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Comparison of submerged hollow fibre and flat membrane modules using the example of wastewater in breweries

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For three years now, Badische Staatsbrauerei Rothaus AG has been operating an SBR (Sequencing Batch Reactor) facility with downstream ultrafiltration for wastewater treatment. Hollow fibre ultrafiltration membranes are installed in this large industrial facility. Pilot tests were also conducted over a period of one year with a flat membrane module by Microdyn-Nadir GmbH type BIO-CEL® BC100-100. In the following article, we will first describe the layout of both facilities and then present the results of the one-year pilot test phase.

1. Introduction

For three years now, Badische Staatsbrauerei Rothaus AG has been operating an SBR (Sequencing Batch Reactor) facility with downstream ultrafiltration for wastewater treatment. Hollow fibre ultrafiltration membranes made by Zenon are installed in this large industrial facility. Badische Staatsbrauerei Rothaus AG wants to gain experiences with possible alternative products to gain market independence from the currently installed membranes. It was already investigated during planning, which chamber geometry could also be suitable for other products. The following predominant questions were supposed to be answered in the one-year pilot phase:

- Are there alternative products?
- How extensive is the market-dependency of the operators?
- What about the compatibility of the different membranes with respect to
- Performance
- Energy demand
- Use of chemicals
- Packing density
- Control and Periphery?

The pilot tests were conducted with a flat membrane module by Microdyn-Nadir GmbH type BIO-CEL® BC100-100. Besides the design as hollow fibre or flat membrane, the essential difference between the applied membranes is the membrane material: While the hollow fibres consist of PVDF, PES membranes are installed in the BioCel® module.

Contrary to classical submerged plate and frame flat membrane modules with fixed disks, two membranes each are joined plane with spacer material to form self-supporting pockets in the BioCel® module. This module design allows backwashing of the membranes just like with hollow fibre module.

In the following article, we will first describe the layout of both facilities and then present the results of the one-year pilot test phase.

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2. Layout and description of the facility

2.1 Facility layout

The large industrial facility is dimensioned to 72 m^3/h resp. 11.9 $l/(m^2h)$ in permanent operation. For high-load phases, the facility is dimensioned for 108 m^3/h resp. 17.9 $l/(m^2h)$. This dimensioning is valid for max. 24h on 30 days/year. In exceptional cases, the facility can be operated once or twice a year for at most four hours with 30 $l/(m^2h)$.

The filter surface of the facility per track is 1,512 m^2. The pilot facility (PF) has an installed membrane surface of 100m^2, which results in a 15:1 ratio. Accordingly, the test facility must be operated for the same output in permanent operation with 1.19 m^3/h (corresponds to 11.9 $l/(m^2h)$). The high load of the pilot facility therefore amounts to 1.79 m^3/h (17.9 $L/(m^2h)$).

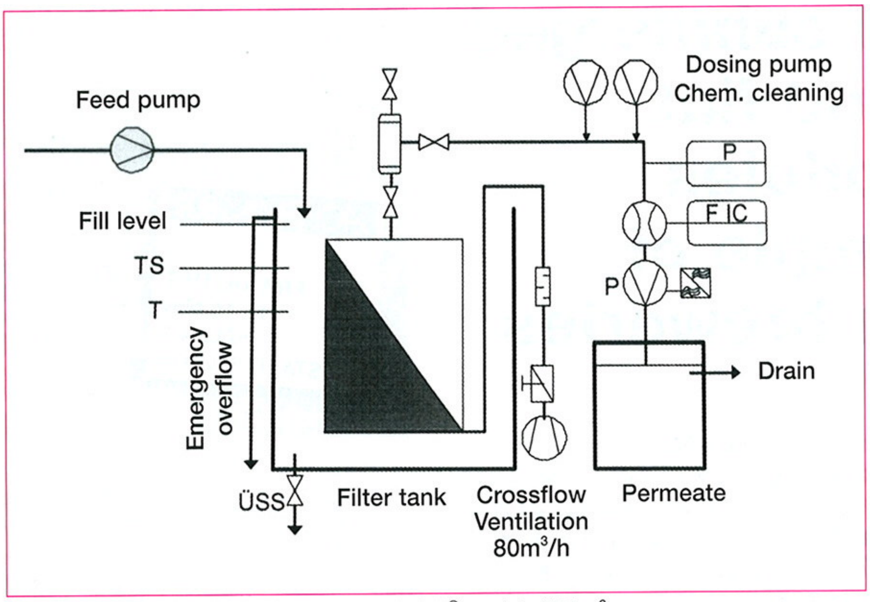

Fig. 1: Diagram of the pilot facility with a BIO-CEL® module (100 m²)

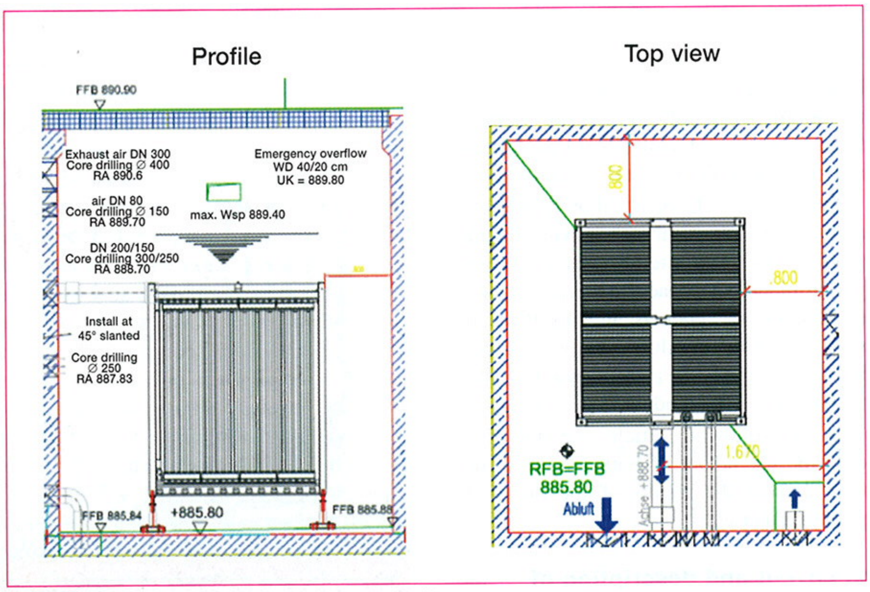

Fig. 2: Filter chamber of the large industrial facility

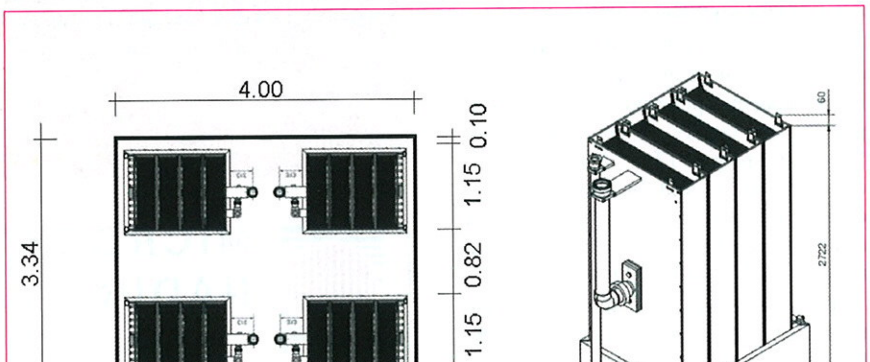

Fig. 3: Filter chamber equipped with 4 BC400, left: BIO-CEL BC400 module

The basin volume per filter track of the large industrial facility is approx. 48 m³ (4.00 x 3.34 x 3.60 m). In accordance with the 1:15 ratio, the basin volume of the pilot facility is 3.2 m³ (1.10 x 2.00 x 1.45 m), so that the sludge concentration is about in the same size range in both facilities. Both facilities have installation density of approx. 32 m²/m³.

2.2 Description of the pilot facility

The pilot facility is operated parallel to the membrane filtration 1 (MF1) of the large industrial facility. The feed is supplied from the drain equalising basin with an inherent pump parallel to the large industrial facility. The permeate and the excess sludge of the pilot facility are conveyed back to the large industrial facility. Fig. 1 shows a diagram of the pilot facility.

The facility is equipped with a possible fully automatic in-situ cleaning unit. The facility is controlled via an SPS connection and treatment is fully automatic. The pilot facility is operated in the following cycle: 8 min filtration, 30 s relaxation, 30 s backwashing, 30 s relaxation.

2.3 Possible substitution of the Zenon with BIO-CEL® modules

The dimensions of the filter chamber are: 4.00 m x 3.34 m x 3.60 m (height of water level). Accordingly, the area is 13.4 m² per filter chamber. One Zenon module with the dimensions 2,112 x 1,739 x 2.536 mm and a membrane surface of 1.512 m² (Fig. 2) is installed per filter chamber. The dimensions of the BIO-CEL® modules type BC400F-C100-UP150 are 1.152 x 1.440 x 2.722 mm and include 400 m² membrane surface (Fig. 3).

This allows the installation of 4 BIO-CEL modules with a total membrane area of 1,600 m² and the substitution of the Zenon module without loss of membrane area. An access would be possible with a width of approx. 80 cm.

3. Results of the one-year pilot phase

3. 1 Hydraulic performance

The tests were divided into two sections: In the first testing period, which lasted around 5 months, the pilot facility was operated parallel to the MF1 with respect to loading and operating times. However, the flow was increased continuously across this period to investigate the performance capacity of the facility. In the second test phase, both facilities were operated parallel – also with respect to the throughput capacity – to be able to compare both facilities under the

Table 1: Chemicals requirement of the facilities

	Large facility Zenon	Pilot facility BIO-CEL®
Sodium hypochlorite	0,23 L/m² per year	0,11 L/m² per year
Citric acid	0,06 kg/m² per year	0

same conditions. One exception here was the cleaning strategy: the large industrial facility was cleaned chemically in-situ every 4 weeks (MC on air), the pilot facility (BIO-CEL®) was operated without chemical cleaning.

Test period 1: Increase of the flow in the pilot facility / start-up phase

At the start, the pilot facility was operated with a flow of approx. 8 l/(m²h), which was subsequently increased up to 20 l/(m²h). The flat membrane had an initial permeability of approx. 450 l/(m²h bar), the final values were around 250 l/(m²h bar). Fig. 4 shows the course of the first pilot phase in a graphic.

As you can see, the level of permeability (flow up to 14 l/(m²h) remained constant in the first 2 months and then significantly decreased at high flow rates of 20 l/(m²h), but then remained at a constant level. Altogether it shows that flow rates up to 20 l/(m²h) could be achieved over several weeks, however with decreasing permeability. Cleaning operations must therefore be performed with high flow rates. It can be ascertained that the admissible top load of 17.9 l/(m²h) of the large industrial facility can be securely achieved with the BIO-CEL modules over several weeks.

A direct comparison of the BIO-CEL module with the large industrial facility is not possible, because the facilities were operated with different flow rates (the large industrial facility was operated at a constant 12 l/(m²h)).

Test period 2: Parallel operation of both facilities

Since October 2007, both facilities were operated parallel with the same flow rates. Fig. 5 shows the respective gross and net flow rates. As you can clearly see, both facilities realise almost the same hydraulic flow rates, which is a good basis for comparison.

Both facilities were cleaned prior to the second test phase (recovery cleaning). Due to a defect MLSS probe, sludge thickening initially occurred in the test facility and lead to significant permeability loss. However, this regenerated in the further process without cleaning. The large industrial facility only showed a slight permeability loss across the entire test period of 100 % (400 l/m²h bar) to 80 % of the initial permeability. The large industrial facility was cleaned regularly during the test period (every 4 weeks) out in the air with chemicals, while the test facility was operated without cleaning. Fig. 6 shows the progress since the exchange of the TS probe (November 2007) after which there were no more disruptions.

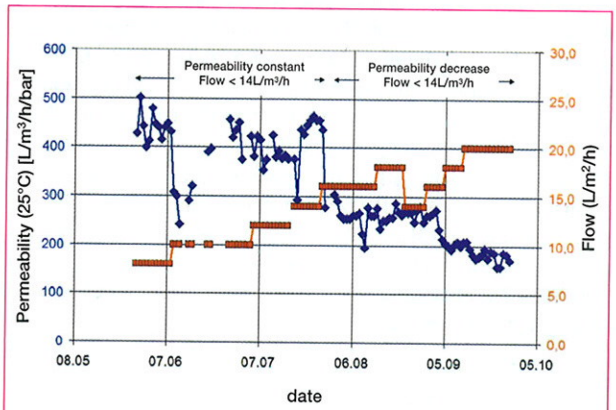

Fig. 4: Progression of permeability and hydraulic flow during the first pilot phase

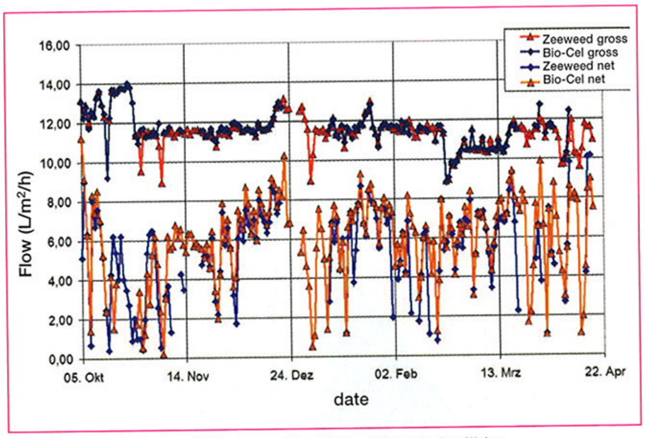

Fig. 5: Comparison of the specific flows of both facilities

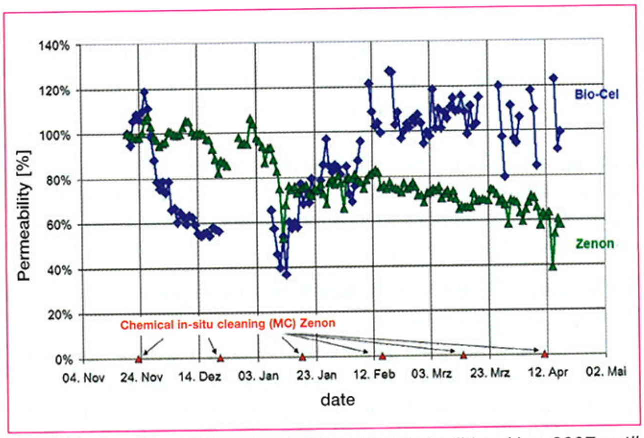

Fig. 6: Comparison of the permeability of both facilities, Nov. 2007 until April 2008

If we look at the parallel operation of both facilities without disruptions, the permeability of the test facility towards the end of the test (April 2008) is about the same as the one at the start of the test (November 2007), while that of the large industrial facility reduced in this period (Fig. 6).

It turned out that the pilot facility (no chemical cleaning, BIO-CEL®) showed fluctuations in permeability. However, after a decline of the permeability, it increased again. The large industrial facility on the other hand (regular cleaning) did not show such fluctuations. The reason for the different behaviours cannot be clearly allocated. One possible reason may be the difference in the cleaning strategy. It is assumed that these permeability fluctuations are remedied by cleaning and that fouling layers are removed directly through cleaning.

Altogether it can be ascertained that reliable operation with flow rates of up to 20 l/(m^{2}h) can be maintained with the BIO-CEL® module, even without regular cleaning.

3.2 Required chemicals

The required chemicals for the large industrial facility in the comparison period (annual quantity 2007, 1,700 kg sodium hypochlorite, corresponds to 1.42 m^3) were approx. 0.23 l NaOCl per m^2 membrane surface and 0.06 kg/m^2 citric acid. During the test period of one year, the pilot facility was merely cleaned once chemically (RC, recovery cleaning). This cleaning operation required approx. 11 litres NaOCl. The specific chemical requirement is therefore approx. 0.11 l/m^2 filter surface/annually. This way, only 50% of the NaOCl quantity was required for the flat membrane compared to the hollow fibre membrane in this one-year comparison. In addition, the flat membrane does not require any citric acid. Table 1 summarises the required quantity of chemicals.

3.3 Energy demand

The energy demand of the large industrial facility with hollow fibre membranes is approx. 0.5 kWh/m^3 (measured values). As the pilot facility is not equipped with an electricity meter, its energy demand can only be determined mathematically. If a specific energy demand of 5.4 Wh per m^3 air is used, this results in an average energy demand of approx. 0.5 kWh/m^3 for cross-flow ventilation. The further energy demand for the permeate pump and the sludge drain can be estimated with 0.1 kWh/m^3. Altogether, the hollow fibre membrane has a slight energetic advantage over the flat membrane. Please note that the energy demand was not optimised during the tests. The BC400F modules applied in a large industrial installation are more energy-efficient and poss. cancel the energy difference.

4. Conclusion and summary

The pilot facility was installed with the aim of comparing the BIO-CEL® modules with the Zenon modules installed in the large industrial facility with respect to flow output, cleaning demand and energy demand. The pilot facility was installed for 1 year to be able to compare all seasonal fluctuations. Summary of the results of the pilot phase:

- Due to the operating modes of the BIO-CEL® modules, which were operated with backwashing analog to the large industrial facility, it is possible to substitute the hollow fibre modules with the flat membrane modules with slight modification efforts on the control.
- The construction of the filter chambers in the large industrial facility allows the substitution of the present hollow fibre modules with BIO-CEL® modules.
- The required throughput rates (11.9 l/(m^{2}h) can be effortlessly realised with both membrane facilities. The BIO-CEL® module achieved this throughout rate over several months without any chemical cleaning.
- The admissible peak load of 17.9 l/(m^{2}h) of the large facility was securely realised with the BIO-CEL® modules across several weeks; even flow rates up to 20 l/(m^{2}h) were achieved.
- In the comparison period, the flat membrane needed lesser chemicals than the hollow fibre membrane. This is due to the fact that the flat membranes do not require regular cleaning (MC).

Compared to the tested BioCel® 100 m^2 modules, the hollow fibre membranes have a slightly lower energy demand as these are operated with a lower air volume flow. When using the 400 m^2 module in large facilities, however, the specific air quantity of the BioCel® module reduces by approx. 40%.

These central results allow the operator to use membranes by other manufacturers (e.g. BIO-CEL® flat membranes) besides the original product (hollow fibre membrane) when membrane changes are pending. Operators are therefore no longer dependent on one membrane supplier, which increases profitability due to several potential products.