ELSEVIER

Desalination 131 (2000) 75–86

DESALINATION

Reduction of water consumption and wastewater quantities in the food industry by water recycling using membrane processes*

V. Mavrov**, E. Bélières

Institute for Environmentally Compatible Process Technology, University of the Saarland,
Im Stadtwald 47, D-66123 Saarbrücken, Germany
Tel. +49 (681) 934-5317; Fax +49 (681) 934-5380; e-mail: v.mavrov@rz.uni-sb.de

Received 4 July 2000; accepted 17 July 2000

Abstract

Due to the rising costs for fresh and wastewater, the treatment and reuse of low-contaminated process water streams from food processing companies is increasingly gaining in importance. In this study it was shown that water for reuse could be produced from this water by a specific treatment using membrane processes while achieving reduction of water consumption and wastewater quantities. Three examples of low-contaminated wastewater will be discussed: firstly a vapour condensate from milk processing, secondly chiller shower water from the meat processing industry and thirdly wash water from bottle washing machines. Due to the promising laboratory and pilot-scale experimental results, a demonstration plant with a capacity of 1–2 m³/h, consisting of the following stages, was set up: pretreatment; main treatment — 1st nanofiltration stage; post-treatment — 2nd nanofiltration or low-pressure reverse osmosis stage and UV water disinfection. Economical water treatment was possible in all three examples. The treated low-contaminated process water from chiller showers or bottle washing machines was of drinking quality and therefore suitable for reuse. After treatment, the vapour condensate could be reused as boiler make-up water which is subject to higher standards than drinking water. The experimental technology underwent an authorization procedure at the Saarland Ministry for Health, Germany, and was granted approval.

Keywords: Wastewater; Drinking water; Process water; Pretreatment; Nanofiltration; Low-pressure reverse osmosis, UV disinfection

---

*To mark the occasion of the 60th birthday of Univ.-Prof. Dr.-Ing. habil. Horst Chmiel, Chair of the Process Technology Department, Saarland University, and Managing Director of the Institute for Environmentally Compatible Process Technology, Saarbrücken, Germany

**Corresponding author.

Presented at the Conference on Membranes in Drinking and Industrial Water Production, Paris, France, 3–6 October 2000
International Water Association, European Desalination Society, American Water Works Association, Japan Water Works Association

PII: S0011-9164(00)00103-X

1. Introduction

Compared to other industrial sectors, the food industry uses a much greater amount of water for each ton of product [1]. As a rule, wastewater streams with different levels of pollution load (low, medium and high contamination) are collected and treated in an on-site installation or in a municipal sewage treatment plant. In such cases it is feasible to conduct an inventory analysis in the company in question to establish if low-contaminated process water (COD below 700 mg O_2/l), which can be collected and treated separately, is generated. A pinch analysis should determine the required water quantity and quality [1,2].

Food industry standards specify that spent process water intended for reuse — even for cleaning purposes — must be of drinking quality. Regulations for other applications such as boiler make-up water are even more stringent (Table 1). In the following study, three examples for the treatment and reuse of spent process water with low contamination were investigated:

- vapour condensate in a milk processing company (dried milk production)
- chiller shower water in a meat processing company (sausage production)
- wash water from bottle washing machines (mineral water bottling).

Table 1
Selected parameters for treated low-contaminated process water for various applications

Parameter	Requirements for boiler make-up water[a]	Requirements for drinking water
pH	—	6.5–9
El. conductivity, µS/cm	<40	<2000
COD, mg O_2/l	<10	$KMnO_4$ <5 mg
TOC, mg O_2/l	<4	<4
Ca, mg/l	<0.4	<400
Colony count, 1/ml	—	<100
E. coli/100 ml	—	ND[b]
Coliform bacteria/ 100 ml	—	ND

[a] Circulation boilers with operating pressure <68 bar.
[b] Not detectable.

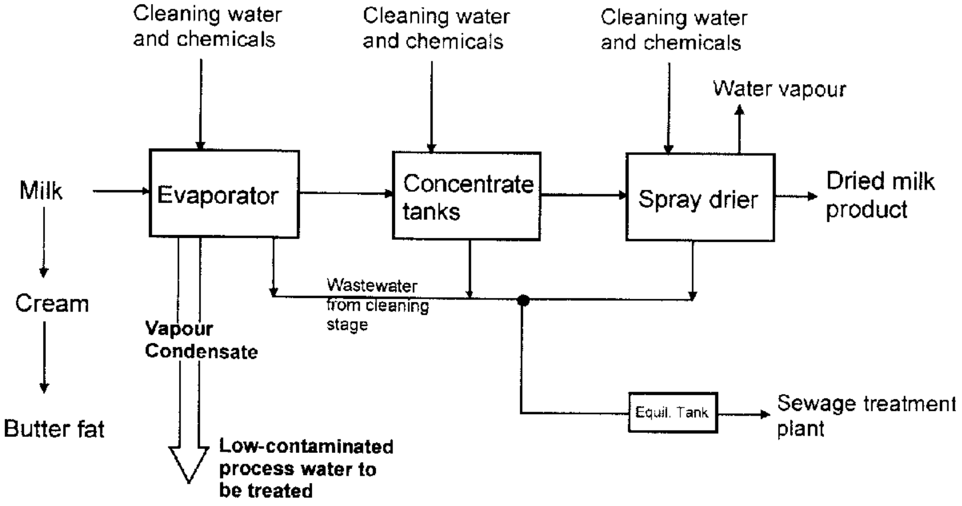

Fig. 1. Simplified flow diagram of dried milk production.

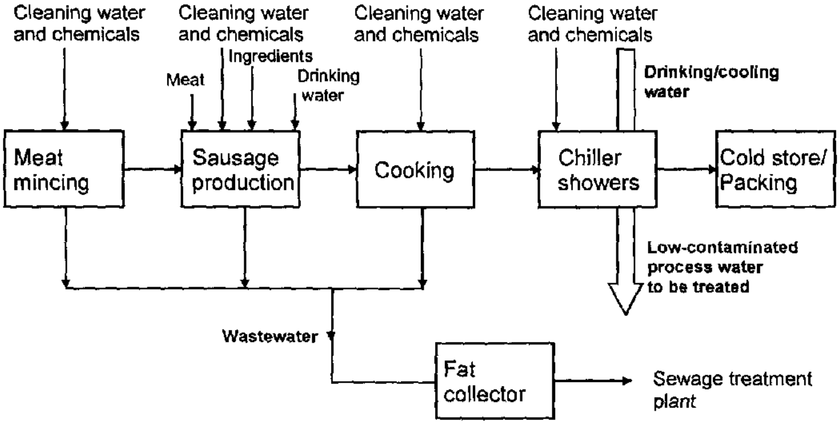

Fig. 2. Simplified flow diagram of sausage production.

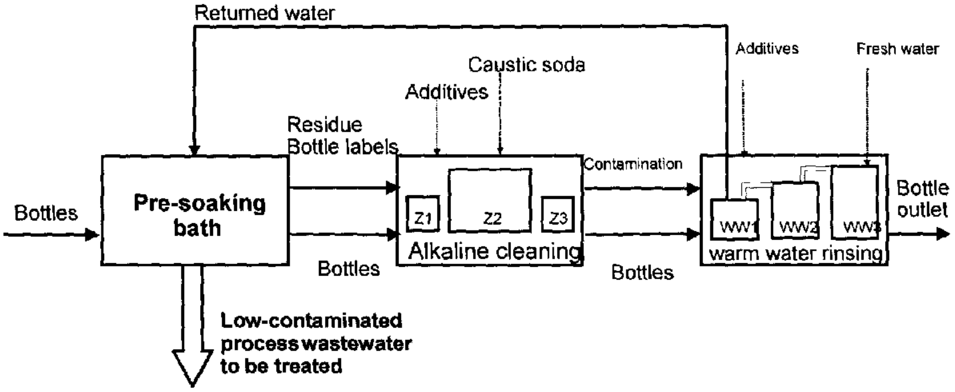

Fig. 3. Simplified flow diagram of a bottle washing machine.

Figs. 1–3 show simplified diagrams of dried milk and sausage production as well as a bottle washing machine indicating where low-contaminated wastewater, earmarked for treatment, is generated.

In order to draw up an appropriate treatment concept, information on the composition of the low-contaminated spent process water and on the standards for treated process water designated for reuse must be available, e.g. drinking water [3], boiler make-up water etc. (Table 1).

Based on several years of laboratory and pilot-scale experiments [4–8], a study was implemented, the objective of which was to determine recycling potential using membrane processes for treating low-contaminated process water from various sectors of the food industry under demonstration operating conditions.

2. Experimental

A demonstration plant with a capacity of 1–2 m^3/h was built and used in the study. A simplified flow diagram of this plant is shown in Fig. 4.

The demonstration plant consisted of the following four treatment stages:

2.1. Pretreatment

The process water to be treated was collected in a feed tank. Two-stage cartridge filtration (the second stage was used as a safety filter) and UV disinfection (reduction of micro-organisms) were used for pretreatment.

Depending on process water composition, primary pretreatment was put into operation upstream of the feed tank (not shown in Fig. 4) to stop the cartridge filters from becoming blocked too quickly. At this point a belt filter was installed to treat chiller shower water and bottle washing machine water, but no further primary pretreatment was needed for the vapour condensate which contained the lowest level of contamination. The purpose of this primary pretreatment was to remove pieces of sausages and fats from chiller shower water as well as glass residue, parts of labels and coarse impurities from the bottle washing water. All the tests proved that pretreatment had a substantial influence on the overall concept. Correct pretreatment did not only reduce operation costs significantly but also ensured adequate membrane permeability in the first membrane stage.

2.2. Main treatment stage

The first membrane stage is a nanofiltration stage (NF1) using spiral-wound modules with a total membrane area of up to 80 m^2.

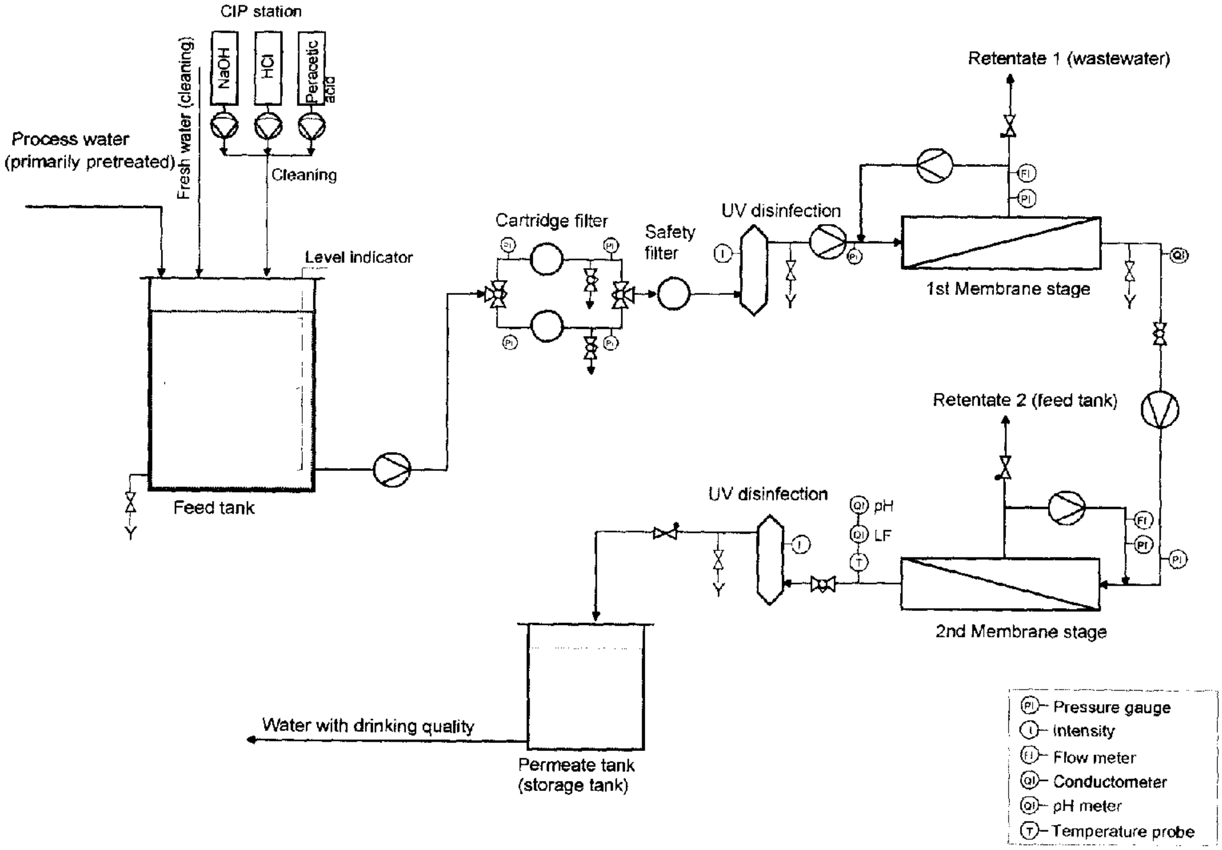

Fig. 4. Flow diagram of the demonstration plant.

2.3. Post-treatment stage

The second membrane stage is a nanofiltration (NF2) or low-pressure reverse osmosis (LPRO 2) stage using spiral-wound modules with a total membrane area of up to 80 m^2.

2.4. UV water disinfection

The following points were considered for the selection, specification, planning and set-up of the demonstration plant under study:

- All the important, water-bearing components in the demonstration plant were made of stainless steel. During the welding of the plant components, care was taken to prevent dead zones in order to hinder microbiological growth for a long period and ensure a correct cleaning and disinfection procedure.
- The membranes in operation in the demonstration plant were approved by the US Food and Drug Administration.
- The UV radiation unit used in the demonstration plant fulfilled the requirements defined in the worksheets of the German Water and Gas Association (W293 and W294).
- To ensure perfect water quality, important operating parameters, particularly el. conductivity, pH, UV lamp intensity, temperature and transmembrane pressure difference were constantly monitored by the control panel of the demonstration plant.
- A CIP (cleaning-in-place) station was integrated into the demonstration plant, and the cleaning procedure was optimized, controlled and automated.

3. Results and discussion

Below are some experimental results of the treatment of the three low-contaminated process water streams.

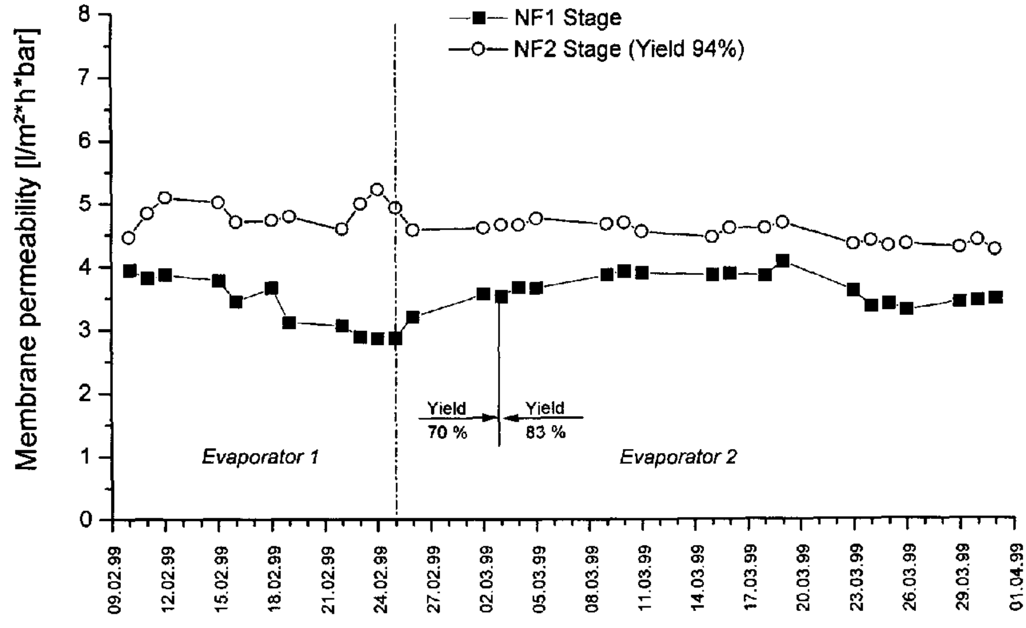

Fig. 5. Membrane permeability as a function of operation time in the treatment of vapour condensate.

3.1. Treatment of vapour condensate [7]

In view of the low contamination (organic and inorganic) in this vapour condensate, the goal was not only to fulfil drinking water regulations but also the standards for boiler make-up water. Fig. 5 illustrates the permeability of the NF membrane modules in the first (NF1) and second (NF2) membrane stages as a function of operation time for two different vapour condensates containing different contamination levels. In NF2, the yield was 94% at a trans-membrane pressure of roughly 4 bar and membrane permeability remained constant at 4.3 l/m^{2}h bar. An increase in yield from 70% to 83% in NF1 did not result in a reduction of membrane permeability.

COD of the feed and permeate of the NF2 stage (product water) are shown in Fig. 6. In spite of considerable fluctuations in the feed, the COD in the permeate was between 1–9 mg O$_2$/l and the required COD value of below 10 mg O$_2$/l could be maintained (for boiler make-up water).

Table 2
Experimental results from the treatment of vapour condensate

	Vapour condensate	Permeate NF2 stage	Requirements for boiler make-up water
pH	4.1–8.5	4–7.5	—
El. conductivity, μS/cm	6–190	2–35	<40
COD, mg O$_2$/l	5–45	1–8.9	<10
TOC, mg/l	1.6–10	1–3.5	<4
Ca, mg/l	0.4–1	<0.1	<0.4
KMnO$_4$, mg O$_2$/l	4.4–16.8	1–2.2	<10

Due to the treatment of the vapour condensate, the electrical conductivity of the permeate was reduced to below the limit value of 40 μS/cm for boiler make-up water (Fig. 7). The hardness component Ca^{2+} in the vapour condensate was extensively removed in the two-stage NF process,

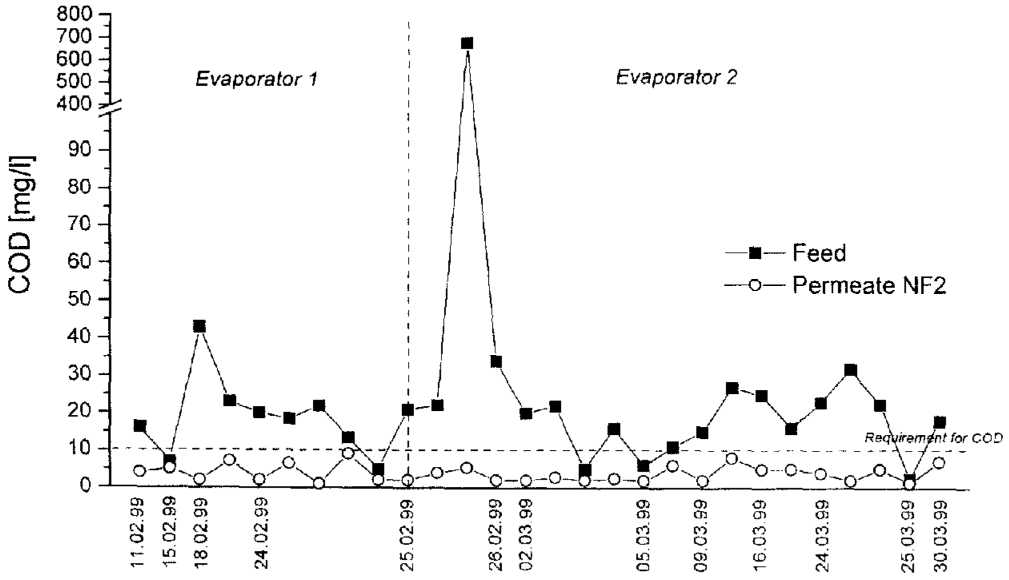

Fig. 6. COD of feed and permeate of the NF2 stage as a function of operation time in the treatment of vapour condensate.

and it remained under 0.4 mg/l. All the parameters of the treated water that were tested fulfilled the requirements for boiler make-up water (Table 2).

It can be clearly seen in Table 2 that the limit values for boiler make-up water were adhered to, thus allowing the treated vapour condensate from milk processing to be reused as boiler make-up water. The chemical and microbiological analyses of the treated vapour condensate also showed that the limit values for drinking water were achieved.

3.2. *Treatment of chiller shower water*

Due to the higher temperature of this water (30–35°C), the objective of the treatment was not only to achieve drinking water quality but also water with low salinity and hardness (Ca, Mg) and to use this treated water as warm cleaning water. Following extensive laboratory and pilot-plant experiments comparing NF and RO membranes [2,4,5], experiments with a demonstration plant throughout a 12-month period, were performed. This test operation of the demonstration plant can be seen in Fig. 8. The first membrane stage (NF1) operated at a constant transmembrane differential pressure (pm 1) of roughly 5.3 bar whereas the second membrane stage (NF2) operated at a transmembrane pressure of only 1.5 bar because the flow rate in relation to the first stage was somewhat lower.

During this test period, a permeability rate in the first stage (Lp1) from roughly 3.5 to 2.0 l/m^{2}h bar was recorded and remained constant at 2 l/m^{2}h bar. In the second stage a constant membrane permeability of 3.5–4 l/m^{2}h bar was obtained.

Fig. 9 shows the change in electrical conductivity during the treatment of chiller shower water. Electrical conductivity was reduced from roughly 1000 µS/cm to below 120 µS/cm. Due to the low salinity and minimum water hardness (below 0.7 mg/l), this treated water could be very effectively reused as warm cleaning water.

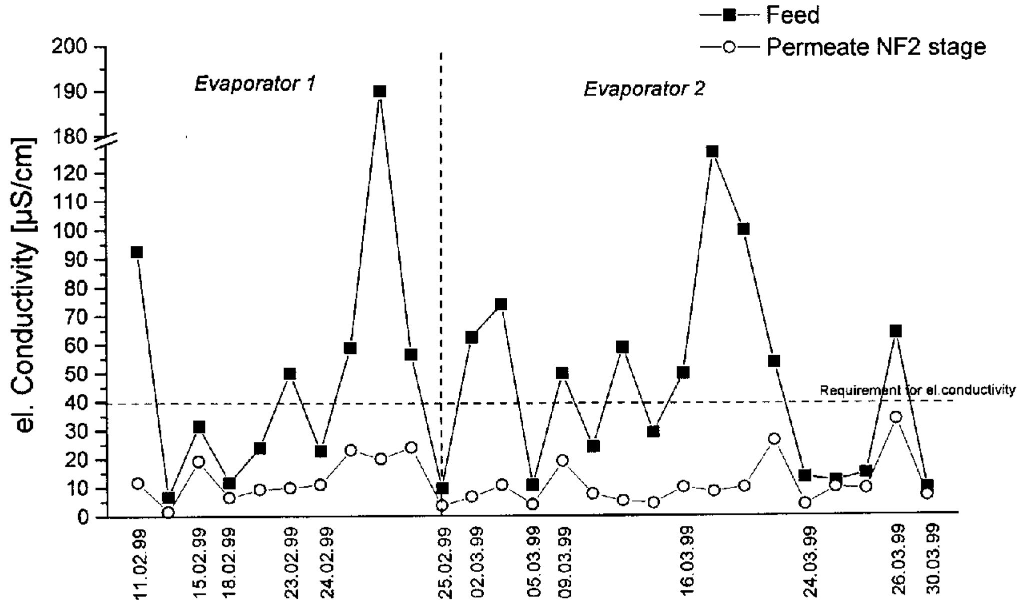

Fig. 7. Conductivity of feed and permeate of the NF2 stage as a function of operation time in the treatment of vapour condensate.

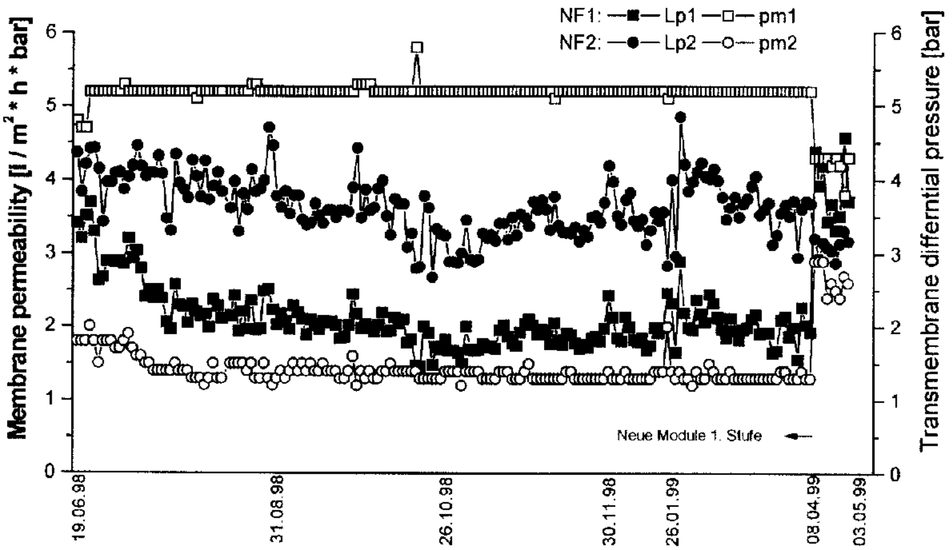

Fig. 8. Membrane permeability (Lp) and transmembrane pressure (pm) as a function of operation time in the treatment of chiller shower water.

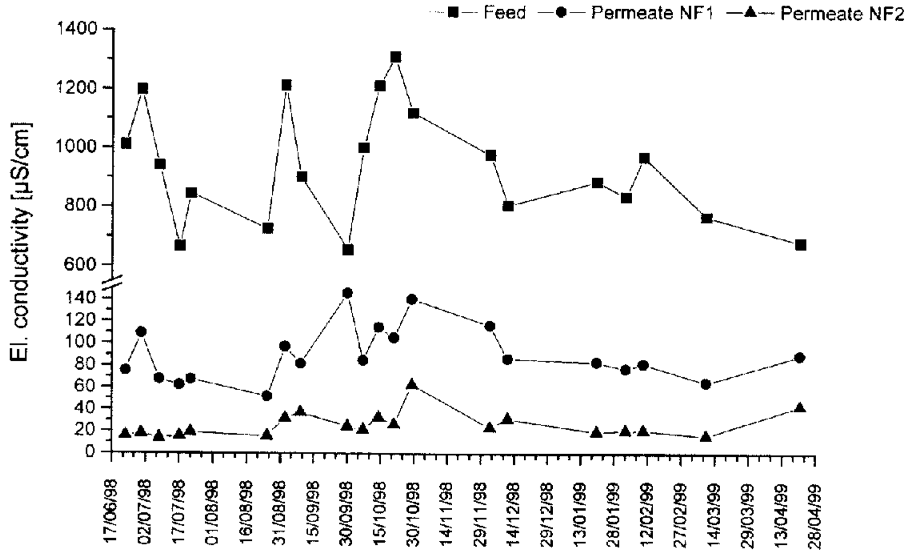

Fig. 9. Electrical conductivity of feed and permeate as a function of operation time in the treatment of chiller shower water.

Table 3 shows the experimental results for some selected chemical parameters in the treatment of chiller shower water. It can be seen that the limit values for all parameters, as defined in the drinking water regulations, were adhered to.

A microbiological analysis whose results correspond with official drinking water standards

Table 3
Treated water quality after treatment of chiller shower water (chemical analysis)

Parameter	Chiller shower water	Treated water	Drinking water requirements
El. conductivity, µS/cm	510–1550	7–120	<2000
TOC, mg/l	8–260	1.4–2.5	<4
Ammonium, mg/l	—	0.03–0.26	<0.5
Calcium, mg/l	—	0.26–0.70	<12
Sodium, mgl	—	1.3–3.8	<150
Chloride, mg/l	1–120	0.7–2.1	<250
Total phosphorus, mg/l	—	<0.02	<5

Table 4
Microbiological analyses for the treated chiller shower water[a]

Institute	Date	Colony count (1/ml)	Coliform bacteria		*Pseudomonas aeruginosa*	
			1/ml	1/100 ml	1/ml	1/100 ml
ChemproControl:	24.08.98		ND	ND	ND	ND
	25.08.98		ND	ND	ND	ND
	26.08.98		ND	ND	ND	ND
	27.08.98		ND	ND	ND	ND
	28.08.98		ND	ND	ND	ND
	07.09.98		ND	ND	ND	ND
	08.09.98		ND	ND	ND	ND
	09.09.98		ND	ND	ND	ND
	10.09.98		ND	ND	ND	ND
	11.09.98		ND	ND	ND	ND
	19.10.98		ND	ND	ND	ND
	20.10.98		ND	ND	ND	ND
	21.10.98		ND	ND	ND	ND
	22.10.98		ND	ND	ND	ND
	23.10.98		ND	ND	ND	ND
	26.10.98		ND	ND	ND	ND
	27.10.98	0	ND	ND	ND	ND
	28.10.98	0	ND	ND	ND	ND
	29.10.98	0	ND	ND	ND	ND
	30.10.98	0	ND	ND	ND	ND
SIGU:	23.11.98	0		ND		ND
	24.11.98	0		ND		ND
	25.11.98	0		ND		ND
	26.11.98	0		ND		ND
	27.11.98	0		ND		ND
	30.11.98	0		ND		ND
	01.12.98	0		ND		ND
	02.12.98	0		ND		ND
	03.12.98	0		ND		ND
	04.12.98	0		ND		ND
	07.12.98	0		ND		ND
	08.12.98	0		ND		ND
	09.12.98	0		ND		ND

[a] Colony count in the feed tank of the demonstration plant was $2\times10^2 - 7\times10^5$ 1/ml.

is essential for the reuse of treated process water in food processing companies. In order to evaluate correctly the microbiological quality of the treated process water in this study, microbiological analyses were conducted not only in-house, but also by an independent laboratory (ChemproControl, Saarbrücken, Germany) and the Official Institute for Health and the Environment (SIGU, Saarbrücken, Germany) (Table 4).

Because of the drinking water quality of the treated process water and the high reliability of the technology, this treatment process was submitted for authorization in 1998 at the Ministry for Health of the Saarland, Germany, and was granted approval for water reuse.

3.3. *Treatment of pre-soaking water from bottle washing machines*

Because of the old construction of the bottle washing machine in question, the residue in the bottles is emptied into the pre-soaking bath, leading to higher pollution in this water, particularly when bottles other than mineral water bottles are cleaned (e.g., lemonade) (Table 5). In this case an increase in COD contamination of up to 2275 mg O_2/l and TOC of up to 690 mg/l can result. As was shown with this higher contaminated process water, in spite of the fact that low-pressure RO membranes were used in the second membrane stage (LPRO2), it was very difficult to reduce the organic content to below the drinking water standards (Fig. 10; operating time from 02.11.1999–16.12.1999).

Table 5
Pre-soaking process water analysis

Parameter	Ranges
pH	6.61–9.28
El. conductivity, µS/cm	1259–2680
COD, mgO_2/l	216–2275
TOC, mg/l	94–690
Calcium, mg/l	67.3–127
Magnesium, mg/l	11.6–55.1
Iron, mg/l	0.07–15.9
Chloride, mg/l	135–182
Nitrite, mg/l	0.1–5.8

Table 6
Chemical analysis (selected parameters) of the treated pre-soaking process water (cleaning of mineral water bottles)

Parameter	Permeate 2 (treated water)	Drinking water regulations
El. conductivity, µS/cm	18	<2000
COD, mgO_2/l	1.8	—
TOC, mg/l	3.6	<4
Calcium, mg/l	<0.1	<400
Magnesium, mg/l	<0.1	<50
Iron, mg/l	<0.05	<0.05
Chloride, mg/l	0.3	<250
Nitrite, mg/l	<0.1	<0.1

Table 7
Microbiological analysis of the treated pre-soaking process water (Permeate 2)*

Date	Colony count, 1/100 ml			
	Standard		Endoagar	Lactose peptone
	20°C	37°C	37°C	37°C
03/01/00	0	0	0	ND
05/01/00	0	0	0	ND
06/01/00	0	0	0	ND
11/01/00	0	0	0	ND
12/01/00	0	0	0	ND
13/01/00	0	0	0	ND
18/01/00	0	2	0	ND
19/01/00	0	0	0	ND
20/01/00	0	0	0	ND
24/01/00	0	0	0	ND

*Colony count in the feed tank of the demonstration plant 10^2–10^4 1/100 ml

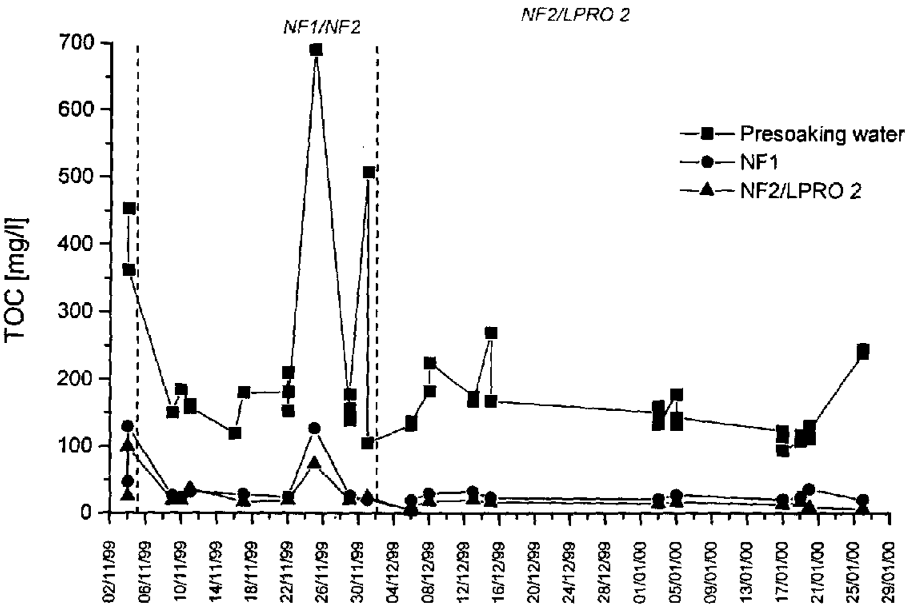

Fig. 10. TOC in feed and in the permeate as a function of operation time in the treatment of pre-soaking water.

In the case where only mineral water bottles are cleaned, low-contaminated water with COD of 200–500 mg O_2/l and TOC 100–250 mg/l is generated (Fig. 10; operating time from 16.12.1999–21.01.2000). By treating this low-contaminated water in a demonstration plant where the NF2 or LPRO2 stages were used, water with drinking quality as shown in Tables 6 and 7 could be obtained.

The treated pre-soaking water of drinking quality could be recirculated in the bottle washing machine prior to fresh water rinsing (Fig. 3) or could be reused for cleaning purposes.

4. Conclusions

In this study it was possible to illustrate, using a demonstration plant with a capacity of 1–2 m³/h, on the basis of the treatment of three low-contaminated process water streams in the food industry, that by a combination of pre-treatment, membrane filtration and UV disinfection, treated water of a defined quality could be obtained and reused in accordance with the company's needs.

It was shown by numerous chemical and microbiological analyses that with a two-stage membrane combination of NF and low-pressure RO, the appropriate design and construction of the treatment plant and suitable cleaning procedure for the plant that the limit values for drinking water and/or boiler make-up water could be adhered to at all times. After the authorization procedure, the tested technology was granted approval for water reuse in the food industry.

References

[1] H. Chmiel, A. Fähnrich, V. Mavrov and Ch. Schneider, Fleischwirtschaft, 76(10) (1996) 1019.
[2] H. Chmiel, A. Fähnrich, H.D. Janke, M. Kaschek, J. Kluth, V. Mavrov and F. Rögener, Brauwelt, 1/2, (1997) 16.
[3] German regulations on drinking water and water

for food processing companies (Trinkwasserverordnung); BGBl. I, 1990, pp. 2613–2629.

[4] H. Chmiel, V. Mavrov and A. Fähnrich, Proc., Int. Membrane Science and Technology Conference, Sydney, Australia, 2 (1996) 122.

[5] A. Fähnrich, V. Mavrov and H. Chmiel, Chemie-Ing. Technik, 1997, p. 1147.

[6] V. Mavrov, H. Chmiel, A. Fähnrich and F. Rögener, Proc., Kolloquium: Entwicklung zur Produkt- und Wasserrückgewinnung aus Industrieabwässern, Berlin, 1998, pp. 75–88.

[7] H. Chmiel, V. Mavrov and E. Bélières, Filtration Separation, 7 (2000) 24.

[8] V. Mavrov, H. Chmiel, J. Kluth, J. Meier, F. Heinrich, P. Ames, K. Backes and P. Usner, Desalination, 117 (1998) 189.