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Research article

Osmosis process for leachate treatment in industrial platform: Economic and performances evaluations to zero liquid discharge

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A B S T R A C T

The industrial processes require large quantities of water. The presence of discharges results not only in significant environmental impact but implies wastage of water resources. This problem could be solved treating and reusing the produced wastewaters and applying the new zero liquid discharge approach. This paper discusses the design and the performances of reverse osmosis membranes for the upgrading of full scale platform for industrial liquid wastes. The final effluent from the ultrafiltration unit of the full scale plant was monitored to design the reverse osmosis unit. Previous modelling phase was used to evaluate the specific ordinary and maintenance costs and the final effluent quality (2.7 €/m^3). The system was designed in triple stages at different operative pressures. The economic feasibility and the payback period of the technology at different percentages of produced permeate were determined. The recovery of 90% was identified as profitable for the reverse osmosis application. One experimental pilot plant applying the reverse osmosis was used to test the final effluent. Moreover, the same flow was treated with second pilot system based on the forward osmosis process. The final efficiencies were compared. Removals higher than 95% using the reverse system were obtained for the main macro-pollutants and ions. No sustainable applicability of the forward osmosis was determined.

1. Introduction

Water supply for the productive sectors is one of the major problems of the recent years (Greenlee et al., 2009). The European countries, also because of the economic crisis, are focused on the optimization of the industrial operative costs and on the valorization of the water resource (Jiménez-Cisneros, 2014). In fact, the European use of water in the manufacturing industry changed from 85.7 ± 92.6 m^3/y/inhabitant of 2003, to 75.0 ± 82.27 m^3/y/inhabitant of 2005 up to 72.2 ± 91.94 m^3/y/inhabitant of 2009 with progressive decrement of percentage of public supply. The amount of consumption of public water decreased respectively from 10.2% of 2003 to 9.9% of 2005 and up to 7.3% of 2009 (Eurostat, 2010). The remaining necessity of water is self-produced or comes from surface systems or from wells. In this scenario the possible recovery of wastewaters formed during the industrial processes is increasingly representing one of the important goals of the manufacturing sector (Service, 2006). In fact, in the industrial processes the presence of discharge of wastewater not only produces considerable environmental impact but also represents waste of hydraulic resources which could be suitably treated and reused. Therefore, the new approach of zero liquid discharge started to be applied in different industrial sectors linked to the minimization both of final liquid products and of solid wastes (Sueviriyapan et al., 2016). The flow scheme applied to realize the ZLD changes for the different industrial areas considering the variation of the chemical and physical characteristics of the produced wastewaters and the final level of quality to be obtained for the reuse. Independently from the type of industry (Oil Industry, Seawater or Groundwater Desalination, Textile Industry, Palm Oil Production), the ZLD cases reported in the scientific literature consider always the use of the Reverse Osmosis process (Loganathan et al., 2016; Tufa et al., 2015; Vergili et al., 2012; Tabassum et al., 2015; Sobhani et al., 2012). In fact, the RO membranes are the most efficient method for the treatment of the liquid waste with high recovery of water, for salts removal and for minimization of brackish water (Ning and Troyer, 2009). Notwithstanding the elevated level of efficiency, the RO is characterized from high energy footprint (2.3–4.5 kWh/m^3: National Research Council, 2008; Pearce, 2008). For this motive the more cheap Forward Osmosis process (Valladares Linares et al., 2016) has been recently proposed as new and competitive

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Nomenclature

b_n	annual benefits, €/y
C_0	investment cost, €
c_n	annual operating cost, €/y
COD	chemical oxygen demand, mg/L
DS	draw solution
FO	forward osmosis
FP	feed booster pump
FS	feed solution
HRT	hydraulic retention time, d
i	inflation rate, %
J′	forward solute flux, mg/m^2/h
J_w	net water flux, L/m^2/h
MF	microfiltration
MLVSS	mixed liquor volatile suspended solid, mg/L
n	generic year
NH_4^+-N	ammonia, mgN/L
NO_2^--N	nitrites, mgN/L
NO_3^--N	nitrates, mgN/L
NPV	Net Present Value, €
PO_4^{3-}-P	phosphate, mgP/L
PP	piston pump
r	discount rate, %
RO	reverse osmosis
RO1	stage 1 of reverse osmosis
RO2	stage 2 of reverse osmosis, high pressure
RO3	stage 3 of reverse osmosis
S1	storage tank for effluent from UF membranes
S2	storage tank for permeate of stage RO1
S3	storage tank for concentrate of stage RO1
S4	storage tank for FO feed solution
S5	storage tank for FO draw solution
S6	storage tank for RO permeate (FO pilot)
S7	storage tank for feed solution concentrate
SME	small and medium enterprise
SRT	sludge retention time, d
TKN	total Kjeldahl nitrogen, mgN/L
UF	ultrafiltration
ZLD	zero liquid discharge
π	osmotic pressure, bar
Δπ	osmotic pressure drop, bar

desalination technology. The FO is osmotically driven membrane process without utilization of external hydraulic pressure (Cath et al., 2006). The FO configuration determines intrinsically the low fouling propensity (Mi and Elimelech, 2010). The driven force of the treatment is related with the needed draw solution at higher salinity. However, considering the necessity of the draw solution recovery, the energetic balance and the removal efficiencies have to be evaluated for the comparison with the conventional RO technology.

The paper deals with the techno-economic analysis to reach the near zero liquid discharge approach in the full scale platform for the treatment of leachate from landfill of not dangerous urban wastes. The platform is situated in small industrial area (190 ha) in Center of Italy where 150 of small enterprises (SME) and industries are located, mainly of the mechanical sector. Actually, the main flow scheme of the plant is structured with pretreatment, chemical-physical unit, biological reactor and ultrafiltration membrane (Eusebi et al., 2009b). The effluent flow is discharged in the sewer system. The studied upgrading is carried out to evaluate the technical and economical sustainability of new reverse osmosis unit to produce water for the reuse in the industrial area. The platform was monitored for 12 months to define the process performances and the actual operative costs. Afterwards, the economic analysis (Net Present Value) (Žižlavský, 2014) to determine the availability of the RO technology was made also considering the initial investment costs. Moreover, tests on the effluent from the UF of the full scale platform were carried out both through forward and reverse osmosis pilot plants to compare the quality of the final flows and to evaluate the applicability of the low expensive FO technology.

2. Material and methods

2.1. The full scale platform

The full scale platform for the treatment of industrial liquid wastes has the nominal capacity of 300 m^3/d. The influent is manly composed by landfill leachate (81%) and liquid wastes from urban origin (8%). The discharged wastes are screened, gritted and submitted to chemical coagulation and flocculation. Subsequently, the supernatant is equalized and fed to the biological process. The process is performed with activated suspended biomass in continuous stirred reactor (1000 m^3). The process applies oxic and anoxic phases (Battistoni et al., 2003; Eusebi et al., 2009a) automatically controlled on basis of the dissolved oxygen (DO) and the oxidation reduction potential (ORP) probes (Eusebi et al., 2012). The reactor was designed with elevated HRT (up to 10 days) to enhance the kinetic transformations and is managed with SRT of about 30 d. The ultrafiltration membranes are applied as tertiary treatment after the secondary clarifier. The treated effluent is discharged in sewer system. The chemical and physical characterization of the influent and effluent flows was determined with daily averaged samples once a week according to Standard Methods (APHA, 2005). Moreover the energy consumption, the amount of chemical reagents and the quantity of discharged sludge were monitored to define the specific actual ordinary and maintenance treatment cost (€/m^3).

2.2. Modelling RO performance

The characterization of the final effluent from the UF phase of the full scale plant was used to design the reverse osmosis unit according with the ZLD approach. The RO system was designed in three different stages (RO1 – RO2 and RO3): at low pressure for the RO1, high pressure for the RO2 and with third phase of refinement (RO3) (Lee et al., 2011). The first stage (RO1) was fed with flow rate of 300 m^3/d of effluent from UF. The concentrate of RO1 was sent to the RO2 at high pressure. Differently, the permeates of RO1 and of RO2 were the influent of the refinement phase (RO3). Finally, the concentrate of RO3 was recirculated in the main UF leachate to the RO1. The concentrate of RO2 represents the final liquid wasted product to be disposed or destined to other treatments to attain solid waste. The number of necessary modules of membranes and the performances of the process were evaluated with a thermodynamic model (ROPRO version 8.05, Koch Membrane Systems, Inc.). The first stage (RO1) to assure the treatment of 300 m^3/d consisted of three vessels, each containing 3 spiral-wound membranes in series, model 8060 TFC-HR-590 (commercial product by KMS provided by software). The second stage (RO2)