UNIVERSITY OF FLORIDA

Clean Drinking Water using Advanced Solar Energy Technologies

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Description: Water and energy scarcity poses a future threat to human activity and societal development around the world. The state of Florida is vulnerable to fresh water shortages. Florida ground water is contaminated in many locations from leaky underground tanks, agricultural pesticides, and other chemicals. Although it is possible to desalinate sea water, conventional systems are energy intensive. Solar energy utilization for desalination systems is being investigated to provide adequate fresh water for the state’s needs. Solar diffusion driven desalination (DDD) system has been developed for both bulk water desalination and small community needs/disaster response. Solar DDD may be a competitive method for small scale seawater desalination.
Budget: $252,000
Universities: UF
External Collaborators: NA

Progress Summary

Solar energy utilization for desalination systems is being investigated to provide adequate fresh water for the state of Florida. A solar diffusion driven desalination (DDD) system is developed for both bulk water desalination and small community needs/disaster response. A theoretical model is developed to describe the heat and mass for the solar diffusion desalination process from the basic principles of mass and energy conservation. The developed model takes into account the transient variations in the water, air, and packed bed temperatures when it is subjected to a variable heat source such as a solar thermal collector. The transient theoretical model has been solved numerically, and a flat plat solar collector is modeled and used as the heat input to the desalination system. A laboratory scale desalination facility has been constructed to conduct a set of experiments to validate the theoretical models. It is found that the transient model has a good prediction capability in determining the evolution of the temperature profile within the evaporator and the condenser of the system. Theoretical modeling is useful as a design tool to identify the optimal operating conditions and improve the performance of the solar DDD system. The energy consumption of the solar DDD is 0.0023 kW-hr/kg$_{fw}$, which is low compared to other desalination technologies. Using the solar DDD system, it is possible to achieve fresh water production per solar collector area of more than 6 L/m^2-day. Solar DDD may be a competitive method for small scale seawater desalination.

1. A theoretical model is developed to describe the heat and mass for the solar diffusion desalination process from the basic principles of mass and energy conservation. The developed model takes into account the transient variations in the water, air, and packed bed temperatures when it is subjected to a variable heat source such as solar collector.
2. The transient theoretical model has been solved numerically.
3. The solar DDD is driven by flat plat solar collectors that harvest the solar thermal energy.
4. A Laboratory scale facility is constructed to conduct a set of experiments to validate the theoretical models.
5. It is found that the transient model has a good prediction capability in determining the evolution of the temperature profile within the evaporator and the condenser of the system.
6. A numerical study was carried out to investigate the thermal response of the solar DDD when operating in the transient mode.

7. A set of simulation runs were performed to study the theoretical model sensitivity to the liquid hold-up, packing wettability, and packing heat capacity.
8. The time response to reach a steady state for various parameters such as liquid volume fraction (hold up), packing wettability, and packed bed heat capacity are investigated to study their dynamic thermal behavior of the system.
9. The solar DDD water production can be improved by increasing the evaporator inlet water temperature.

2010 Annual Report

Water and energy scarcity poses a future threat to human activity and societal development around the world. Supplying sufficient quality water is essential to the development of any country. Seawater desalination offers an excellent option to meet freshwater needs. However, all of the conventional desalination technologies are energy intensive. Non-renewable energies, such as fossil fuel, are increasingly depleting, and extensive technological development for harnessing renewable energy is the only solution for energy and water shortage problems. Although solar energy utilization for seawater distillation is a promising option for solving fresh water shortage problems, some challenges associated with solar energy utilization arise, such as the intermittency of the solar energy, high cost of harnessing and storage which put a restraint on the utilization of alternative energy that makes it difficult to compete with non-renewable energy.

This research concerns a transient analysis of Solar Diffusion Driven Desalination process (Solar DDD). This low-temperature distillation process uses solar energy harvested with a flat plat collector that separates salt from seawater using direct contact evaporation and condensation. A schematic diagram of the Solar DDD system is shown in Fig. 1. In order to optimize the utilization of solar energy for seawater distillation, it is necessary at first to model the heat and mass transfer between the liquid, air and the packed bed in the direct-contact evaporator and condenser. The theoretical modeling enables understanding the underlying physics relating to heat and mass transfer between water, air and the packed bed. Further, the modeling enables testing the performance of solar DDD for various operating parameters such as the solar energy intensity, water and air flow rates, and size of seawater storage tank.

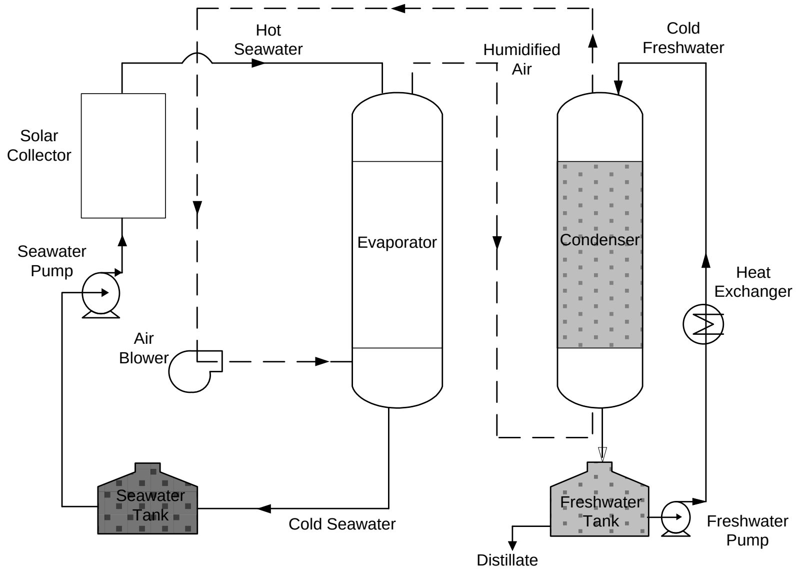
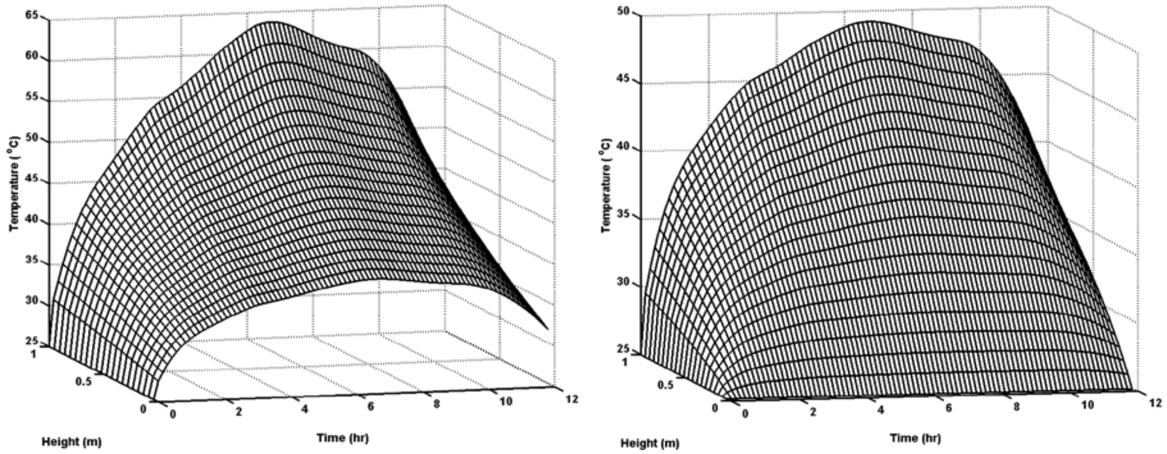


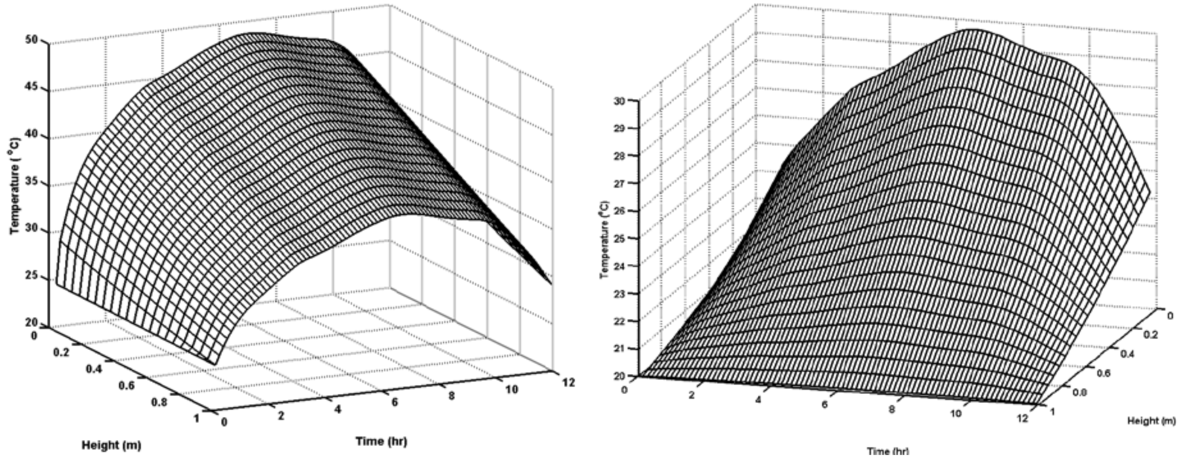
Figure 1 Solar Diffusion Driven Desalination

Theoretical models describing the transient heat and mass transfer within the evaporator and condenser have been developed based on conservation principles. The developed models take into account the transient variations in the water, air, and packed bed temperatures when it is subjected to a variable heat source such as solar collector. A numerical scheme has been implemented using a finite difference method to solve for the water and air temperatures and humidity ratio profiles in the evaporator and the condenser. It is found that the transient model has a good prediction capability in determining the evolution of the temperature profile within the evaporator and the condenser. Figs. 2 and 3 depict the water and air temperature profiles in the evaporator and condenser, respectively for a typical set of operating conditions, L = 1 kg/m^2-sec, gas mass flux G = 0.5 kg/m^2-sec, H = 1 m, $T_{a,evap,in}$ = 25 ^{o}C, T_{amb} = 25 ^{o}C (evaporator) and L = 2.0 kg/m^2-sec, G = 0.5 kg/m^2-sec, H = 1 m, $T_{L,cond,in}$ = 20 ^{o}C (condenser).



(a) Water (b) Air

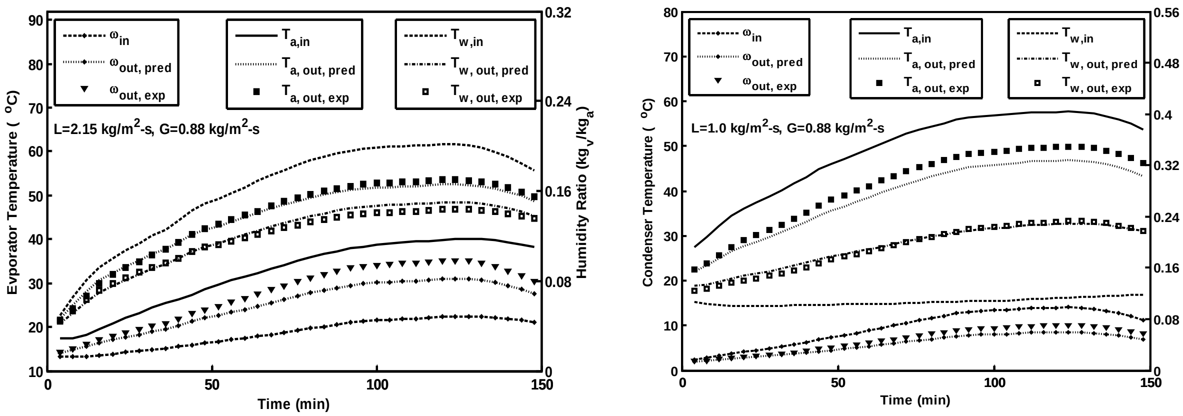
Figure 2. Temporal and spatial water and air temperature distribution along the height of the evaporator.



(a) Water (b) Air

Figure 3. Temporal and spatial water and air temperature distribution along the height of the condenser.

A laboratory scale Solar DDD system is fabricated to study the feasibility of utilizing a solar collector to power the DDD process. The solar collector is simulated via an electric heater controlled via Pulse-Width Modulation (PWM) method. Solar data for a typical summer day is used in the simulations. Solar thermal power for the city of Jacksonville, Florida is used. A set of experiments are conducted to validate the transient models of the solar DDD. Fig. 4 compares the computed and measured water and air temperatures entering and exiting the evaporator and condenser and humidity ratio for different air mass fluxes. From the comparison made between the numerical and measured temperatures and humidity ratio profiles, it is shown that the transient model has good predictive capability for the thermal and mass transport within the evaporator and condenser.



(a) Evaporator

(b) Condenser

Figure 4. Evaporator and condenser transient temperatures and humidity ratios variation.

A numerical study was carried out to investigate the thermal response of the solar DDD when operating in the transient mode. A set of simulation runs were performed to study the theoretical model sensitivity to the liquid hold-up, packing wettability, and packing heat capacity. The following conclusions are highlighted:

1. The response time for the exit liquid temperature is shorter for a low hold-up compared with higher hold-up. The steady-state exit temperatures are independent of the liquid hold-up.
2. Higher wettability of the packed bed has insignificant influence on the response time, but it does result in improved heat transfer with a higher exit air temperature and lower exit water temperature.
3. The response time for the exit air temperature is insensitive to the packing material. The steady state temperatures do not depend on the heat capacity of the packing material.

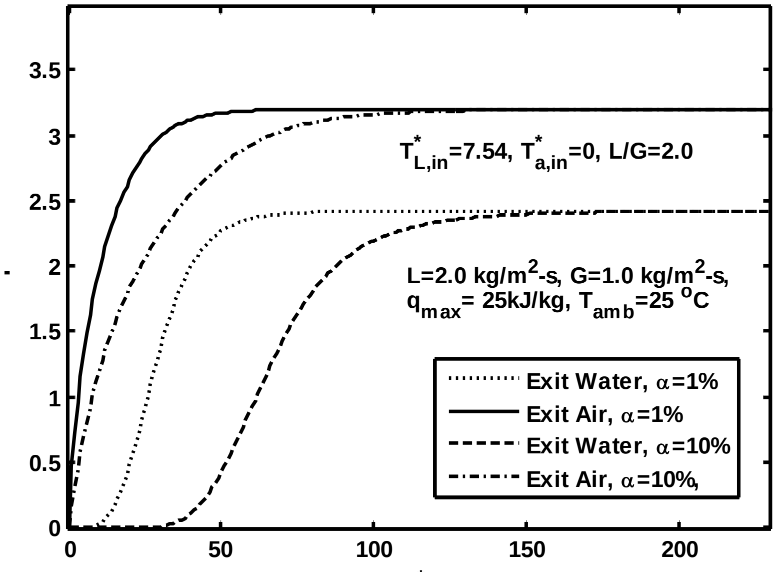


Figure 6 Dynamic response of evaporator exit water and air temperatures for different liquid hold-

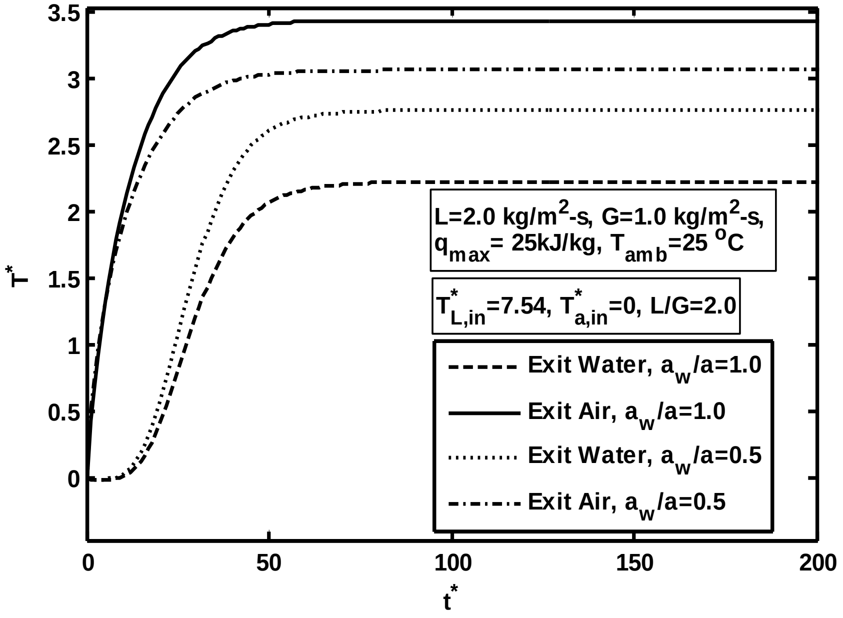


Figure 7 Dynamic response of evaporator exit water and air temperatures for a_w/a=0.5 and a_w/a=1.0.

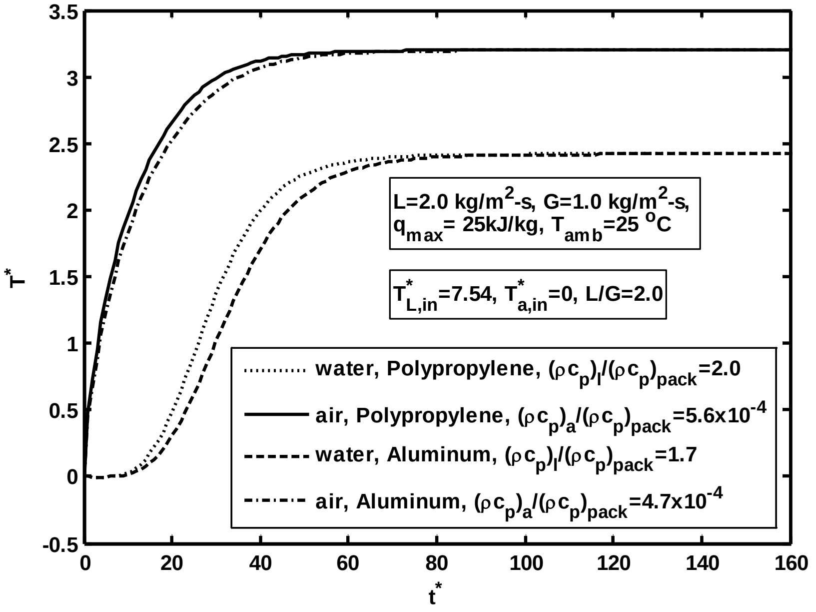


Figure 8 Evaporator exit water and air temperature for different packed bed material.

The transient behavior of the evaporation and condensation processes and storage tank have been examined. The solar DDD water production can be improved by increasing the evaporator inlet water temperature. The system water production per solar collector area can be improved to 7.5 L/m^2-day. It has been demonstrated that the system energy consumption can be reduced to as low as 1.65 kWh/m^3. It is believed that solar DDD can be promising for small scale applications.

This study gives better understanding of the evolution of the water, air/vapor, and packing temperature in the evaporator and condenser as time progress. The developed model provides a good predictive capability for the thermal and mass transport within the evaporator and condenser. The model is useful as a design tool to identify the optimal operating conditions and analyze the performance of direct contact evaporation and condensation processes with significant transient variation during the normal operation. The fundamental transient analysis should find utility in a broad variety of applications.