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Treatment of dairy industry wastewater by reverse osmosis for water reuse

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Abstract

The dairy industry is among the most polluting of the food industries in volume in regard to its large water consumption. The present work was related to investigations about practices of water management of 11 dairy plants. Treatment of the process water produced in the starting, equilibrating, stopping and rinsing processing units was proposed to produce water for reuse in the plant and to lower the effluent volume. Reverse osmosis of such wastewaters, collected in dairy plants, was performed after a prior check of their stability during storage. Filtration performances were focused on permeate flux versus water recovery and on water quality (TOC, conductivity). Reverse osmosis water similar to available vapour condensates (produced in drying processes) can be achieved allowing this water to be reused for heating, cleaning and cooling purposes. A 540 m^2 RO unit is required to treat 100 m^3/d of wastewater with 95% water recovery.

Keywords: Effluent; Milk; Process water; Reverse osmosis; Water reuse

1. Introduction

In a background of natural water resource availability and cost increase, wastewater treatment for water reuse can lower the overall water consumption and the global effluent volume of industrial plants. Like other industries (textile, pulp and paper, tanneries, etc.), the food industry looks at membrane processes for wastewater treatment to produce purified water for recycle or reuse. In the beverage industry, nanofiltration and low-pressure reverse osmosis were used for treating water from bottle washing water to produce water of drinking quality [1]; spent process water from fruit juice was processed using a membrane bioreactor and two-stage nanofiltration for water reuse [2]. Ultrafiltration and

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nanofiltration were used for water recycling from wastewater of the fishmeal industry [3,4]. Micro- and ultrafiltration of surimi process water enabled the recycling of the treated water [5]. A combined nanofiltration–reverse osmosis system was developed to treat soybean soaking water for water recovery [6]. Poultry slaughterhouse chiller tank effluent was recovered using ultrafiltration and nanofiltration for purified water recycling [7]. Cooling water from sausage products was treated by nanofiltration to produce drinking quality water [8–10].

Among the food industries, the dairy industry is the most polluting in volume (generating from 0.2 to 10 L of effluent per litre of processed milk) in regards to its large water consumption. Several works focused on the treatment of dairy effluents demonstrated that membrane operation were convenient: microfiltration [11], ultrafiltration, UF [12], nanofiltration, NF [13], reverse osmosis, RO [14] or two-stage operations such as NF+NF [10] or RO+RO [13]. Chmiel et al. [15] showed that NF and RO of low contaminated vapour condensate from milk processing can produce reusable water.

The process waters produced in the starting, equilibrating, stopping and rinsing any of the processing units generate a large volume of effluents (flushing water, first rinse water, etc.), contributing significantly to the total wastewater production. Membrane treatment of these selected dairy wastewaters with the aim of water reuse could simultaneously lower the total water consumption and the effluent production of the dairy plant. The purified water produced by membrane treatment could be reused in the dairy factory as heating or cooling water, as boiler make-up water or for cleaning purposes. Its quality must be, at least, similar to those of vapour condensates, collected during the product drying and evaporation processes and often reused for such applications [16–18]. If the quality reaches the drinking water standards, the field of applications could be broadened with applications such as cooling water for pump seal or plate heat exchangers where unexpected contact with dairy products may occur, but therefore derogation by French authorities will be required.

The objective of this study was to use RO units for the treatment of several selected wastewaters from dairy plants for water reuse purposes. This paper summarises first results of investigations (inquiries, visits and samples collection and analyses) made in 11 dairy plants in order to collect qualitative and quantitative informations about dairy process waters, vapour condensates and practices of water management. Stability of wastewater during storage before filtration was also studied. In previous feasibility studies with a synthetic solution (diluted skim milk), performances of eight NF and RO membranes were compared by dead-end filtration [19]. Two selected membranes (one NF and one RO) were assessed for crossflow experiments: the results agreed with those of dead-end filtration [20]. More complex model solutions, representative of the composition variation of the dairy process waters, were processed by the selected NF and RO membranes [21].

It can be concluded that, in the range of the study, heat treatment, fat content and whey/milk ratio of the model solutions do not have significant effect on the performances (purified water quality, permeate flux). The study also showed that RO operation gave better water quality than NF, as NF did not provide a better permeate flux. Therefore RO membrane was chosen for the treatment of dairy wastewaters presented in this study. Performances in terms of permeate flux, purified water quality and recovery, milk component removal efficiency were discussed. Scaling-up of a RO plant of 100 m^3/d was outlined.

2. Experimental

2.1. Feed solution: dairy wastewater (DWW)

Eleven French dairy plants were involved in inquiries about their wastewaters. These inquiries were completed by visits of eight plants in order to collect qualitative and quantitative information. This study showed that dairy process waters (mainly flushing waters, first rinse waters, etc.) were mixtures of milk products diluted with water without chemicals from the cleaning in place steps. Composition and concentration depend on the dairy plant main production and on the processing units. These selected wastewaters are mainly mixtures of milk, whey and cream with dry matter (DM) ranging from 0.4 g.L^{-1} to 71 g.L^{-1}, fat content (0 to 22%) and heat treatment (no heat treatment to high heat treatment: 130°C, 20 mn).

Eight samples were collected in flushing waters from concentrator or pasteuriser processing of skim milk or whey (from five plants). Their compositions are given in Table 1. DM of the eight dairy wastewaters (DWW) ranged from 0.4 to 54.3 g.L^{-1}; this large variation depends on the sampling time (beginning or end of the flushing step). It can be observed that the other characteristics depend on dilution, so that the ratio of concentration to dry matter is in the same proportion than in original fluid. For the flushing step, either drinking water or vapour condensate (almost demineralised) was used. When conductivity and ionic concentration (especially nitrate or chloride) were high related to dry matter, as common sense drinking water was used as flushing/rinsing water: this was the case for DWW B, 1 and 3.

Table 1
Main characteristics of dairy wastewater samples from dairy plants

		Dairy wastewater								Original fluids	
		Skim milk					Whey				
Samples		A	B	C	2	3	1	D	E	Skim milk	Whey
pH		7.1	7.1	6.6	7.2	7.1	5.8	6.7	7	6.9	6.5
Dry matter	g/L	2.3	0.4	54.3	3.5	8.6	9.8	4.6	31	90	65
Conductivity	µS/cm	350	1550	4640	680	1400	2110	860	2190	4770	5980
Suspended matter	mg/L	590	31	796	71	140	490	80	10	4190	299
TKN	mg/L	95.6	25	1360	126	770	116	94	1890	5090	6570
NO_3^-	mg/L	<2	14	< 2	< 2	32	30	< 2	< 2	-	-
HPO_4^{2-}	mg/L	44	4	440	25	152	17	313	209	954	1000
Mg^{2+}	mg/L	5.2	0.7	61.3	7.1	22	54.8	19.5	34.2	108	71
Ca^{2+}	mg/L	42.6	7.6	238	43	139	278	124	383	1170	500
Na^+	mg/L	14.4	28.3	357	23.2	107	181	68	147	477	527
K^+	mg/L	20.7	9.2	1420	16.4	36	340	120	638	1,431	1,450
Cl^-	mg/L	34	45	680	39	211	241	80	560	963	1,210
COD	mg O_2/L	3470	380	59,100	3,800	9,500	8,200	4,410	38,500	109,000	65,000
DOC	mg/L	—	24.3	22,600	490	2,860	5,100	596	9,000	—	—
TOC	mg/L	—	96	—	945	2,460	3,120	1,310	13,200	—	—

2.2. Membrane

A commercially available RO spiral-wound membrane was used in this study, a TFC HR SW 2540 (provided by KOCH Membrane Systems) with a NaCl rejection of 99.5%. It is a thin film composite (TFC) membrane with polyamide active layer and an effective filtration area of 2.5 m^2.

Deionised water membrane permeability (at 25°C) was 2.5 $L.h^{-1}.m^{-2}.bar^{-1}$.

The membrane pure water permeability was measured with deionised water at 25°C before each experiment. After each experiment, the membrane was cleaned up with a 0.04% w/v of alkaline detergent at pH 11 (Ultrasil 10, Henkel-Ecolab) for 1 h at 43°C and 10 bar. After cleaning, the membrane permeability to water was checked again. If permeability was not achieved, an additional acid cleaning with HNO_3 at pH 2 was made for 1 h at 30°C and 10 bar followed by a second alkaline cleaning step. The membrane was stored in a 0.5% w/v sodium metabisulfite solution.

2.3. Operating conditions

The crossflow RO filtration device was designed by TIA (Bollène, France). Transmembrane pressure (TMP) and crossflow flowrate, $Q_{R,}$ were set at 20 bar and 800 $L.h^{-1}$, respectively. Temperature (T) of the solutions was controlled at 25°C. The stainless steel feed tank capacity of the filtration device was 50 L. The volume of wastewater ranged between 130 and 200 L and was well mixed in a storage tank. At the beginning of the filtration, the feed tank was entirely filled with 50 L of solution. The filtration was performed according to a continuous concentration mode with step by step feed addition: 5 L of feed solution (wastewater from the storage tank) was added in the feed tank each time 5 L of permeate were collected (fed-batch mode). The concentrate stream was recycled back to the feed tank. So the volume in the feed tank ranged between 45 and 50 L during the first part of the filtration (as long as feed solution was added). The feed solution was continuously concentrated up to a volume reduction ratio VRR of 7 to 17 depending on the feed volume.

VRR was defined as

$$VRR(t) = \frac{V_{feed}(t)}{V_R(t)} = \frac{V_{feed}(t)}{V_{feed}(t) - V_P(t)} \qquad (1)$$

where V_{feed} (t) is the processed feed volume at time t; and $V_R(t)$ and $V_P(t)$ are the retentate and permeate volumes at time t, respectively.

Water recovery was calculated according to

$$\text{Recovery (\%)} = \frac{V_P(t)}{V_{feed}(t)} \times 100 \qquad (2)$$

2.4. Analysis

Feed, retentate and permeate samples were assessed for physicochemical and chemical analysis: dry matter, DM (accuracy ± 2%); suspended matter (French standard method EN 872, accuracy ±2%); dissolved organic carbon (DOC) (French standard method EN 1484, accuracy ±2%); total Kjeldahl nitrogen (TKN) (French standard method EN 25663, accuracy ±1%); total organic carbon (TOC) (OI Analytical TOC analyser, accuracy ±2%); pH (accuracy ±0.05). COD was determined with rapid test tubes (oxidation with potassium dichromate/sulphuric acid/silver sulphate at 148°C, accuracy ±3%) and photometric measurement (Nanocolor 300D) provided by Macherey Nagel. Cation (Na^+, K^+, Ca^{2+}, Mg^{2+}) concentrations were measured by atomic absorption (Spectra 300, Varian Associates) and anions (phosphate, NO_3^-, Cl^-) concentrations by ion chromatography (Dionex DX 500). Accuracy was about 1% for all ions. Lactose concentration was determined spectrophotometrically at 488 nm by the phenol-sulphuric acid method with an accuracy of 3% [22]. Lactate concentration was determined spectrophotometrically at 425 nm using the method described by Ling [23] with an accuracy of 5%. Ethanol, acetone and acetoin were determined by headspace gas chromatography according to the method described by Richelieu et al. [24]. The conductivity χ was measured (CDM 210, Radiometer Analytical) with an accuracy of 2%.

The observed rejection of the membrane was obtained by the following equation:

$$R\ (\%) = \left(1 - \frac{C_P(t)}{C_R(t)}\right) \times 100 \qquad (3)$$

where $C_P(t)$ and $C_R(t)$ are the permeate and the retentate concentrations at time t, respectively.

Whatever the components, for runs with increasing VRR, it is recommended to use the removal efficiency obtained from the following equation:

$$E\ (\%) = \left(1 - \frac{C_P}{C_0}\right) \times 100 \qquad (4)$$

where C_0 and C_p are the feed and the overall permeate concentrations, respectively.

3. Results and discussion

3.1. Water management practices in dairy plants

Investigations were conducted in 11 French dairy plants in order to collect information about consumption, origin and uses of water (in 2001). The water consumption depended on the volume of processed milk, on the water requirements of the different processes and on the practices of water management at the factory. The daily consumption ranged between 800 and 3400 m^3/day with an average value of 1700 m^3/day. When river water or groundwater was used as cooling water in open loop, the consumption could reach 12,000 m^3/day. The volume of processed milk ranged from 330 to 1000 m^3/day, consequently the water consumption varied from 1.2 to 3.4 L per L of processed milk (Fig. 1a). A low ratio showed a good optimisation of the water management.

The water used at the factories came mainly from three origins: drinking water supplied by water provider, water from the natural environment (river water or groundwater) often treated to be potable, vapour condensates coming from the product concentration and drying processes (also called “cow water”). The origin of consumed water depended on the availability of water, on the type of use (with or without food contact) and on the practices of management in each dairy plant. Fig. 1b illustrates that drinking water from water provider was used in 10 plants and represented from 11 to 75% of the consumption. Groundwater was pumped and used in seven plants after treatment in the dairy to make it potable. However, since 2001, the use of groundater still increases because of drinking water cost increase. Fig. 1b shows that *in situ* available vapour condensate was used in all except one factories (20 to 48% of the water consumption). This statement is consistent with Daufin et al. [25] who showed that condensated vapours were used in almost all the dairy plants and that the recycled volume can reach 10^3 to 4×10^3 m^3/day in some cases.

The available volume depended on the size of the concentration and drying unit of the dairy. Inquiries did not provide information on the quality of vapour condensate, so five samples were collected on site and analysed. Physico-chemical analyses of the five vapour condensates from skim milk, whole milk or whey drying units are shown in Table 2. Condensates from (whole or skim) milk were low mineralised ($\chi <$ 18 $\mu S.cm^{-1}$) and did not contain proteins (TKN <2.1 $mg.L^{-1}$). In two samples, TOC was even

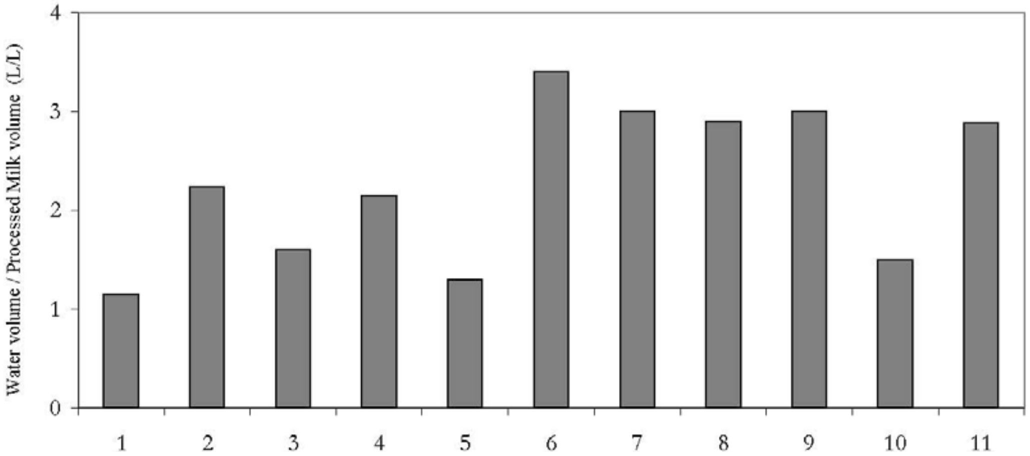

Fig. 1a. Water consumption (in liter per liter of processed milk) for 11 dairy plants located in France (in 2001).

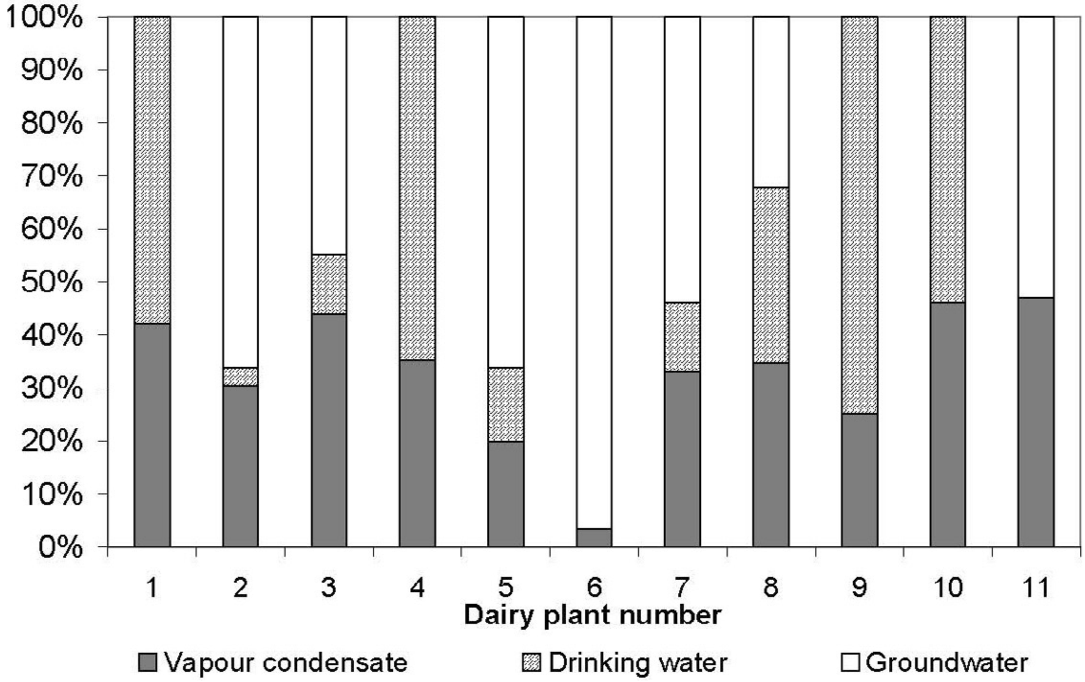

Fig. 1b. Origin of water (vapour condensate, drinking water, groundwater) used in 11 dairy plants located in France (in 2001).

lower than 2 mg.L^{-1} (threshold value for drinking water in France). Vapour condensate coming from whey was more mineralised ($\chi \approx 100$ µS. cm^{-1}) and had higher TOC value (11 mg.L^{-1}). This observation is consistent with data of Stroem [17] and Holmström [16] who showed that generally vapour condensate organic matter content of milk drying processes was lower than that of whey. The objective was to identify organic compounds involved in TOC. Stroem [17]

Table 2
Main characteristics of vapour condensate samples according to their origin

Sample		VC1	VC2	VC3	VC4	VC5
Origin of vapour condensate		Skim milk	Skim milk	Whole milk	Whole milk	Whey
Conductivity	µS/cm	4	18	9	15	101
Suspended matter	mg/L	3	<2	2	3	3
TKN	mg/L	0.3	2.1	1.5	1.8	7.2
COD	mg O_2 /L	<15	24	<15	40	30
TOC	mg/L	0.7	3.7	1.3	3.3	11
Lactose	mg/L	<3	<3	<3	<3	9.9
Lactate	mg/L	<2	<2	<2	<2	<2
Ethanol	µg/L	130	4430	<50	760	2190
Acetone	µg/L	<50	240	<50	1650	525
Acetoine	µg/L	120	120	1120	160	700

analysed the vapour condensates by gas chromatography in order to identify the organic molecules involved in COD and detected small molecules like ethanol, acetone, acetoine, diacetyl and dimethylsulfide. The five collected samples were assessed for such analyses completed with lactose and lactate determination. In vapour condensates from milk drying processes, acetone, acetoine and ethanol were detected and responsible for 20 to 70% of TOC. In vapour condensates from whey drying processes, lactose and ethanol represented 50% and 10% of TOC, respectively. The comprehensive identification of all organic molecules involved in TOC would be difficult to perform because more than 100 small volatile organic molecules were detected in fresh milk [26] without taking into account the new molecules produced during dairy products heating and drying steps [27].

According to French regulations, only drinking water can be used in direct contact with the food products (for instance: starting of processing units, flushing water, last rinsing of pipes, flat cheese rinsing). Drinking water is also required for applications where unexpected contact with dairy products may occur when there is a risk of leakage (pump seal or plate heat exchangers). So, for recycled water such as vapour condensate, uses are restricted to applications without contact with the dairy products.

Our investigation (2001–2002) demonstrated that applications were:

- boiler make-up water (30–275 m^3/day): vapour condensate with conductivity <20 µS.cm^{-1} and with often additional treatment (activated carbon or RO) was used in seven dairy plants (up to 160 m^3/day);
- cooling water in closed loop (70–370 m^3/day): vapour condensate with conductivity <1500 µS. cm^{-1} was used in five dairy plants;
- cleaning in place solutions (30–700 m^3/day): in about half of the plants, vapour condensate was used for preparation of dilute alkaline or acid solutions an for intermediate rinsing;
- outside washing of equipments (8–250 m^3/day): in five plants, vapour condensate permitted to wash floors and the outside of tanks and trucks.

One should note that practices in half of the factories were to use drinking water for such purposes where drinking water quality isn’t required. In order to keep such a safe preventive behaviour, reuse of recycled dairy industry wastewater might be proposed as new alternative practice.

3.2. Dairy wastewater storage

It was shown in a previous study [21] that during storage of diluted dairy products, natural acidification occurred and that quality of permeate after membrane treatment was strongly affected. Therefore, in order to study the stability of dairy wastewater, pH variation of three samples was followed at 25°C during about 5 days (Fig. 2). Due to the sampling and travel time, the delay between collection time (t = 0) and the beginning of storage at 25°C was different for each sample. The initial pH value was quite the same (around 6.5) for the three samples, but after 20 h of storage at 25°C the pH value for whey wastewater decreased by more than one unit whereas pH of skim milk wastewater decreased only by 0.1 unit. After 24 h at 25°C, pH of skim milk wastewater began to decrease strongly. Therefore the stability of milk wastewater was better than that of whey wastewater. These results were checked using milk and whey: natural acidification of whey at 25°C occurred before that of milk probably due to a buffer behaviour of caseins [28]. For milk and whey solutions kept at 4°C, pH remained higher than 6 after 90 h. In addition, during the acidification process, low molecular weight organic molecules (such as lactate and ethanol) were produced by lactose degradation [21]. These by-products lower membrane performance because their rejection was low, inducing an increase of permeate TOC. In conclusion, dairy wastewater needs to be stored at low temperature in order to limit natural acidification, otherwise it shall be treated within a few hours after collection, in order to prevent degradation of milk components.

3.3. Dairy wastewater crossflow RO filtration

Three dairy wastewaters were sampled and filtered in the crossflow filtration device with the procedure previously mentioned. The volume of feed solution was 130 L for DWW 1 and 200 L for DWW 2 and DWW3. Permeate fluxes of RO filtration were plotted vs volume reduction ratio (Fig. 3). The flux declined continuously for each experiment during retentate concentration. DWW 1 produced in whey concentrator showed a higher flux than DWW 2 and 3 from skim milk processes, below VRR 5, despite a higher DM content. This lower flux with skim milk wastewater can be explained by membrane fouling due to deposit and/or gel formation of caseins; this gel was previously observed on membrane surface of dead-end filtration experiments with diluted skim milk [19]. For VRR higher than 5, the flux fell very low for DWW 1, perhaps due to a deposit of suspended matter which was very high for this sample and possible precipitation of calcium phosphate (scaling). At the start of the run, permeate flux was higher for DWW 2 than for DWW 3 in accord with DM content. But shortly after beginning, the fluxes were similar for the two wastewaters, despite different retentate concentrations, showing similar fouling resistances. It must be outlined that flux decline and fouling analysis were not obvious because the feed solutions were complex mixtures of milk products which are responsible of both osmotic pressure (salts and lactose) and fouling resistance such as suspended matter deposit with in some cases gel formation (probably due to milk caseins) and scaling (precipitation of calcium phosphate). Classical models (as osmotic pressure model, resistance model, gel polarisation model and combined models [29]) were tested, nevertheless due to the complexity of the feed solution it was very difficult to find a model which describes or predicts quantitatively or even qualitatively the total effect of the solutes on flux decline. This mechanistic aspect should be considered in the future with model solutions.

Performances of the filtration i.e. average permeate flux and TOC of collected RO permeate were given according to water recovery which is a key parameter of the wastewater treatment (Figs. 4 and 5). Average permeate flux could be

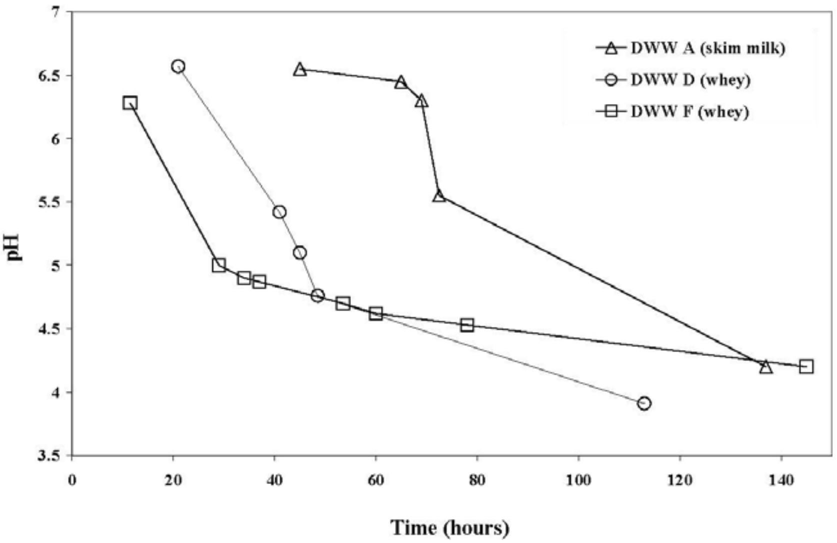

Fig. 2. pH variation of dairy wastewater with storage time at 25°C.

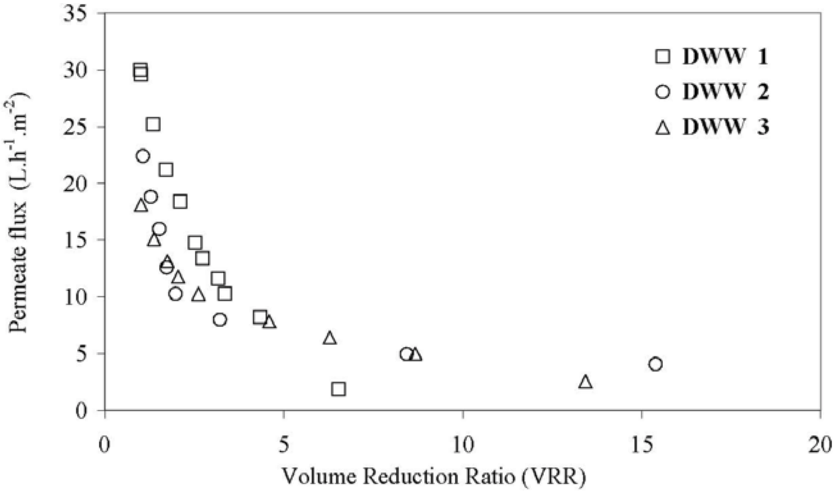

Fig. 3. Permeate flux of RO vs. volume reduction ratio of dairy wastewater.

determined by integration of instantaneous permeate flux or ratio of collected permeate volume to filtration time. For the three samples, average permeate flux decreased vs. water recovery: average flux was in the range 11–13 L.h^{-1}.m^{-2} for about 90% recovery and 10–11 L.h^{-1}.m^{-2} for 95%.

TOC of overall permeate increased slowly until 80% recovery, but at higher water recovery, permeate TOC increased significantly up to 2, 3.5 and 7 mg.L^{-1} for DWW 2, 3 and 1, respectively (Fig. 5). As expected, permeate TOC was dependent on the wastewater concentration, about 3 times higher for DWW 1 (DM 9.8 g.L^{-1}) than for DWW 2 (DM 3.5 g.L^{-1}). Inspection of data illustrated that RO operation can reach a water recovery of 90 to 95 % with an average permeate flux around 11 L.h^{-1}.m^{-2} and with TOC of purified water lower than 7 mg.L^{-1}.

Removal efficiency of the RO operation was calculated for TOC, Conductivity, TKN, ions, and lactose (Table 3). As expected, removal efficiency for RO membrane was high for all the compounds: organic matter removal was very

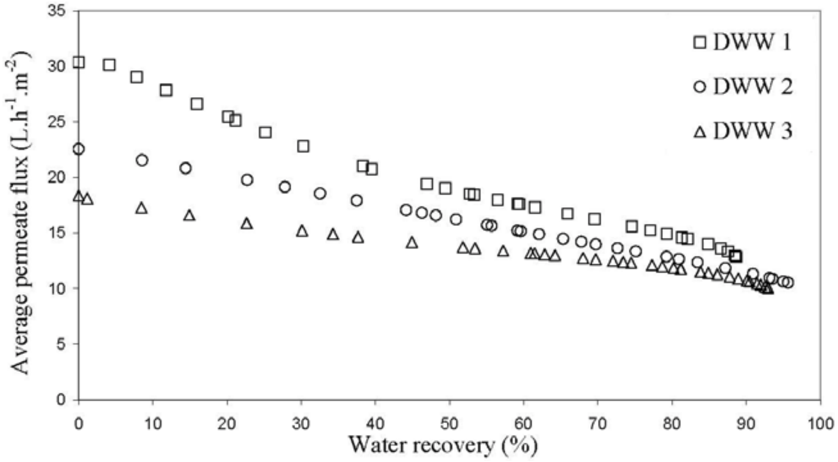

Fig. 4. Average permeate flux vs. water recovery for dairy wastewaters.

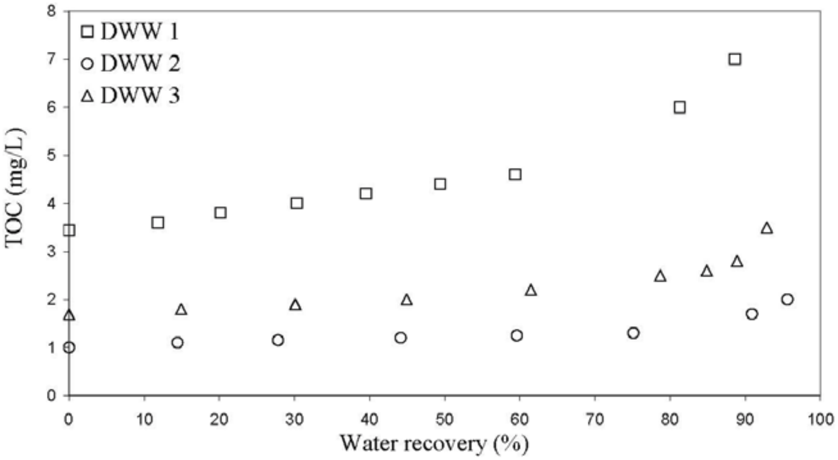

Fig. 5. TOC of purified water (RO permeate) vs. water recovery for dairy wastewaters.

high (>99.8 % for TOC and > 99.5% for lactose), nitrogenous matter removal was around 96% and conductivity removal was about 97% (higher than 95% for multivalent ions and 87% for monovalent ions). Results do not show significant difference between DWW 1 from whey and DWW 2 and 3 from milk. At the beginning of the filtration (at VRR 1), TOC rejection was 99.9% and conductivity rejection around 99.5%. These data were fairly consistent with those obtained previously for a RO treatment of a dairy model process water [21].

3.4. Purified water quality

RO permeate characteristics are given in Table 4 for each wastewater. In all the cases, permeate was low mineralised with a conductivity value lower than 50 µS/cm, corresponding mainly to monovalent ions (Na^+, K^+ and Cl^-). Organic matter content was even very low, TOC value ranging from 2 to 6.7 $mg.L^{-1}$. Lactose concentration ranged from 5 to 12 $mg.L^{-1}$ while lactate concentration was lower than the threshold value of the analysis method. Lactose contribution to permeate TOC ranged from 76% to 100% (Table 5). Other small organic molecules (like lactate, ethanol, and acetone) could probably contribute to the remaining organic matter content involved in TOC but their identification would be difficult because more than 100 small volatile organic molecules were identified in milk

Table 3
Removal efficiency of RO operation with dairy wastewaters

	RO removal efficiency (%)		
	DWW 1	DWW 2	DWW 3
VRR	6.8	17	13
TOC	99.8	99.8	99.9
Conductivity	97.8	97.5	97.2
TKN	—	96.3	95.9
HPO_4^{2-}	>95.5	>99.6	>99.9
Mg^{2+}	>99.8	>98.6	>99.5
Ca^{2+}	>99.6	>98.0	>99.3
Na^+	98.7	94.4	96.8
K^+	98.3	87	87
Cl^-	98.3	—	98.1
Lactose	99.7	99.5	99.8

Table 4
Permeate characteristics of RO operation with dairy wastewaters

		RO permeate		
		DWW 1	DWW 2	DWW 3
VRR		6.8	17	13
TOC	mg/L	6.7	2	3.5
Conductivity	µS/cm	46	17	40
NO_3^-	mg/L	<2	<2	<2
HPO_4^{2-}	mg/L	0.8	<0.1	<0.1
Mg^{2+}	mg/L	<0.1	<0.1	<0.1
Ca^{2+}	mg/L	<1	<1	<1
Na^+	mg/L	2.4	1.3	3.4
K^+	mg/L	5.9	2.1	4.7
Cl^-	mg/L	4	< 3	4
Lactose	mg/L	12	5.5	9
Lactate	mg/L	<2	<2	<2

Table 5
Lactose contribution to permeate TOC of RO operation for dairy wastewaters

Permeate	Lactose mg/L	$TOC_{lactose}$ (TOC from lactose, calculated), mg/L	TOC, mg/L	$TOC_{lactose}$/ TOC, %
DWW 1	12	5.1	6.7	76
DWW 2	5.5	2.3	2	~100
DWW 3	9	2.9	3.5	83

products [26] and their concentrations were too low to be detected by analysis methods. RO permeate characteristics do not show significant difference between permeate from milk products (DWW 2 and 3) and permeate from whey (DWW 1). But results show that permeate TOC is strongly related to wastewater concentration (i.e. dry matter): the higher the wastewater concentration the higher the permeate TOC.

For the three wastewaters, purified water (i.e. RO permeate) quality was compared to vapour condensates sampled in dairy plants (Fig. 6). Purified water showed TOC concentration and conductivity similar to those of vapour condensates. For DWW 2, TOC reaches even the drinking water standard. So the purified water produced by RO from selected wastewater could be reused in the dairy plants for the same purposes than vapour condensates (i.e. heating, cooling and cleaning applications).

A RO polishing operation was performed after the first RO stage for the improvement of water quality. Permeate flux was quite constant during the filtration around 50 L.h^{-1}.m^{-2}. TOC rejection ranged between 77 and 81% at VRR 1 only, probably due to the low rejection of the small organic molecules. Table 6 illustrates that RO+ RO purified water was quite significantly demineralised (conductivity = 3 µS.cm^{-1}) and that TOC complied with the French drinking water standard (TOC <2 mg.L^{-1}) in two cases and was very close to this standard in the last case (2.1 mg.L^{-1}). With derogation from the French authorities, such purified water could be used for new applications where unexpected contact with milk products can occur.

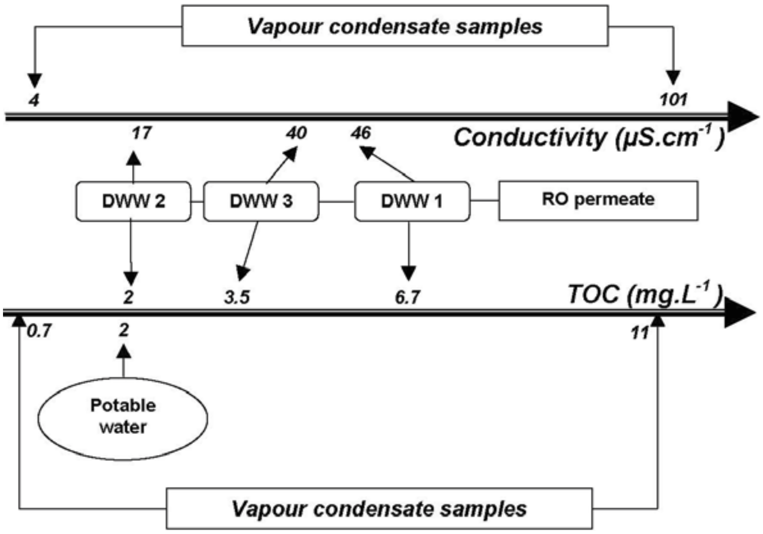

Fig. 6. Comparison between RO treated water (permeate) from dairy wastewater (DWW 1, DWW 2, DWW 3) and vapour condensate quality (TOC and conductivity).

Table 6
Permeate characteristics of RO+RO operations with dairy wastewaters

		DWW 1	DWW 2	DWW 3
VRR (polishing RO stage)		35	25	24
TOC	mg/L	2.1	0.7	1
Conductivity	µS/cm	3	3	3

3.5. Scale-up

Scale-up was carried out for a RO treatment of 100 $m^3.day^{-1}$ wastewater in fed-batch mode. The membrane area was determined under the following assumptions: filtration at 20 bar, 25°C, 800 $L.h^{-1}$ during 16 $h.day^{-1}$ with an average permeate flux of 11 $L.h^{-1}.m^{-2}$ (corresponding to the average permeate flux obtained with wastewater). In order to achieve a water recovery of 95%, the filtration plant will require 540 m^2 RO membrane arranged for example with 18 spiral-wound 8" elements (30 m^2 per element, 3 elements per pressure vessel, 6 vessels in parallel).

4. Conclusion

Water management practices in 11 French dairy plants show that water was mainly coming from three origins: drinking water from water provider, riverwater or groundwater (often treated to be potable) and vapour condensates. One should note that half of the factories used drinking water for applications where such quality was not required. Dairy wastewater stored at 25 °C shall be processed within a few hours after sampling in order to prevent increase of permeate TOC due to degradation.

RO treatment of the selected wastewaters was carried out until 90–95% water recovery was achieved with an average permeate flux around 11 $L.h^{-1}.m^{-2}$. TOC of purified water was lower than 7 $mg.L^{-1}$ and came mainly from lactose (76–100%). Purified water was low mineralised: conductivity <50 $\mu S.cm^{-1}$ corresponding essentially to monovalent ions (Na^+, K^+ and Cl^-). Quality of purified water was similar to vapour condensates, so it can be reused for the same applications as heating, cleaning and cooling.

Scale-up was proposed: a plant of 540 m^2 RO membrane area permits the recovery of 95% of 100 m^3 per day wastewater. A polishing step with

RO stage could be added in order to get water fulfilling requirements of drinking water.

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