14,000 PE (@ 54 g BOD) under winter conditions (7.5°C) and a capacity of 18,500 PE (@ 54 g BOD) under summer conditions (17.5°C). The total hydraulic capacity is 650 m^3/h, and the DWF is calculated to be 150 m^3/h.

The membrane section consists of six membrane stacks in parallel, each of them equipped with 14 modules, which can be extended to 18 modules (Fig. 6). No pilot studies were carried out for the design of Ootmarsum WWTP so the design of the membrane installation was based on experience with the sidestream concept at other locations where the design base for Ootmarsum has proven itself over a period of several years [2]. In preparation for full-scale plant operation, an intensive pilot study was made in order to develop a start-up protocol, train operators, check control philosophies, and optimise the overall processing. The construction work of the 650 m^3/h plant started in mid-2005 and was finished in the second half of 2007. The plant was commissioned successfully and the process settings are currently being optimised.

(a)

(b)

Fig. 6. Norit Airlift MBR: WWTP Ootmarsum plant: (a) bioreactor; (b) AirLift UF stacks.

4. Conclusions

The out-of-basin approach for MBR systems is unique and has many advantages:

- Robust and reliable, based on a long experience and extensive track record; the low-fouling tubular membranes have a proven record for long life.
- Simple process set-up applying a modular skid construction.
- Flat slab construction as no additional membrane tanks for the submerged membranes are required.
- Easy cleaning through continuous cross-flow or air scouring resulting in a low chemical use for a stable long term operation.
- Easy maintenance because the membrane modules are easily accessible.
- Good effluent quality using UF membranes enabling reuse of the permeate.
- Small footprint due to the higher suspended solid concentration in the bioreactor compared to conventional activated sludge systems and the high flux rates of the membrane resulting in a compact membrane section.
- Low operational expenses based on the high flux rates in case of the CrossFlow system and well-designed air driven circulation the in the case of the AirLift system.

Two case studies were presented: (1) industrial Crossflow MBR for a maltery and (2) Airlift MBR for municipal waste water treatment in the Netherlands. With growing knowledge on side-stream MBR technology, a technically feasible and economically viable alternative for the submerged systems is available. New possibilities and improved performances are now within reach by applying this out of the box principle where many examples are available.

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