Reclaiming Potable Quality Water from Impaired Waters by Low Temperature Distillation Method

Veera Gnaneswar Gude† and N. Nirmalakhandan*

ABSTRACT

The feasibility of a solar-powered process for reclaiming high quality water from municipal wastewater treatment plant effluents is proposed. In the proposed process, barometric head is utilized to maintain near-vacuum level pressures in an evaporation chamber without any mechanical energy input. Under such low pressures, water can be evaporated at 45 to 50^{o}C and condensed to yield product water. The energy required to maintain this temperature can be obtained from direct solar insolation and/or through photovoltaic modules to charge a bank of batteries to power DC electric heaters. This system was able to reclaim 12 L/day of product water continuously, without any energy input from the grid. Quality of the product water exceeded the US EPA drinking water standards. Removal of key contaminants form the effluent were as follows: total dissolved solids from 727 m/L to 21 mg/L (97%); > nitrates frm 2.4 mg/L to 0.1 mg/L (>95%); > ammonia from 23.2 to 0.5 mg/L (>97%); and coliform bacteria from 77 mg/L to 1 mg/L (>98%).

INTRODUCTION

Demand for water to meet potable, commercial, and industrial needs has been increasing world-wide due to population growth and rapid industrialization. Meeting this demand for today's society as well as ensuring adequate supplies for future generations is a major problem locally, regionally, and world-wide. This problem is compounded by dwindling sources of appropriate quantity and quality due to impairment by natural and man-made pollution. Even though several technologies are available for restoring impaired waters, most of them are not sustainable in that they consume nonrenewable energy sources and contribute to environmental harm, directly or indirectly. Since water is essential to continued existence of life, it is critical to develop alternate water sources one hand and, sustainable technologies on the other, to ensure that water demands of future generations can be met utilizing renewable resources.

The goal of this study was to demonstrate the feasibility of a solar-energy driven process that has the potential to produce high quality water from impaired waters in a sustainable manner. The proposed system is based on a low-pressure phase-change desalination process that could be driven by low grade heat sources (Al-Kharabsheh & Goswami, 2003a; Al-Kharabsheh & Goswami, 2003b; Al-Kharabsheh & Goswami, 2004). We have developed refinements of this process for utilizing waste heat sources as well as solar energy on a continuous basis (Gude, 2007; Gude & Nirmalakhandan, 2008a, 2008b, 2008c).

Proposed process configuration

The premise of the proposed approach can be illustrated by considering two barometric columns at ambient temperature, one with freshwater and one with feed water. The head space of these two columns will be occupied by the vapors of the respective fluids at their respective vapor pressures. If the two head spaces are connected to one another, water vapor will distill spontaneously from the freshwater column into the feed water column because the vapor pressure of freshwater is slightly higher than that of feed water at ambient temperature. However, if the temperature of the feed water column is maintained slightly higher than that of the fresh water column to raise the vapor pressure of the feed waterside above that of the fresh waterside, water vapor from the feed water column will distill into the fresh water column. A temperature differential of about 15ºC is adequate to overcome the vapor pressure differential to drive this distillation process. Such low temperature differentials can be achieved using low grade heat sources such as solar energy, waste process heat, thermal energy storage systems etc.

A schematic arrangement of a distillation system based on the above principles is shown in Figure 1. Components of this unit include an evaporation chamber (EC), a natural draft condenser, heat exchanger, and three barometric columns. These three columns serve as the feed water column; the waste withdrawal column; and the freshwater column, each with its own constant-level holding tank. These holding tanks are installed at ground level while the EC is installed atop the feed water and waste withdrawal columns at the barometric height of about 10 m above the free surface in the holding tanks to create a Torricelli's vacuum in the headspace of the EC. The top of the freshwater column is connected to the outlet of the condenser. When the temperature of the feed water in the EC is increased by about 10-20ºC above ambient temperature, water vapor will flow from the evaporator to the condenser where it will condense and flow into the freshwater column. By maintaining constant levels in the holding tanks with suitable withdrawal rates of waste and distilled water, this configuration enables the desalination process to be run without any mechanical energy input for fluid transfer or holding the vacuum. The purpose of the heat exchanger is to preheat the feed water by the waste stream withdrawn from the evaporation chamber.

The prototype scale system tested in this study had an evaporator area of 1.0 m^2 and photovoltaic panel area of 6 m^2. The heat energy required to maintain the evaporation chamber at the desired temperature was provided by a 12-V/18-W DC heater, which was powered by a bank of batteries, which were charged by the photovoltaic panels. Ambient temperature was measured by a thermocouple with an accuracy of ± 0.2%. Evaporation chamber temperature was set at various values and was measured by a thermocouple with an accuracy of ± 0.2%. Evaporation chamber pressure and condenser pressure were measured using pressure transducers with an accuracy of ± 0.3%. The power consumption was calculated from voltage and current measurements. A Campbell scientific data logger recorded the process data at ten-minute intervals. The depth of water in the evaporation chamber was fixed at 0.05 m. A rain gauge sensor with an accuracy of ± 1% was used to measure freshwater production rate.

RESULTS

Typical temperature and pressure profiles over a 24-hr period shown in Figure 2 demonstrate the practical feasibility of the concept. These results were obtained with a set evaporation temperature of 50^{o}C. The measured evaporation temperature varied between 42 and 49^{o}C due to fugitive losses. As can be seen from this figure, the system maintained a low pressure of 0.082 atm. without any mechanical energy input.

One of the key variables in this process is the temperature of the evaporation chamber. An analysis of the process based on the first law of thermodynamics shows that freshwater production rate is a direct function of the evaporation chamber temperature. However, higher evaporation chamber temperatures demand higher energy requirements to satisfy the sensible and the latent heat loads. A more relevant parameter to be considered in this evaluation is the specific energy, defined here as the energy requirement per unit mass of freshwater produced. First law analysis shows that specific energy can be reduced by lowering the evaporation temperature. Experimental results relating evaporation temperature, freshwater production rate, and specific energy illustrated in Figure 3 agree with the first law analysis and show the advantage of low temperature operation, made possible through the proposed concept. Other benefits of low temperature distillation include smaller PV array size, smaller battery bank, shorter start-up time, lower scaling and corrosion rates.

Water quality analysis of feed water and product water are summarized in Table I. This summary shows that this process has the potential to recover high quality water from typical municipal wastewater treatment plant effluents.

CONCLUSIONS

This system produced 12 L/day of reclaimed water continuously, without any energy input from the grid. Water quality analysis of the product water exceeded the US EPA drinking water standards. Removal efficiencies of key contaminants were s follows: > 93% total dissolved solids; >95% nitrates; > 97% ammonia; and > 99.9% coliform bacteria. The paper will include details of the proposed system and the experimental procedures and the results.

ACKNOWLEDGEMENT

This research was funded by a grant from the New Mexico Water Resources Research Institute.

BIBILIOGRAPHY

1. Al-Kharabsheh, S. & Goswami, D.Y., "Experimental study of an Innovative solar water desalination system utilizing a passive vacuum technique", *Solar Energy*, 75, 395-401, 2003.
2. Al-Kharabsheh, S. & Goswami, D.Y., "Analysis of an innovative water desalination system using low-grade solar heat", *Desalination*, 156, 323-332, 2003.
3. Al-Kharabsheh, S. and Goswami, D.Y., "Theoretical analysis of a water desalination system using low grade heat", *J. Solar Energy Engrg*., 126, 774-780, 2004.
4. Gude, V., Desalination using low grade heat sources, PhD Dissertation, New Mexico State University, Las Cruces, NM, 2007.
5. Gude, V. and Nirmalakhandan, N., Desalination using low-grade heat sources, *ASCE J Energy Engrg*., 134, 3, 95-101, 2008.
6. Gude, V. and Nirmalakhandan, N., Combined desalination and solar-assisted air-conditioning system, *Energy Conv. & Management*, 49, 3326-3330, 2008.
7. Gude, V. and Nirmalakhandan, N., Desalination at low temperatures and low pressures, To appear in *Desalination*, 2008.

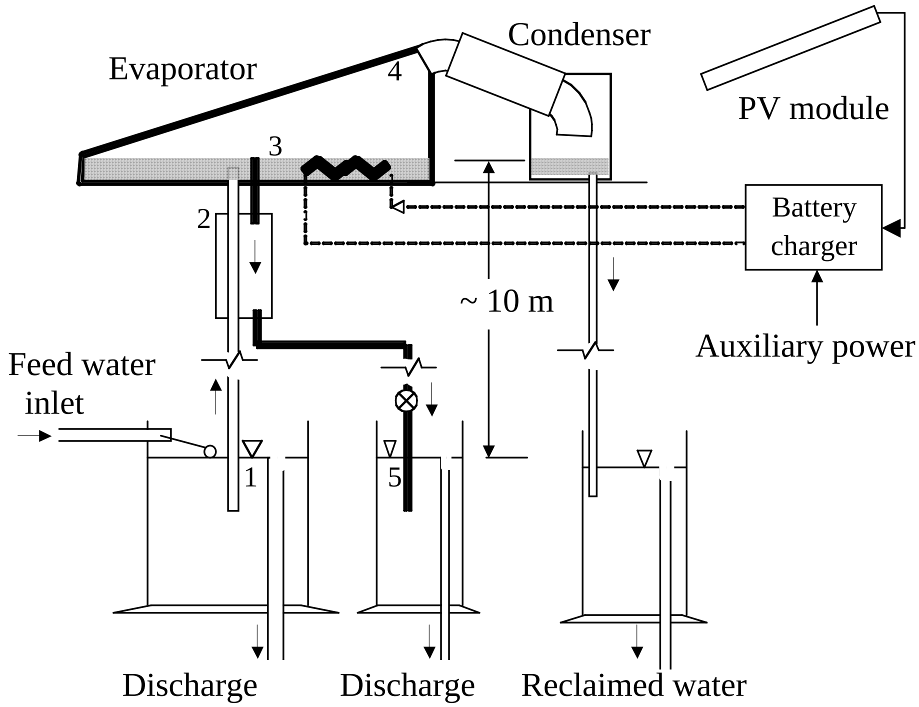

Figure 1. Schematic of process configuration

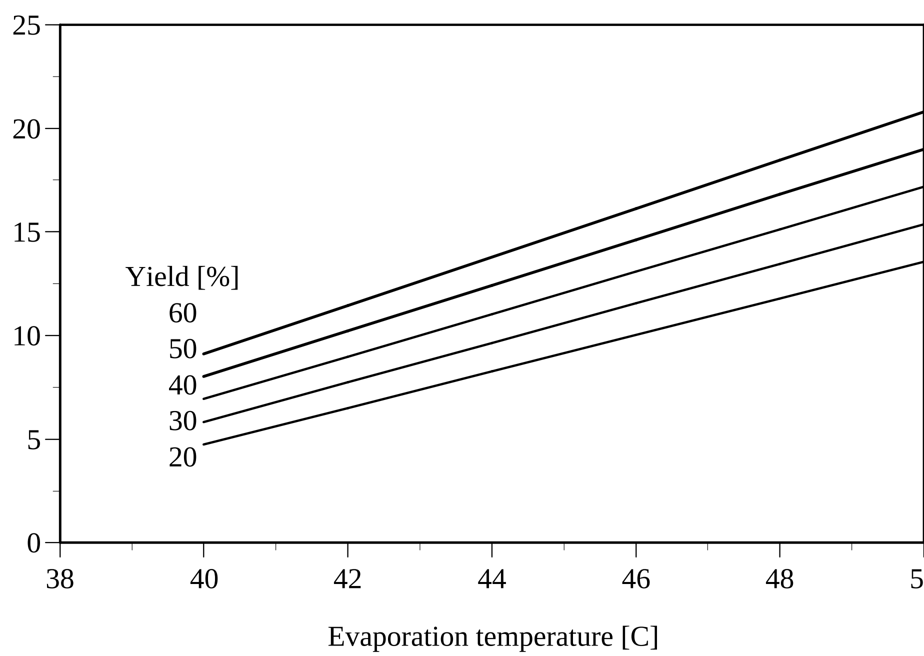

Figure 2. Relationship between PV array area/evaporator area, product yield, and evaporation temperature

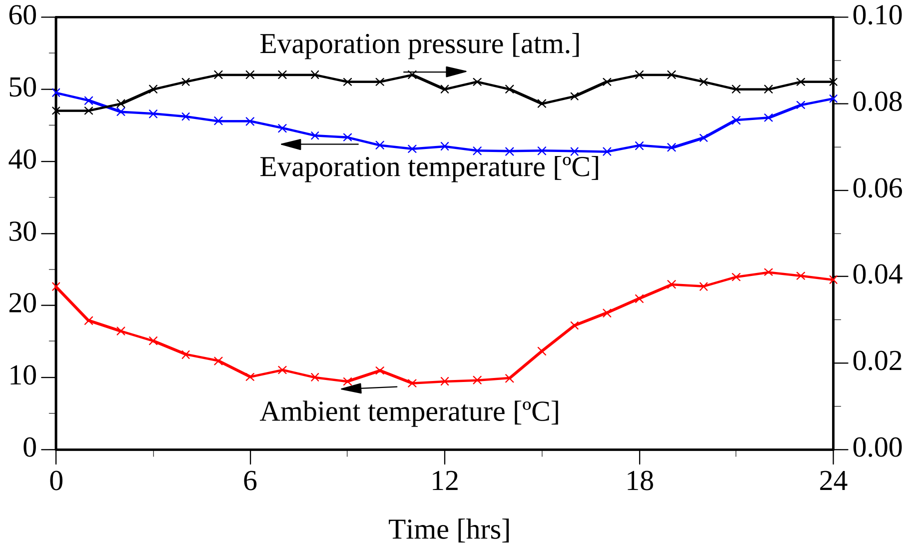

Figure 3. Typical temperature and pressure profiles over 24-hrs.

Table I. Water quality measures before and after treatment

Water quality measure	WWTP effluent	Product water	US EPA Standards
BOD (mg/L)	9.7	-	
TSS (mg/L)	5.1	< 1	
TDS (mg/L)	727	21	500
Nitrates/nitrites(mg/L)	2.4	< 0.1	1
NH_3(mg/L)	23.2	< 0.5	
Chlorides (mg/L)	0	0	4
Coliform (cfu/100)	77	< 1	0
pH	7.1	7.1	6.5-8.5