USING HYBRID MEMBRANE SYSTEMS FOR SECONDARY EFFLUENT POLISHING FOR UNRESTRICTED AGRICULTURAL IRRIGATION

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ABSTRACT

Integrative experiments are in progress for verifying the feasibility of polishing secondary domestic wastewater through membrane processes and ultimately apply the improved effluent for unrestricted irrigation. The experimental pilot system consists of an UltraFiltration (UF) stage and soon will be combined with a Reverse-Osmosis (RO) component. Spiral wound membranes are used. The field results indicate the high organic matter and pathogen removal during the UF stage, allowing essentially unrestricted agricultural reuse. The UF effluent is used to feed the RO membranes. The RO permeate is subsequently applied for vegetables irrigation. Field results indicate the importance of the UF component in the removal of the organic matter and the pathogens that are still contained in the secondary effluent. Under specific conditions, when the dissolved solids content is relatively low, regarding sanitary and health aspects, the UF effluent can be applied for unrestricted irrigation. During the RO stage most nutrients are removed, allowing applying the effluent without jeopardizing the soil fertility and the aquifers. Preliminary economic assessment indicates that the extra cost for effluent polishing via the UF stage only is in the range of 5 to 15 US cents/m^3. The extra cost for the RO stage is as well assessed at 10 to 25 US cents/m^3. The additional cost depends to a large extent on the quality of the incoming raw secondary effluent and local requirements at the command region.

KEYWORDS: Effluent; Hybrid membrane systems; Irrigation; Unrestricted Reuse

INTRODUCTION

Spiraling demand for high quality water, coupled with natural shortage mainly due to intensive exploitation of groundwater from aquifers and continuous deterioration of supplies, primarily in arid zones, has stimulated the search for alternative sources and water treatment methods. The gap between supply and demand can be primarily closed by implementing two major strategic directions: (i) to import water from external sources, and; (ii) to further develop the extra water sources (saline water, runoff water and wastewater) and under specific conditions to treat the water to acceptable levels (Asano, 2002). Potential additional water treatment includes the use of membrane technology, primarily for saline and seawater however, also for treated wastewater. Membrane treatment of effluent sounds since these waters are stable sources. However, the brine disposal is still of high concern due to potential environmental problems.

Effluent treatment received vast attention, during past decades as means to alleviate water shortage problem (Asano and Levine, 1996; Oron et al., 1998). The improved technology for the removal of particles, turbidity, bacteria and cysts, without the use of disinfectants is based on the use of membranes, mainly in MicroFiltration (MF) and UltraFiltration (UF). The advantage of MF or UF for organic matter removal with the selectivity salt removal of Reverse Osmosis (RO) membranes makes an integrated hybrid system a very promising technology (Jolis et al., 1996; Bick and Oron, 2000). Consequently, a pilot study was performed to evaluate the efficiency of the UF/RO system for treatment of secondary effluent. The objectives of the on-going study are: (i) to define the performance of the UF/RO system in term of water quality and membrane performance, and (ii) to understand the process mechanism in order to improve membrane facility design.

MATERIALS and METHODS

The Experimental Layout

The experiments are in progress adjacent to wastewater treatment system [waste stabilization ponds (WSP) system] located several km west of the City of Arad, Israel. Secondary effluent from the WSP is used as a feed for the membrane pilot system. The secondary effluent is initially treated by a mechanical ring filter and subsequently by a UF membrane system. The permeate from UF system is used for irrigation as well to feed the Reverse Osmosis (RO) stage. The RO permeate is as well applied for irrigation, adding special amounts of fertilizers to comply with the content of the original secondary effluent. The schematic treatment system is depicted in Figure 1.

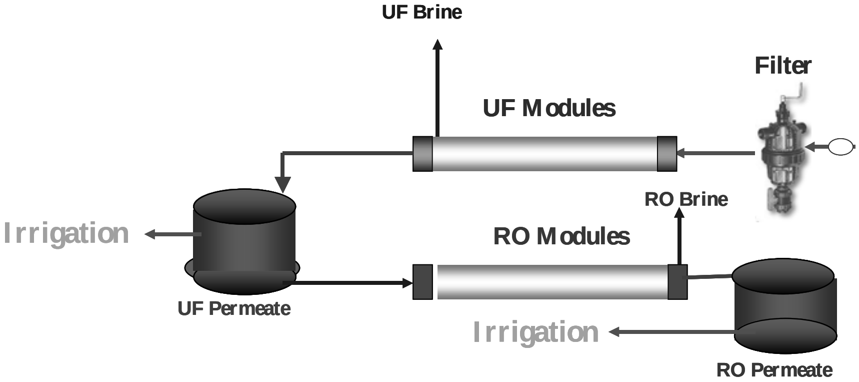


Figure 1. The Hybrid membrane wastewater polishing treatment system

The Membrane Treatment System

The UltraFiltration stage (Figure 1) consists of a small temporary storage ($5m^3$), a ring filter, a circulation pump, and three modules with twelve UF 8” Spiral Wound (SW), a flushing system and a chemical cleaning unit. Manual valves allow controlling the circulation rate in the membrane system.

The UF membrane consists of three layers: a polyester support web, a micro-porous poly-sulfone interlayer, and an ultra-thin barrier coating on the top surface. Two-stage spiral wound UF membrane modules are used for irrigation and supply $10m^3$/hr. Except for the chemical cleaning process, the UF plant runs automatically under the control of an on-board Programmable Logic Controller (PLC). UF type is

NIROSOFT RM10-8, 8040 spiral wound. The molecular weight cut-off (MWCO) of the membrane is 20 K Dalton. The defined removal rate is 88-93% at 3 bars, 20^0C, stirring cell. Other characteristics of the UF system used are given in Table 1 and Table 2.

Table 1. Characteristics of the UF system under operation

Parameter	Value
Membrane length, mm	1,016
Membrane diameter, mm	200
Product water tube diameter, mm	28.6
Membrane active area, m^2	37.1
Number of membranes used at stage 1	8
Number of membranes used at stage 2	4

Table 2. Characteristics of thin-film composite UF membrane

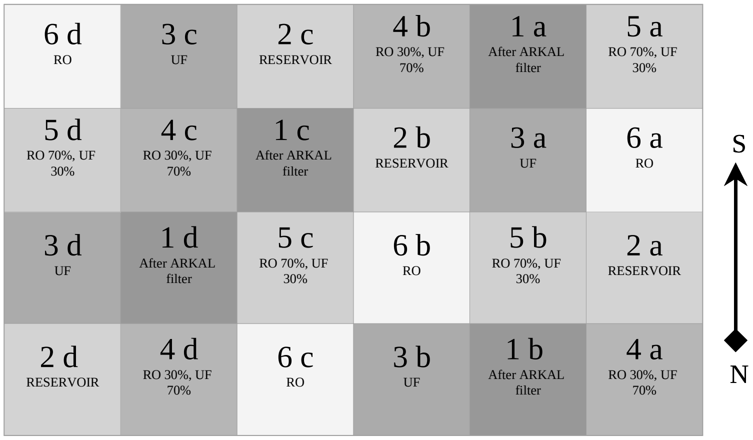
Parameter	Value
Molecular weight cut-off, Dalton	20,000
Max. chlorine tolerance, ppm	1,000
Max. hydrogen Peroxide tolerance, ppm	1,000
Max. operating temp., ^{0}C	45
Max. operating pressure, bar	40
Max. pressure drop per element, bar	0.9
Max. pressure drop per vessel, bar	4.1
pH range, continues operation	2-11
pH range, short term cleaning (Max 45^0C, 2	1-12
Permeate flow rate, m^3/hr	0.4-4.0
Max. feed flow rate, m^3/hr	12
Min. concentrate flow rate, m^3/hr	3.6

The experiments are performed at pH 8, feed pressure is 5 bars and the operating temperature is around 26^oC. The feed water (secondary effluent) is pumped directly from Arad secondary effluent reservoir. The UF system was operated in feed-and-bleed mode. Selected effluent quality parameters are presented in Table 3.

The RO unit consists of a two-stage array with four 4" elements (Filmtec type FT30 4040 thin film composite membrane in spiral wound configuration). The membrane coating is remarkable in that it has surface pores controlled to a diameter of approximately 150 angstroms (Huisman, 1993). Except for the chemical cleaning process, the pilot runs automatically and the feed was pretreated with acid (HCl) without antiscalant. There was no post-treatment: permeate was delivered to a reservoir and supplied to the customers. The RO elements were not back-washed: the membranes were cleaned at 70 hours of operation with citric acid.

The Irrigation System

Several issues were examined during the irrigation study: (i) verifying the effects of Onsurface Drip Irrigation (ODI), applying secondary effluent of diverse qualities (six qualities) on the yield, and; (ii) assessing salinity distribution in the soil as function of the depth and effluent quality application (Figure 2). The possibility of using saline secondary effluent and RO permeate combined with ODI technology for vegetable irrigation was examined in potato and corn field experiment during 2003 and 2004 (Figure 2). The plants were arranged in rows on of 0.93 m wide. The research has begun on August 2003 with the following treatments, all purposely under ODI: (i) irrigation with secondary effluent from the ponds; (ii) irrigation with secondary effluent from the reservoir; (iii) irrigation with UF effluent; (iv) irrigation with RO effluent; (v) irrigation with a mixture of 70 % UF effluent and 30 % RO effluent, and; (vi) irrigation with a mixture of 30 % UF effluent and 70 % RO effluent. All effluents were adjusted to one similar content of nutrients as expressed by NPK.



6 d RO	3 c UF	2 c RESERVOIR	4 b RO 30%, UF 70%	1 a After ARKAL filter	5 a RO 70%, UF 30%
5 d RO 70%, UF 30%	4 c RO 30%, UF 70%	1 c After ARKAL filter	2 b RESERVOIR	3 a UF	6 a RO
3 d UF	1 d After ARKAL filter	5 c RO 70%, UF 30%	6 b RO	5 b RO 70%, UF 30%	2 a RESERVOIR
2 d RESERVOIR	4 d RO 30%, UF 70%	6 c RO	3 b UF	1 b After ARKAL filter	4 a RO 30%, UF 70%

Figure 2. The field experiment layout in Arad, applying diverse effluent qualities

Soil properties were characterized by a standard gravimetric method. Soil salinity was determined by a common method of measuring the Electrical Conductivity (EC) of saturated extracts. Soil samples for moisture and salinity assessment were taken at 0, 30, 60 and 90 cm depths from the equidistant on both sides of the plants, near the emitters and in the middle between two adjacent emitters. The on-line emitter spacing was 0.25 m and two drip lateral served each bed. The emitters flow rate is around 1.25 l/hr.

Table 3. Effluent qualities obtained in the hybrid membrane system

	Fecal coliforms CFU/ 100ml	PO_4 mg/l	NH_4 mg/l	Ca mg/l	K mg/l	Na mg/l	Cl mg/l	Electrical conductivity dS/m	TSS mg/l
Rocky pond	$3.0x10^5$	14.7	60	51.8	43.5	248	264	2.07	194
Ring filter	$3.3x10^5$	17.4	56	50.5	43.5	244	255	1.89	218
UF permeate	0	20.1	55	46.7	42.8	242	262	1.84	20
UF brine	$5.5x10^5$	24.2	62	50.3	41.1	241	245	1.94	344
RO permeate	0	0.92	2.8	3.2	9.5	21.2	16.6	0.1	29
RO brine	0	34.0	93	91.6	90.9	420	554	3.59	5
Big reservoir	$9.6x10^1$	32.2	46	56.8	51.3	266	312	8.02	52

*CFU and PFU – Colony Forming Units and Plaque Forming Unit, respectively

RESULTS

Effluent quality

Table 3 presents typical water quality data of the pilot plant performance. UF treatment provided effective pretreatment for the RO unit. It should be noted that the UF membrane did not removed total organic compounds but on the other hand it provides a disinfecting step, removing completely fecal coliforms. Based on the data recorded it seems that UF membrane barrier guarantees almost total fecal coliforms removal. The tests concerning Somatic Coliphages and Coliphages may indicate the existence of bacteria colonies on the membrane surface that can be removed by sodium hydroxide solution to prevent bacterial re-growth.

RO permeate quality was fairly constant and ionic removal range was 93 to 98%: this indicates superior effluent quality for agricultural irrigation, complying with different regulations (WHO, 1989; EPA, 1992; Shuval *et al*., 1997). Odors were detected in the RO permeate and it is speculated that it indicated the presence of H_2S compounds.

Membrane performance

The membrane performance efficiency can be assessed by the rejection was calculated according to equation 1 and is given by η_i, percent:

$$\eta_i = 100(Cfr_i - Cpro_i)/(Cfr_i)$$

where i parameter, %; Cfr_i is the feed concentration of i parameter, and $Cpro_i$ is the RO permeate concentration of the i parameter. According to the constituents characteristics various values were obtained for η_i for the UF stage and values close to 100 for the RO stage. The general expression for the i normalized effluent quality parameter G_i is given by (2):

$$G_i = Go_i/Gt_i$$

Where Go_i and Gt_i are the values of the specific quality control and/or operating parameters at the beginning of the system operation (t=0) and at time t, respectively.

Figure 3 presents the UF permeate change in the UF stage, including the cleaning trimming. The permeate flow is relatively low due to the low quality of the feed effluent, which is below acceptable standards. Further work is required to improve the UF membrane performance towards increase in the time interval of flushing. These results after extended period of operating the UF membranes.

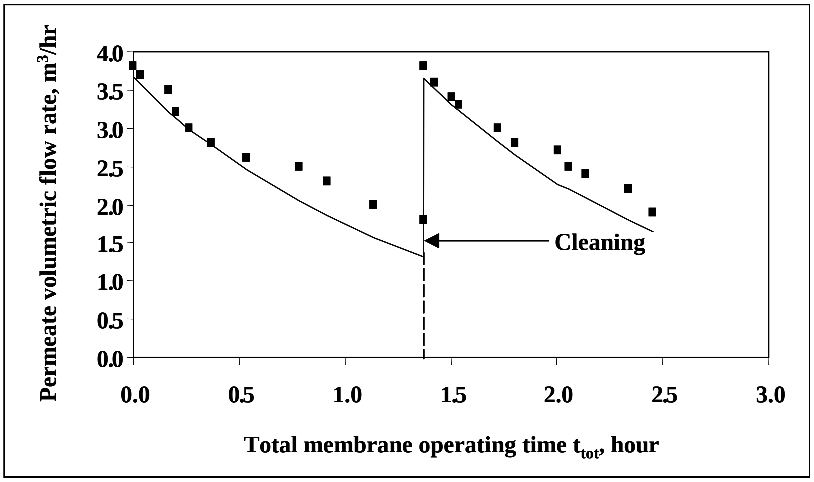


Figure 3. Permeate flow in the UF membrane stage, Arad, Israel

After extended operating time the RO membranes lost about up to 3 percent of its salt rejection. The following conclusions ensued from the study: (i) UF membrane is an excellent pre-treatment alternative for secondary effluent feed to RO, (ii) cleaning of the RO membrane was necessary because of too high recovery operation mode, (iii) after cleaning, the RO membranes kept the original normalized permeate flow, and; (iv) the change in normalized salt rejection is not necessarily associated with biological growth and the suspected cause is the adsorption of colloidal heavy metal matter on the membrane.

Salinity distribution in the soil

Salinity distribution in the soil as expressed by the EC is shown for one date in figure 4. This figure shows the change in salinity with depth and time: (i) the relatively low salinity in the active root zone for all treatments in which RO effluent combinations were applied; (ii) the highest salinity was for the effluent from the reservoir, and; (iii) there is probably a leaching process with time of irrigation by RO permeate and secondary effluent with ODI technology. The superior salinity conditions in the soil for the conditions of RO effluent application, only emphasize the importance of the dissolved scolds removal from the secondary effluent.

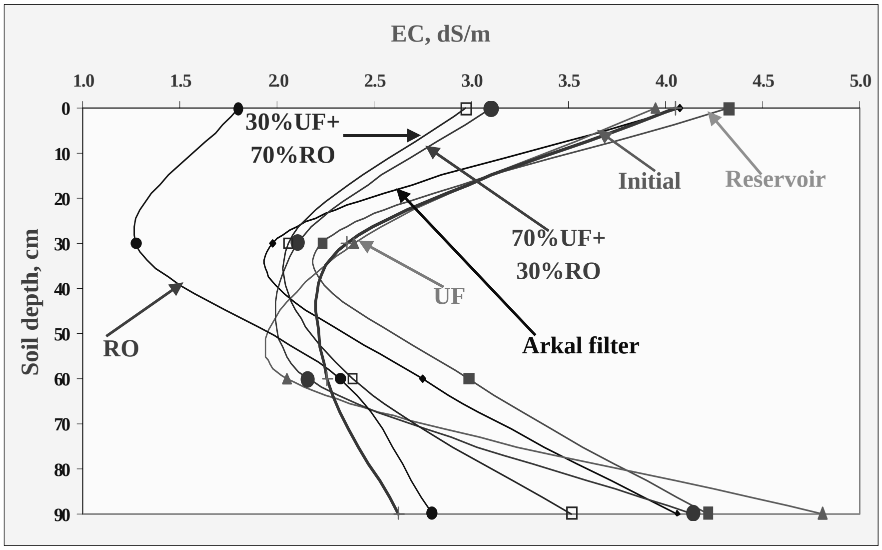


Figure 4. Soil salinity subject to various effluent applications in the Arad experiments, 2003 and 2004

The Agricultural Yields Indicators

The potatoes yield (December 2003) and corn yield (August 2004) were assessed by taking several samples of each treatment in an area of 2 m^2. These preliminary results indicate two the trend of leaching process effects attained during irrigation by blending RO permeate and common secondary effluent the relative low salinity in the active root. It is indeed too early to provide a clear idea concerning the actual yields of the corn and the potatoes. However, some indications are given by the corn plants height and stem diameters (figures). A great advantage could be found under most conditions for the RO effluent with the different levels of UF fractions. The preliminary results comply with previous findings, emphasizing the role of salinity in agricultural production (Hoffman et al., 1986; Hill and Koenig, 1999). Additional work is in progress to confirm these findings.

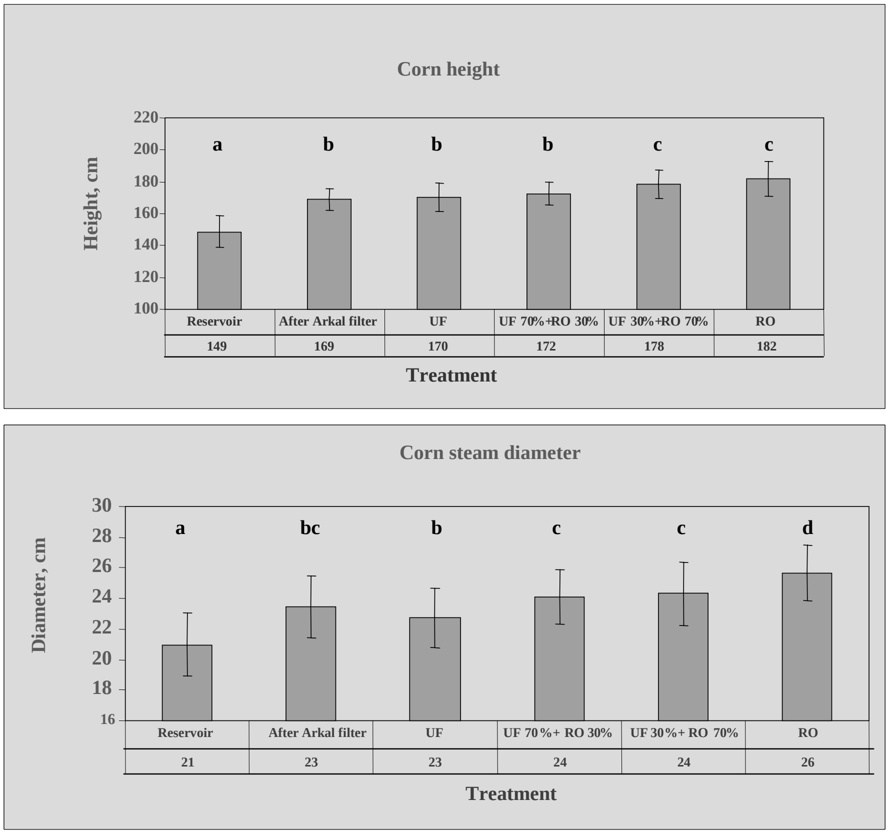


Figure 5. Indication of the corn development, July-August 2004, Arad experiments

ECONOMIC ASSESEMENT

Economic assessment of the proposed production system is based on defining an objective function (in this work an expression for the water cost) to be optimized, subject to a series of technological, environmental, chemical and operational constraints. The components of the objective function include the selection of the pretreatment method and membrane type, pretreatment costs and RO costs necessary to attain a definite permeate quality, transportation brine disposal and permeate storage costs, cost (or profit) for operation and maintenance expenses, design and contingency expenses. The objective (cost) function for UF and RO plants are given by the following general expressions:

$$\begin{bmatrix}\text{UF permeate}\\ \text{Optimal}\\ \text{Cost}\end{bmatrix} = \begin{bmatrix}\text{Effluent}\\ \text{Water}\\ \text{Cost}\end{bmatrix} + \begin{bmatrix}\text{Cost of}\\ \text{UF}\\ \text{Pretreatment}\end{bmatrix} + \begin{bmatrix}\text{Cost of}\\ \text{UF}\\ \text{Unit}\end{bmatrix} + \begin{bmatrix}\text{O \& M}\\ \text{UF}\\ \text{Expenses}\end{bmatrix} + \begin{bmatrix}\text{Cost of}\\ \text{Brine}\\ \text{Disposal}\end{bmatrix} - \begin{bmatrix}\text{Return}\\ \text{for}\\ \text{Permeate}\end{bmatrix}$$

(3)

$$\begin{bmatrix}\text{RO permeate}\\ \text{Optimal}\\ \text{Cost}\end{bmatrix} = \begin{bmatrix}\text{Feed}\\ \text{Water}\\ \text{Cost}\end{bmatrix} + \begin{bmatrix}\text{Cost of}\\ \text{RO}\\ \text{Pretreatment}\end{bmatrix} + \begin{bmatrix}\text{Cost of}\\ \text{RO}\\ \text{Unit}\end{bmatrix} + \begin{bmatrix}\text{O \& M}\\ \text{RO}\\ \text{Expenses}\end{bmatrix} + \begin{bmatrix}\text{Cost of}\\ \text{Brine}\\ \text{Disposal}\end{bmatrix} - \begin{bmatrix}\text{Return}\\ \text{for RO}\\ \text{Permeate}\end{bmatrix}$$

(4)

Selection of the pretreatment method and membrane type takes into account the designed plant capacity, permeate salinity and experimental results in pilot plants. Commonly, selection of the treatment method and successively the membrane type is associated with defining of a set of Boolean variable, receiving 0,1 values only (Oron, 1979). The constraints define a feasible domain in the decision space and refer to the capacity of the system (both storage and flow rates) and energy losses. The objective function and the constraints are given by a set of linear equations. Consequently it allows using commercial available PC software to obtain an optimal value for the objective function and the decision variables (Tora, 1992).

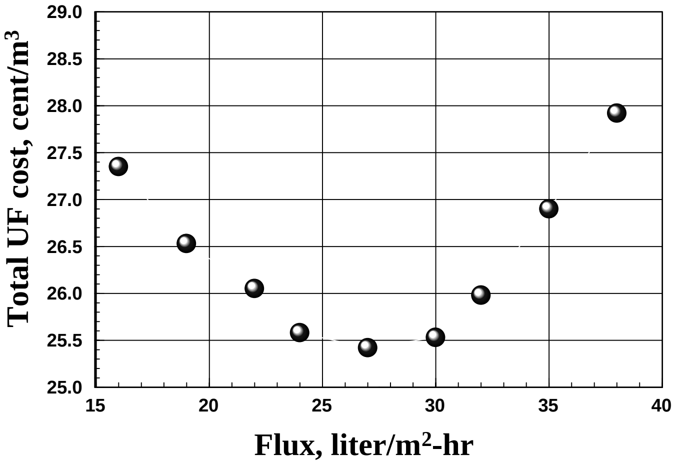


Figure 5. The extra UF cost for a treatment plant with a capacity of 20,000 m^3/day

The field data was used to define management model for economic assessment. The model is based on production of 20,000 m^3/day UF permeates at 95 percent recovery (membrane life span 4 years, interest rate 3.5%, electricity cost 0.062 \$/kWh). Sensitivity analysis and assuming wastewater treatment to a secondary level at a cost 15 US cent/ m^3) indicates that the extra cost for effluent polishing via the UF stage only is in the range of 5 to 15 US cents/m^3. Similarly, and using RO software (Rodesign, 1998; Rosa, 1993) shoes that the extra RO treatment cost is in the range of 10 to 15 US cents/m^3. These findings coincide with previous works (Wilf *et al*., 2001; Laine *et al.*, 2000).

CONCLUSIONS

The performance of hybrid UF and RO membrane systems for treatment of secondary effluent proved that the technology is promising towards efficient removal of pathogens and nutrients. Several directions and tendencies can be emphasized: (i) UF membranes are very effective for removing soluble organic particles including coliform bacteria and control of RO fouling, and (ii) the UF permeate quality meets health regulations for unlimited irrigation. Consequently, the risk of consuming agricultural products irrigated with UF reclaimed effluent is minimal. The UF stage appears to be as effective as disinfection for the removal of pathogens from secondary effluent. Applying RO permeate for irrigation has contributive leaching effects in the active root zone along with improved yields. Using different mixtures of secondary effluent, UF and RO permeates will still allow applying the effluent for unrestricted use and maintain low extra expenses.

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