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Analysis and design of a pilot system for the treatment of industrial wastewaters using membrane processes

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ABSTRACT

The purpose of this study is to undertake the characterisation of industrial-type wastewaters and to provide the design and application of a treatment system using membrane technology backed up by multiple laboratory-based experimental trials to observe and determine the stages required in the process. An analysis of the various industrial sectors of the Autonomous Community of the Canary Islands, Spain, enabled us to establish the source and characteristics of their wastewaters along with the quality indices and typical mean concentrations. The theoretical models were adapted to the observed effects of the trials in the pilot system with an assessment of the various operational possibilities that included operating ranges meeting ASTM standards. These standards included the case of industries that require the use of high-quality water.

Keywords: Membrane process; Industrial wastewaters; Laboratory analysis; Standards

1. Introduction

The industries considered in this study were identified after an exhaustive analysis, with an evaluation of the processes and wastewaters and, following this, their characterisation using standardised methods, analyses and the specific indices of the standard practices of ASTM D5090-D4516 [1]. Experimental trials were conducted to determine the lines of action to be applied for the industrial discharges.

Membrane processes were chosen according to their operational ranges and the specific properties required for the elimination of difficult-to-remove pollutants: multilayer filtration (sand, anthracite [coefficient of uniformity 0.6]), microfiltration (MF) (cartridge filters [5–10 μm]), ultrafiltration (UF) technology, ultraviolet (UV) disinfection and reverse osmosis (RO) with brackish water membranes guaranteeing a high degree of removal of industrial discharge pollutants, including those that require subsequent post-treatment [3]. The treated wastewater is used for recirculation. Such a method enables water consumption optimisation with its evident economic impact. The concept of reuse and recycling needs to be implemented more and more, particularly in locations where water is a scarce and non-renewable asset whose value is added to by the ever stricter standard practices involving industrial effluent discharge [5].

The flow rates were determined together with the reference values of the membranes used in the RO pilot plant of the Industrial Environment division of

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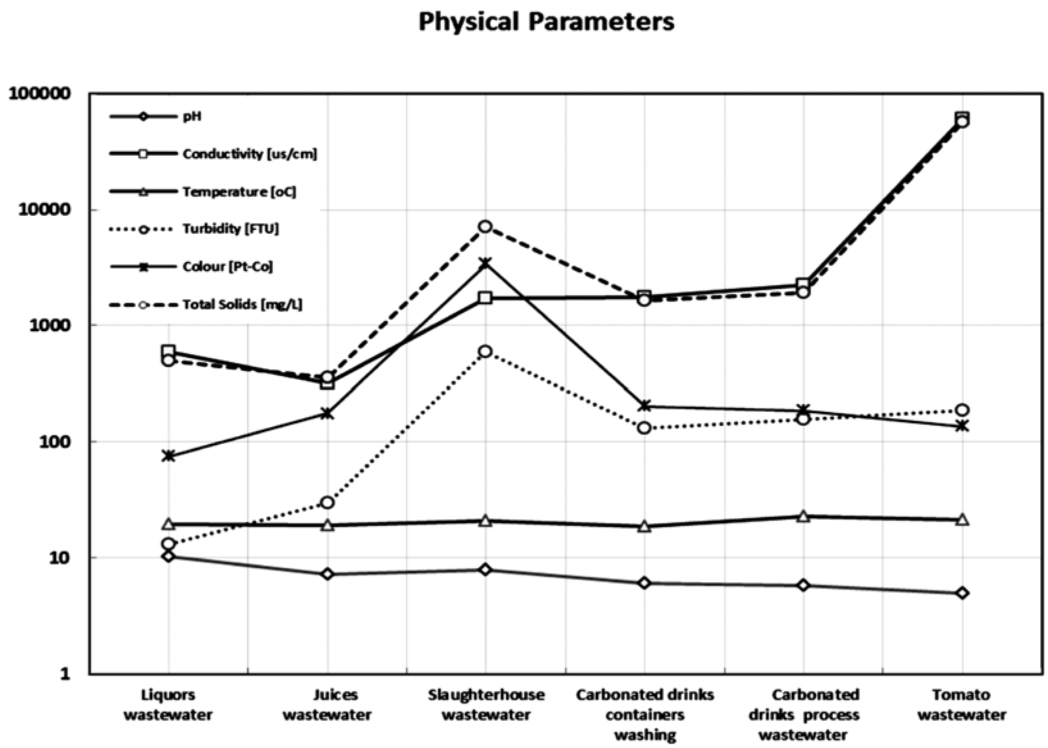

Fig. 1. Physical parameters of the industrial wastewaters.

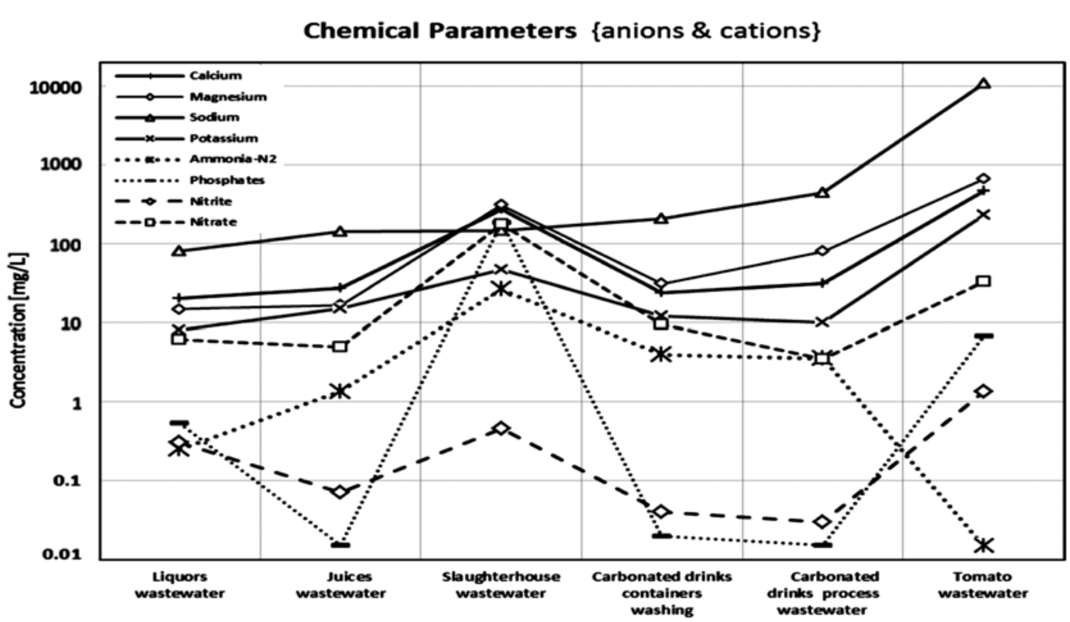

Fig. 2. Chemical parameters (evaluation of anions and cations).

the Process Engineering Department of Las Palmas University (Spain). This RO plant, designed to operate at a maximum capacity of $40\,m^3/d$ of brackish water or sea water, has undergone a series of modifications that enable it to include other necessary processes which encompass the various alternatives for effluent discharge treatment.

The simulations were performed using fixed parameters set in accordance with the theoretical parameters of applicability of the models, while their

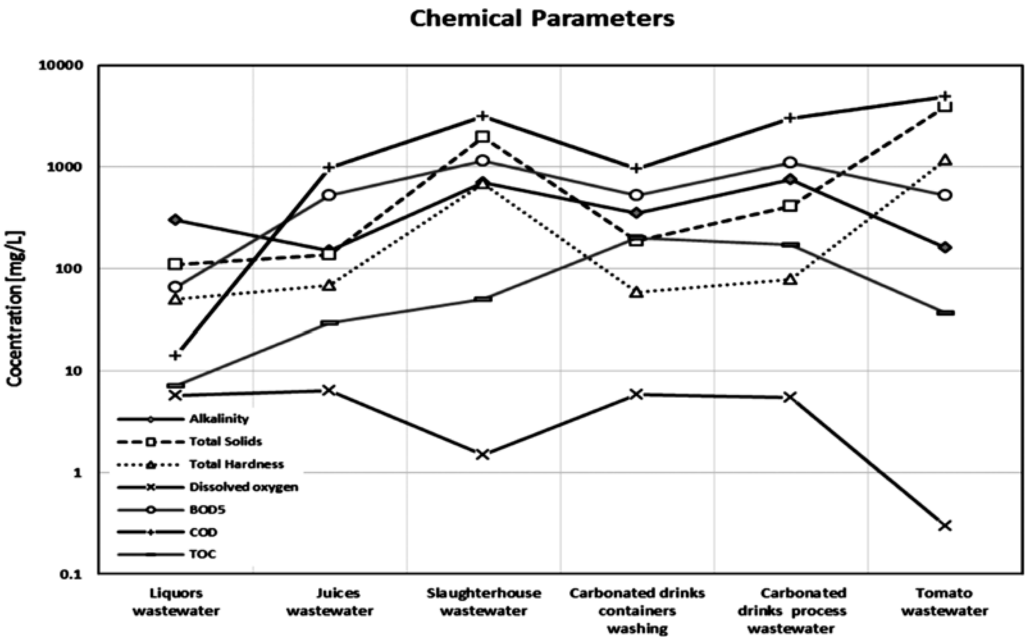

Fig. 3. Complementary chemical parameters.

functionality was varied in order to determine the reference percentage of removal required to conduct trails on industrial-type wastewaters [4]. Independently of the treatment to be performed, operational guides and specific individualised parameter control were determined through an optimisation procedure (see Figs. 1–3).

2. Analysis of the industrial wastewaters

The aim of this stage was to determine the source and characteristics of industrial wastewaters in the Canary Islands (Spain) and their typical mean concentrations in order to evaluate their contaminating impact. Analysis of the most significant parameters was undertaken in the laboratory using the techniques of the AWWA standard methods [2]. The processes that offered a high degree of removal were then established using the data obtained. The wastewaters from the industries listed below were chosen:

- Food, tomato
- Sugar refinery
- Carbonated drinks containers; washing wastewater
- Carbonated drinks; process wastewater
- Beer
- Dairy products; washing
- Laundry; wastewater
- Liquors; wastewater
- Slaughterhouse; general wastewater
- Paint; wastewater
- Fruit juice; wastewater

3. Specification of treatment lines

The treatment stages that industrial processes require using clean technology such as a membrane system were determined in laboratory-based trials. The operating range was optimised according to the pollutants that needed to be eliminated. The design included multilayer filtration as a pre-treatment that withstands macromolecular fouling, tertiary systems of MF with cartridge filters, UF and RO with prior UV disinfection and subsequent post-treatment as determined by the requirements of the industry in question (see Fig. 4).

A recirculation line was set up to optimise water consumption (lower cost and higher recovery). If necessary a nanofiltration (NF) system can be implemented for cases that require softening as well as for certain special types of precursor removal.

The flow rates depend on the type of membrane used. A work plan was initially created with fixed parameters that indicated the removal percentage. Work was then begun on specifying the characteristics of each type of industrial wastewater in the study independently of the treatment to be carried out.

Simulation of the treatment enabled establishment of the reject percentage of each process using two UF membranes (2540) and BW 2540 RO membranes

Analysis and projection of treatment with membrane processes in Canary Island Industries

Parameter	Unit	Liquors	Tomato	Juices	Slaughterhouse	Carbonated drinks: washing	Carbonated drinks: process
pH		10.21	4.90	7.28	7.82	6.05	5.82
Conductivity	μS/cm	593.00	61,400.00	320.00	1,704.00	1,760.00	2,263.00
Temperature	°C	19.60	21.30	19.10	21.10	18.60	23.05
Turbidity	FTU	13.00	187.00	30.00	590.00	131.00	157.00
Colour	Pt-Co	75.00	136.00	176.00	3,400.00	203.00	187.00
Alkalinity	mg/L	300.00	160.00	150.00	700.00	350.00	740.00
Total solids	mg/L	495.00	56,900.00	360.00	7,160.00	1,630.00	1,920.00
Total hardness	mg/L	110.00	3,882.00	137.25	1,960.00	186.27	411.76
Calcium hardness	mg/L	50.00	1,176.00	68.62	686.00	58.82	78.43
Anion							
Calcium	mg/L	20.00	470.40	27.45	275.00	23.52	31.37
Magnesium	mg/L	14.60	657.56	16.68	309.00	30.97	80.00
Sodium	mg/L	80.00	10,800.00	142.00	145.00	210.00	445.00
Potassium	mg/L	8.00	228.00	15.00	47.00	12.00	10.00
Ammonia-N2	mg/L	0.25		1.35	26.40	3.95	3.55
Cation							
Bicarbonate	mg/L	40.00	160.00	150.00	700.00	350.00	740.00
Carbonate	mg/L	260.00	0.00	0.00	0.00	0.00	0.00
Chloride	mg/L	130.00	39,920.00	104.79	923.00	1,596.80	1,197.60
Phosphates	mg/L	0.54	6.75	–	185.00	–	–
Nitrite	mg/L	0.30	1.34	0.07	0.46	0.04	0.03
Nitrate	mg/L	6.19	33.15	5.00	176.80	9.50	3.50
Others							
Coliforms Total	NMP	Presence	Presence	Presence	Presence	Presence	Presence
Dissolved oxygen	mg/L	5.70	0.30	6.40	1.50	5.80	5.40
Sodium chloride	mg/L	214.00	65,868.00	172.90	1,523.00	2,634.72	1,976.04
BOD_5	mg/L	65.00	520.00	520.00	1,136.00	528.00	1,094.00
COD	mg/L	13.80	4,950.00	980.00	3,120.00	948.00	3,010.00
TIC	mg/L	60.30	3.42	7.54	257.86	27.89	35.70
TOC	mg/L	7.08	36.46	29.40	50.10	201.42	170.00
Langelier index		+2.48	−1.53	+0.59	+1.58	−1.56	−1.34
Membrane process		MF-UV-OI	MF-UF-NF	MF-UF	MF-UF-NF	MF-UF-NF	MF-UF-NF
			UV-RO	UV-RO	UV-RO	UV-RO	UV-RO

MF: Microfiltration, UF: Ultrafiltration, NF: Nanofiltration, UV: Ultraviolet, RO: Reverse osmosis.

(two-membrane tube) with laboratory water with TDS of 1,000–2,000 ppm and 100 and 500 ppm concentrations of heavy metals and organic carbon content.

4. Layout and description of pilot plant

The basic plant comprises the following components (see Fig. 5):

Feed: two 1,000-L tanks and a 500-L mixing tank.
Low-pressure pumping: flow of 1,500 L/h at 4 bars.
Active carbon/anthracite/sand filtering: (Te 1.1 mm), bed height 1,800 mm; hydraulic loading rate: $5\ m^3/m^2/h$.
MF: 5-μ cartridge filters of combined propylene.
Reagent dosing: 6 × 125 L tanks, manual stirrer, draining and indicator level, 2 L/h dosing pump.

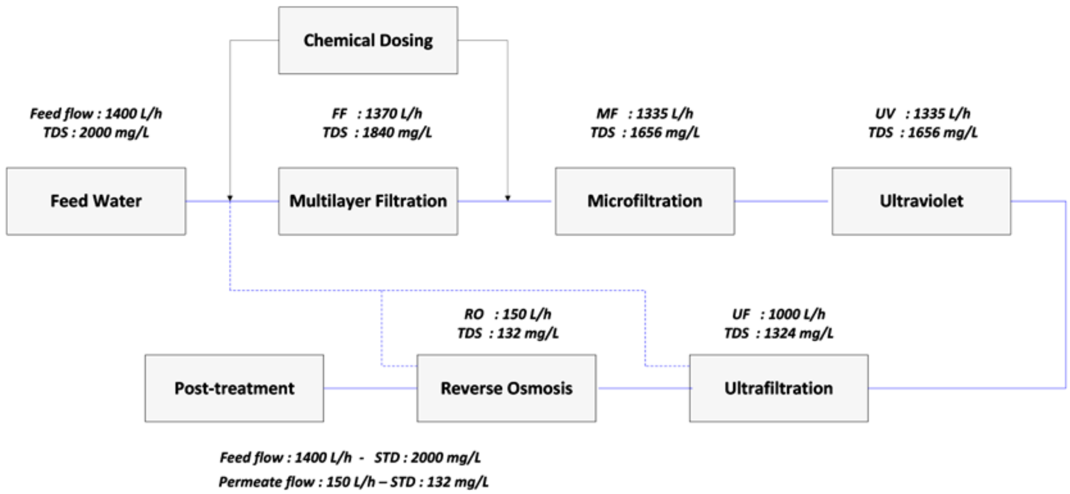

Fig. 4. Flow chart of the processing.

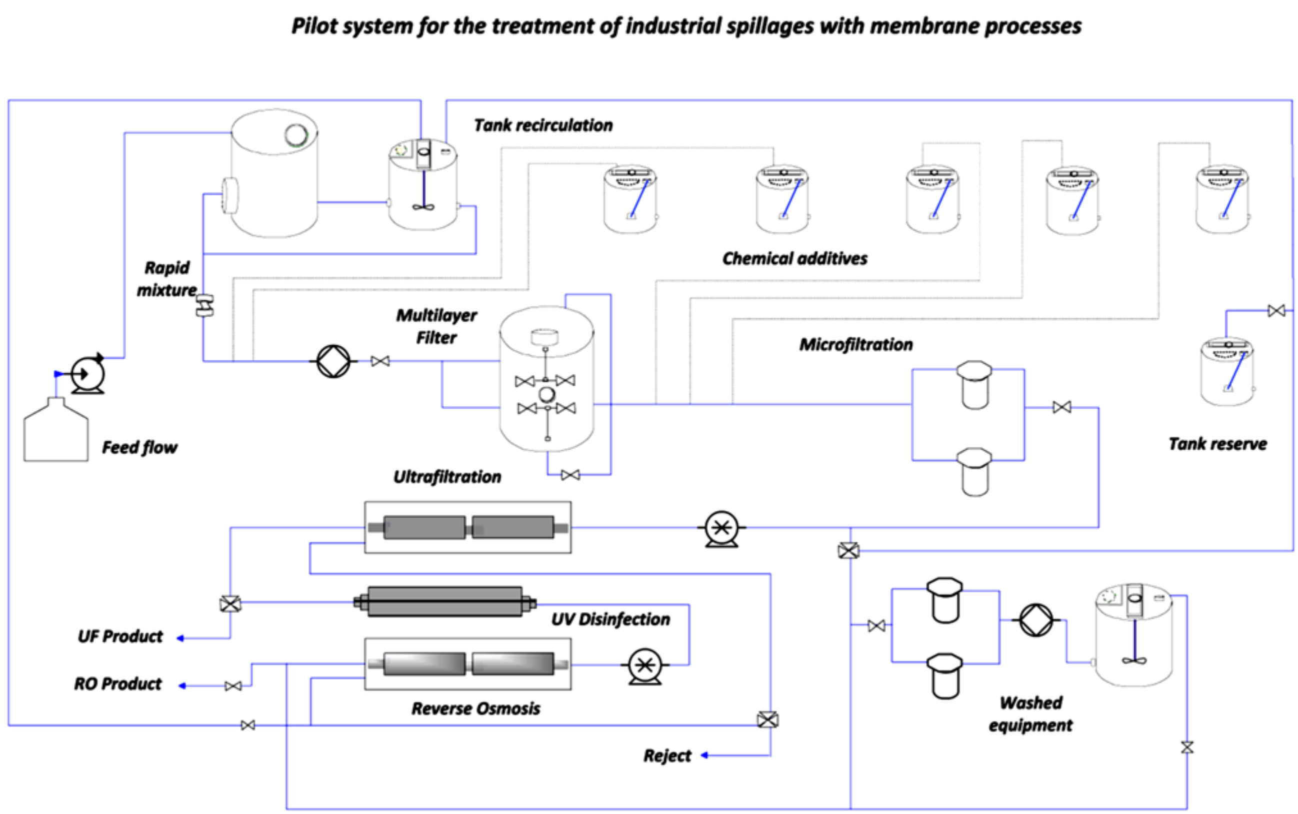

Fig. 5. Scheme of pilot plant.

UF: Pressure tube with two 2,540 membranes specifically for wastewaters, low-pressure centrifugal pump. Disinfection: UV radiation disinfection equipment (turbidity < 40 TU). High pressure pumping: positive displacement motor pump with variable speed drive.

RO membranes: Tube comprising two high-reject BW 2540 membranes.

Parameter	Unit	Value
Conversion	%	15
Feed	L/h	1,400
RO final production	L/h	150
Operating pressure	Bar	17–20
Total dissolved solids	mg/L	2,000
Temperature	°C	20
Permeate quality	mg/L	100–130

Washing equipment: 250-L tank, electric stirrer, recirculation pump and cartridge filter.

5. Conclusions

- Classification of the industrial sectors was undertaken in accordance with the official documentation of the Canary Island Autonomous Community, Spain. The source and characteristics of the industrial wastewaters were specified as well as their typical mean concentrations. The optimum design was determined with the selected treatments, including for industries that require high-quality water. The membrane processes used were MF, UF, RO and UV disinfection.
- The development of this work methodology saw results obtained that were close to the expected levels in terms of permeate flow rate and concentration. The theoretical model guidelines should be considered flexible rather than definitive with an important degree of deviation in experimental applications. Further studies are required of the wastewater discharges to enable us to resolve the problems associated with industrial sector wastewaters using clean technology that promotes the reuse and saving of resources.

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