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RECYCLING OF SPENT PROCESS WATER FROM THE FOOD AND BEVERAGE INDUSTRIES USING A HYBRID PROCESS (BIOLOGICAL TREATMENT PLUS DOWN-STREAM NANOFILTRATION)

Summary. An integrated membrane filtration process was developed to treat polluted process water from small and medium-sized enterprises in the food and beverage industries. It comprises a membrane-supported bioreactor and a combined nanofiltration/UV disinfection stage. Following a successful on-site test operation with a pilot plant, the process was implemented in demonstration scale (up to 2 m^3/h) at a fruit juice production plant in order to produce water of drinking quality. Permission to reuse the treated water was granted by the responsible health authorities.

ZAWRACANIE ZUŻYTEJ WODY PROCESOWEJ Z PRZEMYSŁU SPOŻYWCZEGO I PRODUKCJI NAPOJÓW ZA POMOCĄ PROCESU HYBRYDOWEGO (OCZYSZCZANIE BIOLOGICZNE PLUS NANOFILTRACJA)

Streszczenie. Opracowano zintegrowany proces filtracji membranowej do oczyszczania wody procesowej pochodzącej z małej i średniej wielkości zakładów przemysłu spożywczego i produkcji napojów. System obejmuje bioreaktor membranowy oraz połączony etap nanofiltracji i dezynfekcji UV. Na podstawie badań testowych w skali pilotowej, potwierdzono przydatność procesu w skali demonstracyjnej (do 2 m^3/h) dla instalacji produkcji soku owocowego w celu otrzymania wody do picia. Pozwolenie na ponowne użycie wody uzdatnionej wydały odpowiednie służby sanitarne.

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Introduction

Water and wastewater costs are becoming an increasingly important economic factor for small and medium-sized enterprises. This applies particularly to the food and beverage industries. Therefore, a broadly applicable and cost-effective process was developed that was capable of treating polluted process water (COD 2 000 – 5 000 mg/l) from an on-site mixing and equalising tank and producing water of drinking quality for reuse.

The process developed (Fig. 1) comprises two stages: In the first unit, the wastewater is treated by a membrane bioreactor, which ensures a certain water quality for the second unit where the water is treated further to achieve drinking quality. For this purpose, a downstream nanofiltration (NF) and UV disinfection process is used.

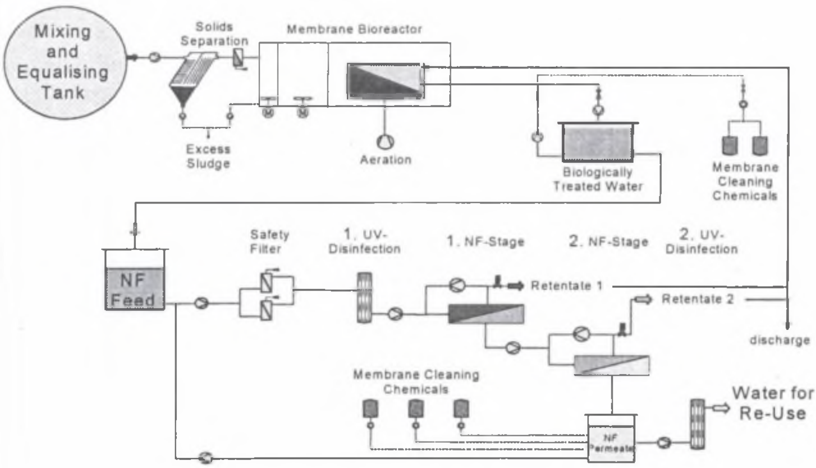

Fig. 1. Simplified flow diagram

Membrane bioreactor (MBR)

The spent process water to be treated is characterized by considerable variations in organic pollution, low nutrient to food ratio and high concentrations of suspended solids (1-3 g/l). To remove the latter ones, upstream of the membrane bioreactor a lamella separator was used, followed by a sieve of 2 mm. The relevant operating parameters of the membrane bioreactor during the one year test run are given in Table 1.

Table 1

MBR operating parameters

Parameter	Unit	Min – Max	Mean
Bioreactor net volume	m³	-	27
Hydraulic flow rate	m³/h	0.5 – 1.3	0.9
HRT (Hydraulic residence time)	h	21 – 54	30
MLSS (Mixed liquor suspended solids)	kg/m³	5 – 18	11,4
Sludge load	kg COD /(kg SS·d)	0.05 – 0.35	0.25
Sludge age	d	8 – 60	13,5
Temperature	°C	13 – 33	25
pH	-	7.8 – 9.0	8.2

Except for certain periods of extreme operating conditions the effluent quality was always below the target values of 200 mg/l COD (see Fig. 6) and 10^4 CFU, respectively, to be met for successful nanofiltration. Removal rates for COD averaged to approx. 95% and were dependent upon neither COD load nor MLSS content. The variation of these operating parameters during the test period are shown in Fig. 2.

The food to nutrient ratio of the spent process water was on average 223:37:1. Although this ratio indicates nutrient deficiency, lowering it to 100:20:1 by adding nitrogen and phosphorous salts had no significant influence on bioreactor performance in terms of COD removal. Nevertheless, dosing of phosphorous was effective to stop foam production by the activated sludge which otherwise created severe difficulties for stable plant operation.

It was found that biological conditions and characteristics of the activated sludge had significant influence on membrane flux. Yet it could not be attributed to a single parameter like nutrient feeding or organic loading.

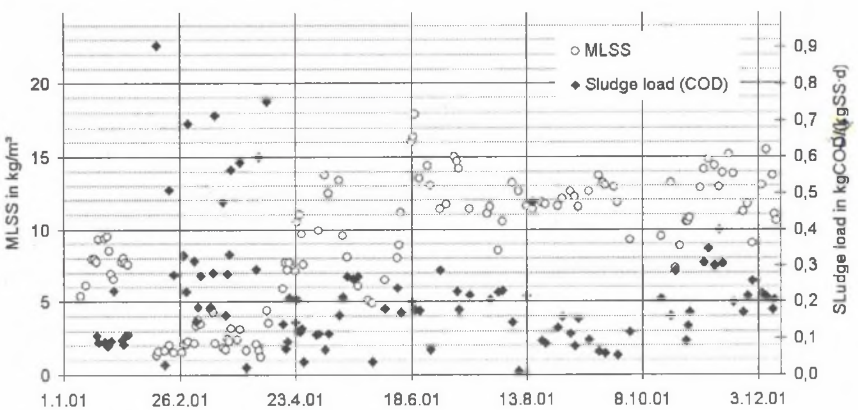

Fig. 2. Sludge load and mixed liquor suspended solids

In order to figure out the most efficient module configuration in a first phase three different submerged membrane module types (tubular, capillary, hollow fibre) were tested in parallel. The capillary module showed high fluxes, but the mechanical strength of the membranes was insufficient. The capillary module showed high fouling due to the hydrophobic nature of the membranes. For further long-term operation of the MBR the tubular modules were chosen. Characteristics of these are given in Table 2.

Table 2

Characteristics of the tubular modules

Membranes Pore size	Tubular (8 mm inner diameter) 0.04 µm
Filtration direc :ion Creation of sh(ar-rate	Inside – out Fine bubble aeration (creating an upward flow of the activated sludge/air mixture inside the tubular membranes)
Membrane are ι per module No. of installe(modules	7 m² 14

Fouling control was conducted exclusively by fine bubble aeration which simultaneously ensured oxygen supply for biodegradation and created sufficient shear rates on the membrane surface. Thus, additional energy costs for coarse bubble aeration, applied in conventional membrane bioreactors, were avoided.

After a start-up period, lasting approximately three months, a stable flux of 14 l/(m²·h) was achieved (Fig. 3) at a transmembrane pressure ranging from 60 mbar (summer period, sludge temperature 30°C) to 80 mbar (winter period, 20°C).

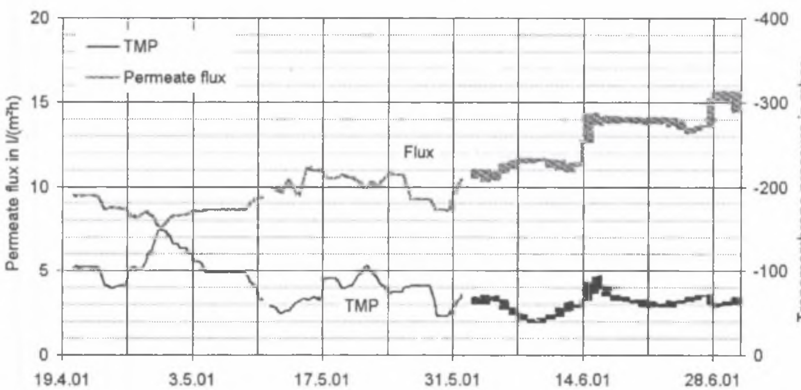

Fig. 3. Membrane flux stabilisation following the start up period

Although transmembrane pressure was low, a further increase of TMP lead to unstable operating conditions, resulting in a continuous decrease of flux and increase of TMP. This means that the chosen membrane flux of 15 $l/(m^2 \cdot h)$ corresponds to the critical flux that cannot be exceeded under the established sludge conditions.

Nevertheless, it could be shown that a short-term increase of flux was possible without irreversible blocking of the membranes (Fig. 4), making it possible to increase the plant throughput for periods of up to two days to satisfy higher water re-use demands by the customer.

The modules were backflushed with permeate every 5 to 10 minutes with the backwashing volumes amounting to between 10 and 20% of permeate flow. During combined operation of the MBR with downstream nanofiltration NF-retentate was used for backflushing of the bioreactor membranes, which proved to be a viable measure to optimise overall process yield. CIP-cleaning of the immersed membranes was conducted weekly using hypochlorite as cleaning agent and disinfectant.

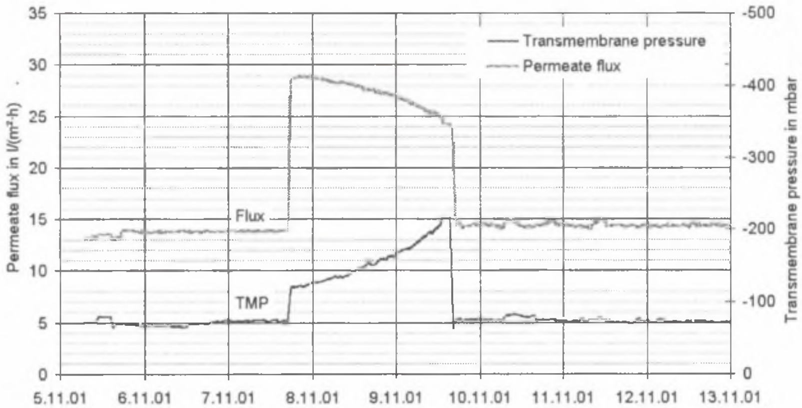

Fig. 4. Short time increase of membrane flux

Nanofiltration

The main focus of the second treatment step centred on membrane permeability in dependence on different operating conditions (e.g. partial yield in the filtration stages) and on the chemical and bacteriological permeate quality obtained.

Fig. 5 shows the permeability of both NF stages over a period of three months. After a pressure increase in the first stage at the beginning of June 2001, permeabilities could be maintained constant. Increase of partial yield (NF1) resulted in flux decline, but the optimised cleaning procedure turned out to be successful for control of fouling on the membranes.

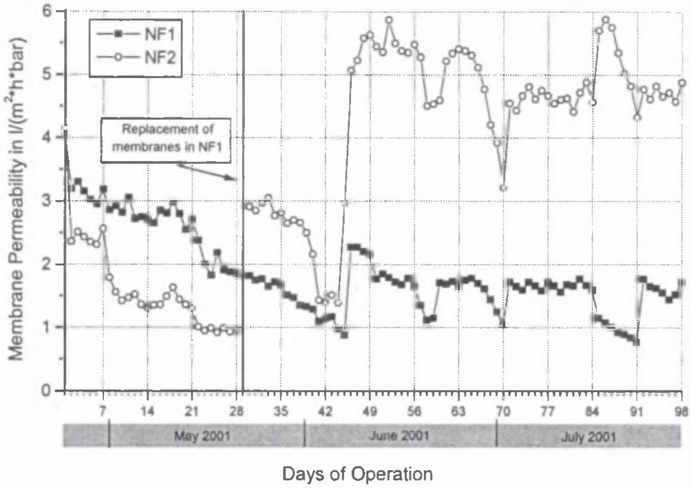

Fig. 5. Permeability of both NF stages (NF1, NF2)

The target value of 4 mg/l TOC (residual organic pollution) in the treated process water was achieved in most cases already after the first NF-stage (Fig. 6).

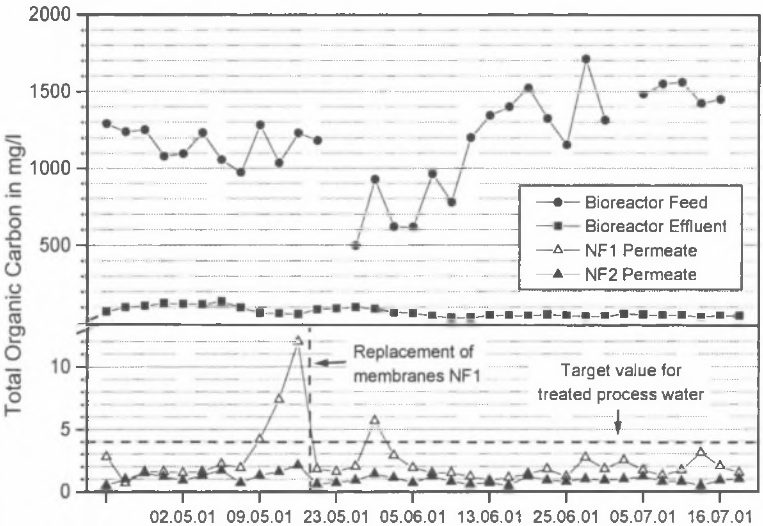

Fig. 6. Reduction of TOC in the process stages

Quality control of the treated water was based on the respective legal standards for drinking water (Table 3). All parameters (chemical, bacteriological) were within the limits of the German Drinking Water Act (DWA).

Table 3

Water quality parameters of the treated water and German drinking water standards
(* value recommended by other guidelines)

Parameter	Spent process water	Membrane bioreactor	Treated process water	Limit values according to the German DWA
pH[-]	7,0–9,5	7,8–9,0	6,9–8,3	6,5–9,5
Electrical Conductivity [μS/cm] Content of Na^+ -Ions [mg/l] Content of Cl^- -Ions [mg/l]	- - -	2 320 – 4 300 839 – 1 670 35 - 68	27 – 1 420 9 – 128 1,2 – 9	2 000 150 250
COD [mg/l] TOC [mg/l]	1 800 – 6 600 340 – 1 800	50 - 400 28 - 100	< 5 < 2	- 4*
Total bacterial count [CFU/ml; 37°C]	-	10^3 - 10^5	≤ 35	100
E. coli / coliform bacteria [in 100 ml]	present (positive test)	-	below detection limit	below detection limit
Faecal streptococci [in 100 ml]	Present (positive test)	-	below detection limit	below detection limit
Sulfite reducing, spore forming anaerobes [in 20 ml]	below detection limit	-	below detection limit	below detection limit

The treated water can be re-used for various purposes such as boiler make-up water, cooling water, pasteurisation, bottle pre-washing. Certification of the whole process has already been granted by the responsible health authorities.

Economical analysis showed that for the developed process amortisation periods of less than 3 years are possible, depending on the water re-use potential.

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