Low Cost Solar Driven Desalination

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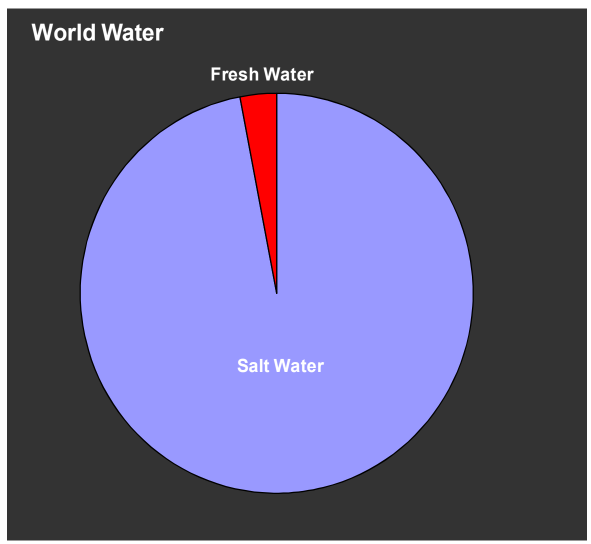
Outline

1. Motivation
2. Research Objectives
3. Experimental Investigation
4. Theoretical Developments
5. Numerical Solution
6. Conclusions

Water shortages

I. 97% of the water on the planet is saline

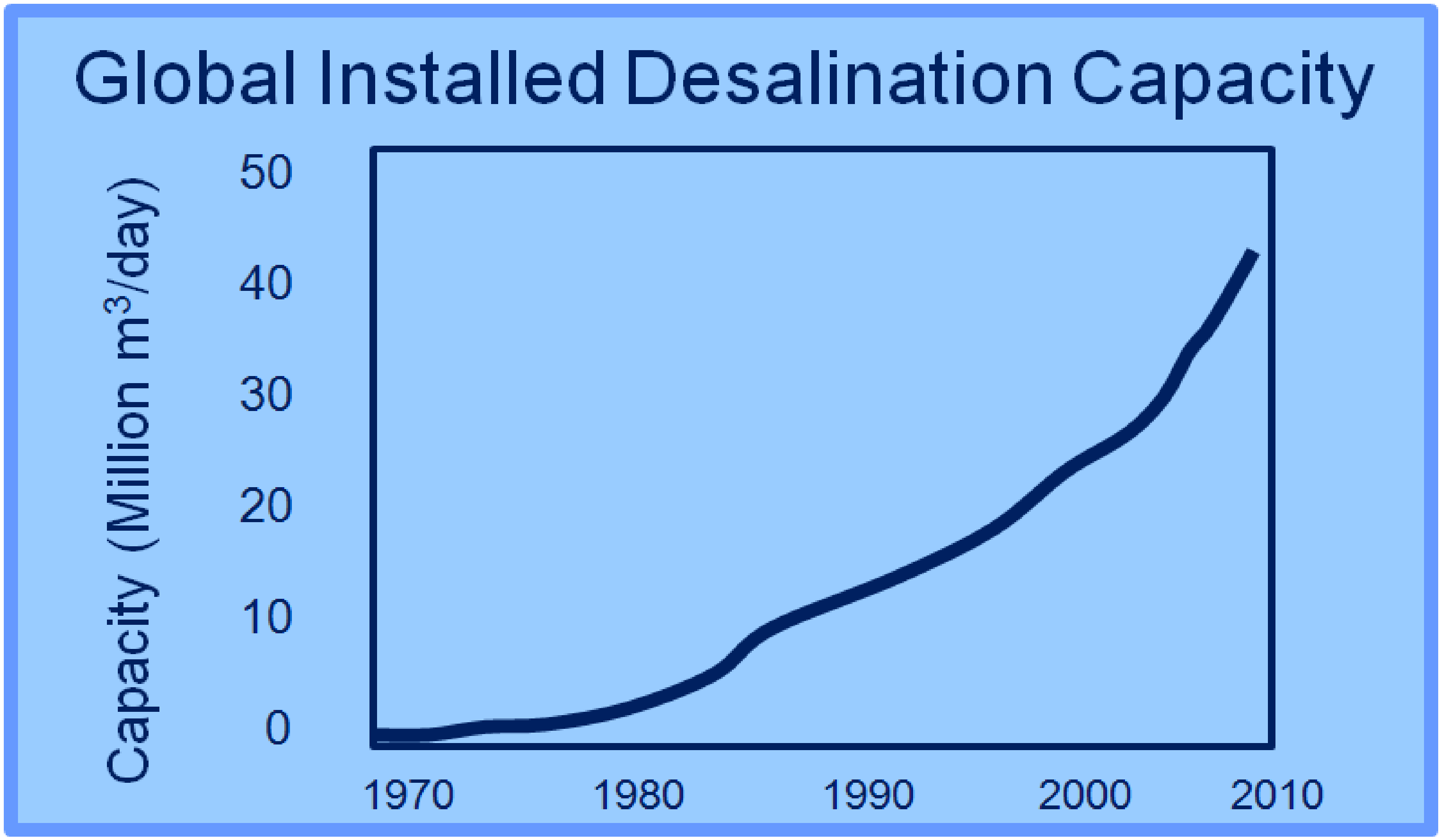
II. Desalination is the main source of water for arid countries and remote areas, and some islands



Desalination

More than 15,000 industrial-scale desalination unit

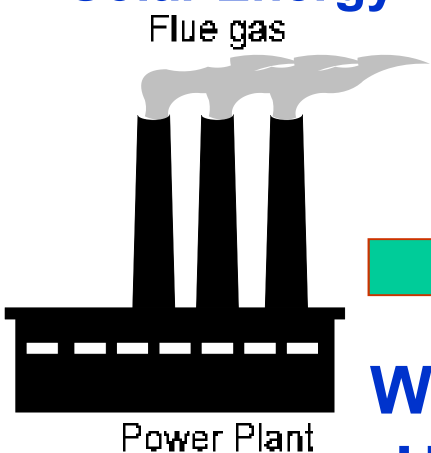
Total worldwide capacity is more than 40 million m^3/day



Diffusion Driven Desalination (DDD)

Develop a low cost small scale solar driven desalination system

Solar Energy



Waste Heat

- **Combustion Engine**
- **Oil Refinery**
- **Geothermal Energy**

DDD

Fresh Water

Sea Water

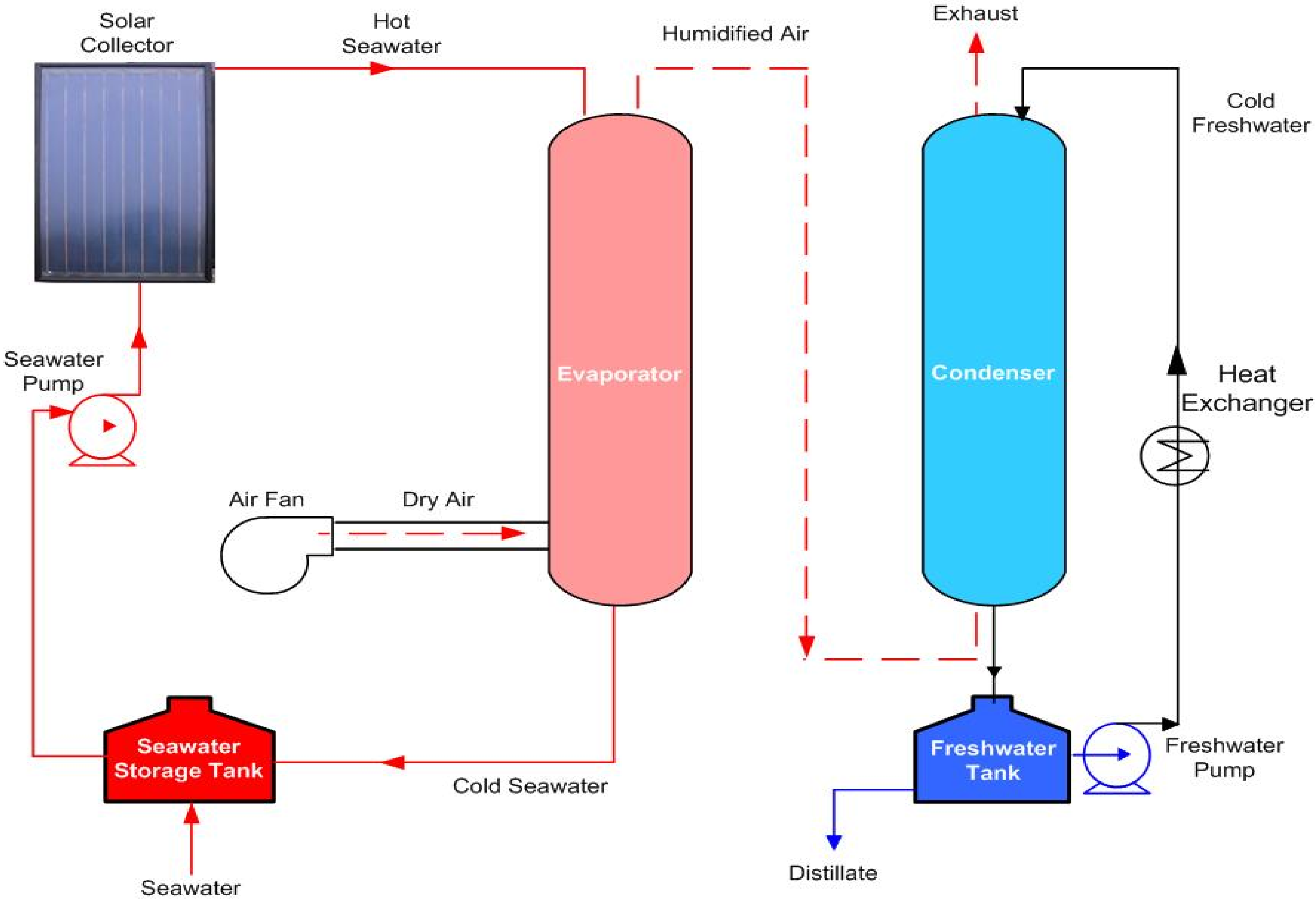
Solar Diffusion Driven Desalination

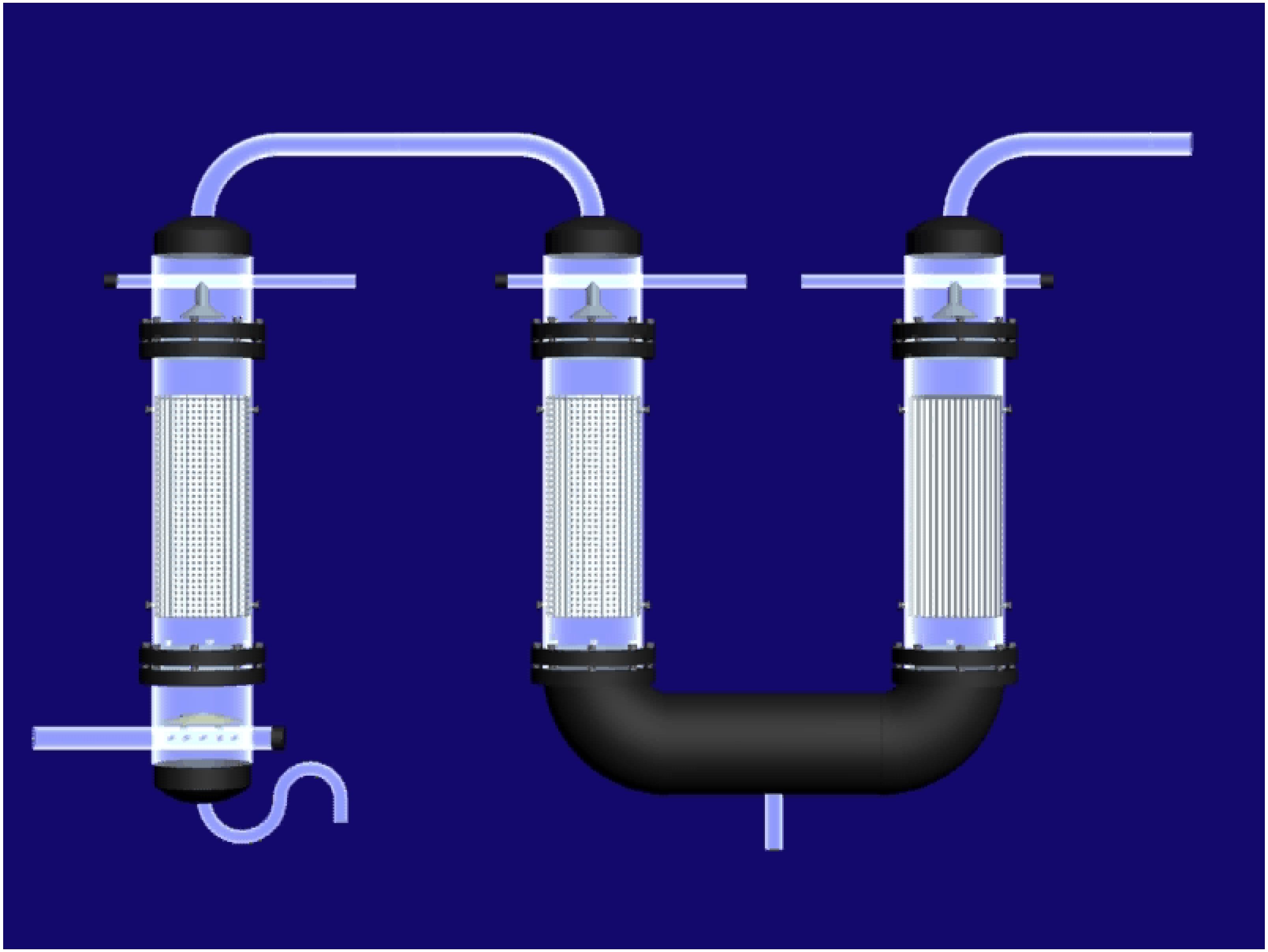
- Promising technology that use solar energy or waste heat to distill seawater

- Use direct contact evaporation and condensation

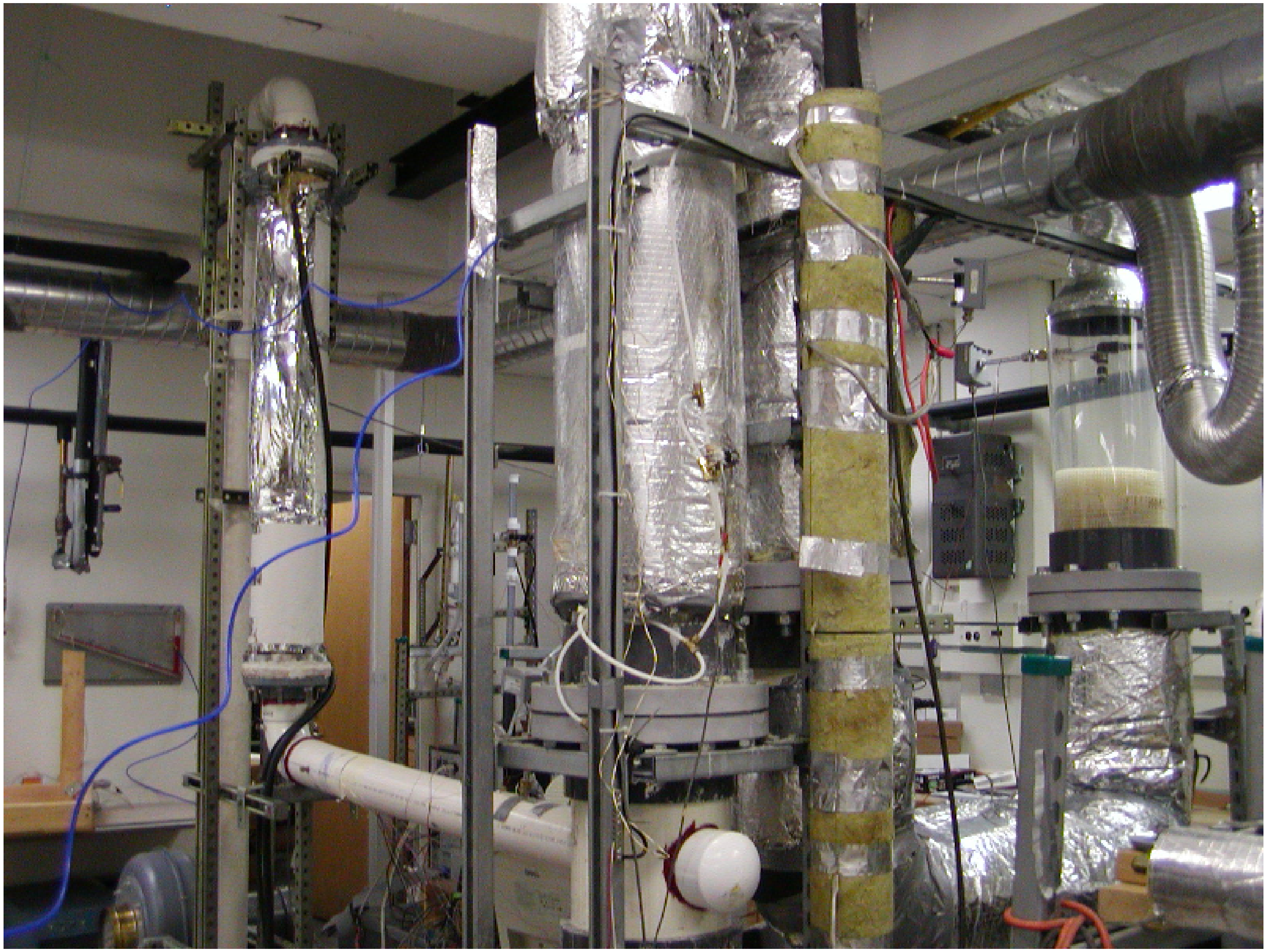
- Low-temperature distillation process with a low electrical energy consumption

Solar Diffusion Driven Desalination (DDD)



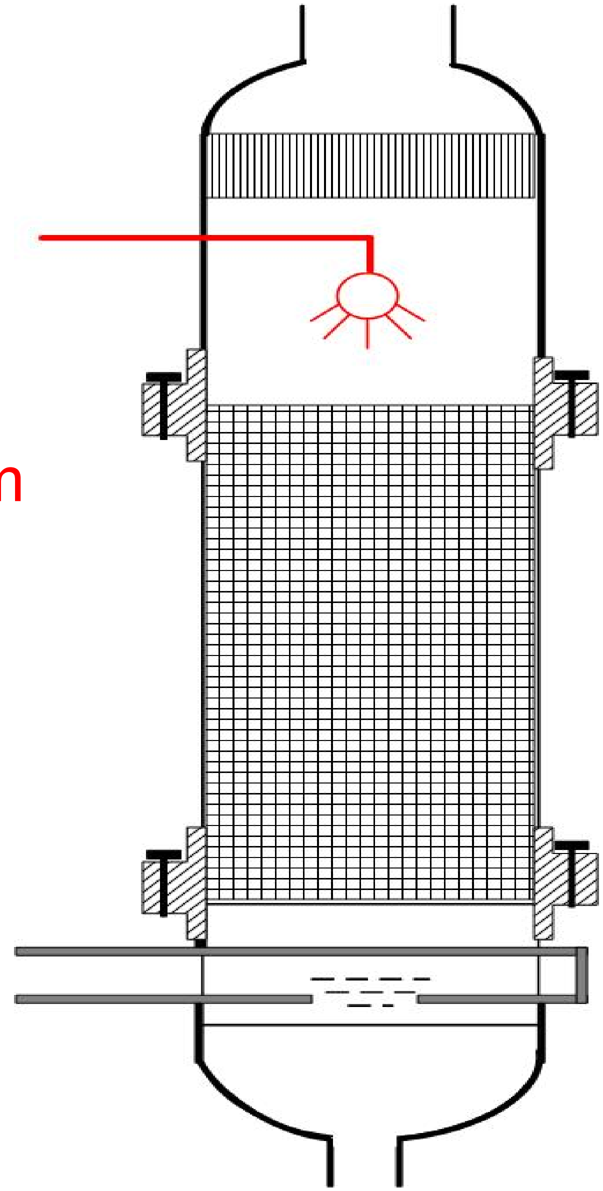


Experimental Investigation



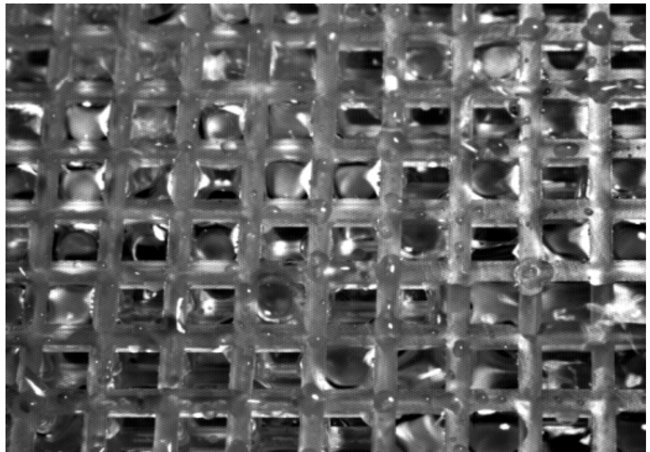
Experimental Investigation

H_{evap}=1.0 m
D=0.254 m

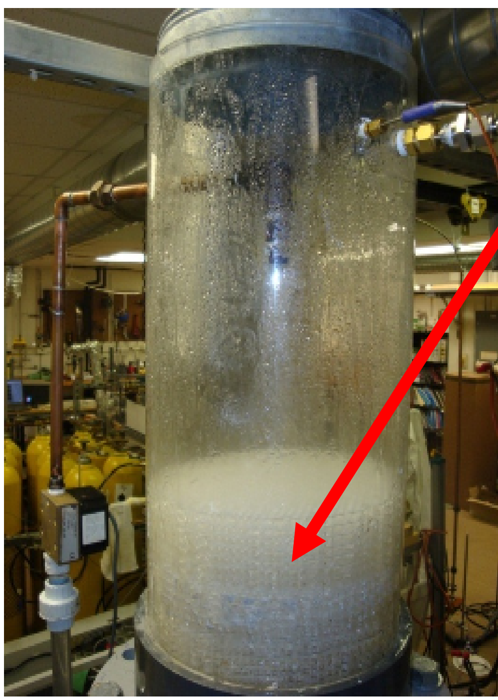


Experimental Investigation

Packed bed



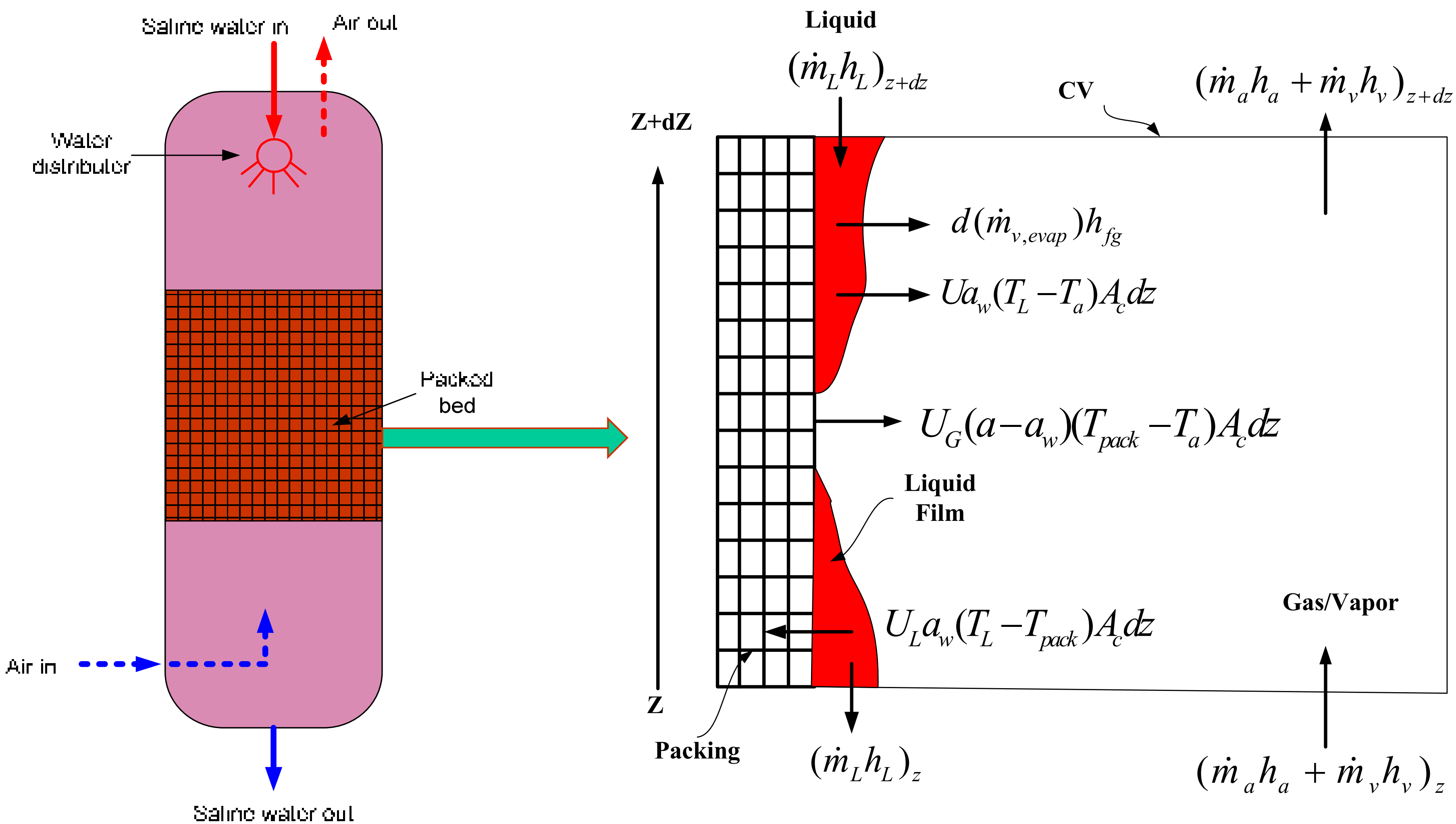
Condenser



Seawater Tank

Fresh Water Tank

Evaporator



Saline water in
Air out
Water distributor
Packed bed
Air in
Saline water out
Liquid
$(\dot{m}_L h_L)_{z+dz}$
CV
$(\dot{m}_a h_a + \dot{m}_v h_v)_{z+dz}$
Z+dZ
$d(\dot{m}_{v,evap})h_{fg}$
$Ua_w(T_L - T_a)A_c dz$
$U_G(a-a_w)(T_{pack} - T_a)A_c dz$
Liquid Film
$U_L a_w(T_L - T_{pack})A_c dz$
Gas/Vapor
Z
Packing
$(\dot{m}_L h_L)_z$
$(\dot{m}_a h_a + \dot{m}_v h_v)_z$

Theoretical Model-Transient

Evaporator

$$\frac{dT_L}{dt} = \frac{L}{\rho_L \alpha_L}\frac{dT_L}{dz} - \frac{d\omega}{dz}\frac{G(h_{Fg} - h_L)}{\rho_L \alpha_L Cp_L} - \frac{U_L a_w (T_L - T_{pack})}{\rho_L \alpha_L Cp_L} - \frac{U a_w (T_L - T_a)}{\rho_L \alpha_L Cp_L}$$

$$\frac{dT_a}{dt} = \frac{-G}{\rho_a \alpha_a}\frac{dT_a}{dz} - \frac{(h_{fg}(T_L) - h_v(T_a))G}{\rho_a \alpha_a (1+\omega) Cp_{mix}}\frac{d\omega}{dz} + \frac{U_G (a - a_w)}{\rho_a \alpha_a (1+\omega) Cp_{mix}}(T_{pack} - T_a)$$
$$+ \frac{U a_w}{\rho_a \alpha_a (1+\omega) Cp_{mix}}(T_L - T_a).$$

$$\frac{dT_{pack}}{dt} = \frac{1}{\rho_{pack}\alpha_{pack} Cp_{pack}}\left(U_L a_w (T_L - T_{pack}) - U_G (a - a_w)(T_{pack} - T_a)\right)$$

$$\frac{d\omega}{dz} = \frac{k_G a_w}{G}\frac{M_v}{R}\left(\frac{P_{sat}(T_i)}{T_i} - \frac{\omega}{0.622 + \omega}\frac{P}{T_a}\right)$$

Theoretical Model-Transient

Condenser

$$\frac{dT_L}{dt} = \frac{L}{\rho_L \alpha_L}\frac{dT_L}{dz} - \frac{d\omega}{dz}\frac{G(h_{Fg} - h_L)}{\rho_L \alpha_L Cp_L} + \frac{Ua_w(T_a - T_L)}{\rho_L \alpha_L Cp_L} + \frac{U_L a_w(T_{pack} - T_L)}{\rho_L \alpha_L Cp_L}$$

$$\frac{dT_a}{dt} = \frac{-G}{\rho_a \alpha_a}\frac{dT_a}{dz} - \frac{(h_{fg}(T_L) - h_v(T_a))G}{\rho_a \alpha_a (1+\omega) Cp_G}\frac{d\omega}{dz} - \frac{U_G(a - a_w)}{\rho_a \alpha_a (1+\omega) Cp_G}(T_a - T_{pack}) - \frac{Ua_w}{\rho_a \alpha_a (1+\omega) Cp_G}(T_a - T_L)$$

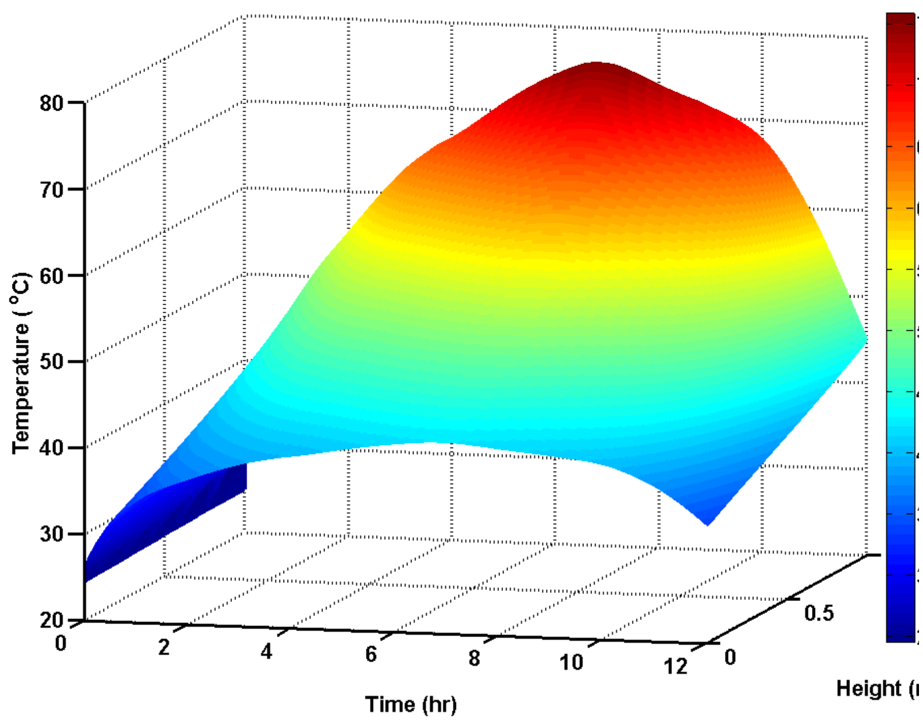
$$\frac{dT_{pack}}{dt} = \frac{1}{\rho_{pack}\alpha_{pack}Cp_{pack}}\left(U_G(a - a_w)(T_a - T_{pack}) - U_L a_w (T_{pack} - T_L)\right)$$

$$\frac{d\omega}{dz} = \frac{dT_a}{dz}\frac{P}{P - P_{sat}(T_a)}\omega_m(b - 2cT_a + 3dT_a^2)$$

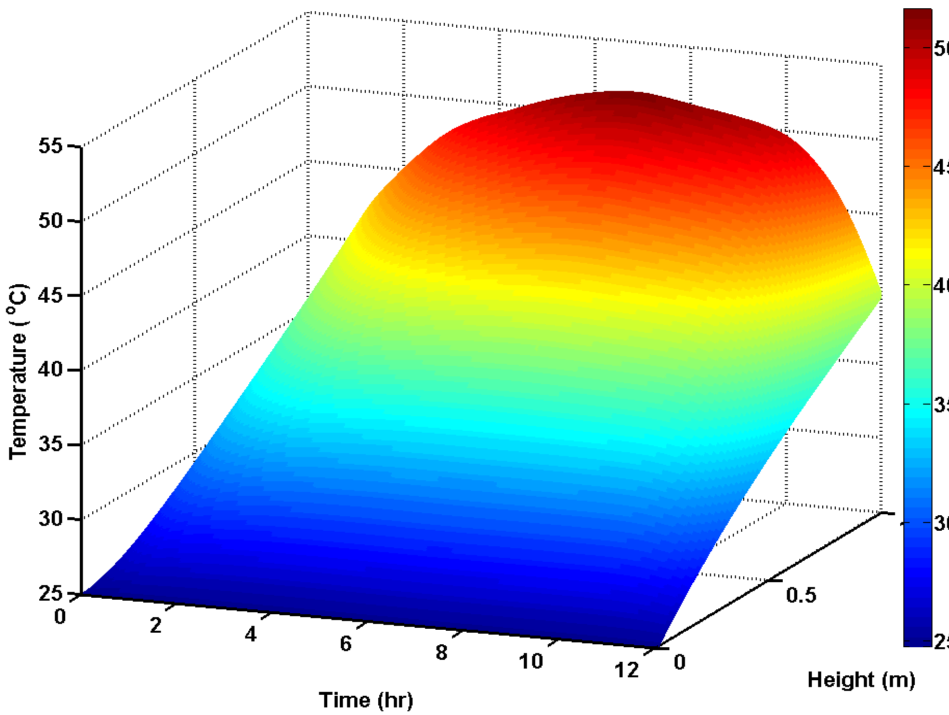
Numerical Solution-Evaporator

L=1.0 kg/m^2-sec, G=0.5 kg/m^2-sec

Water Temperature



Air Temperature

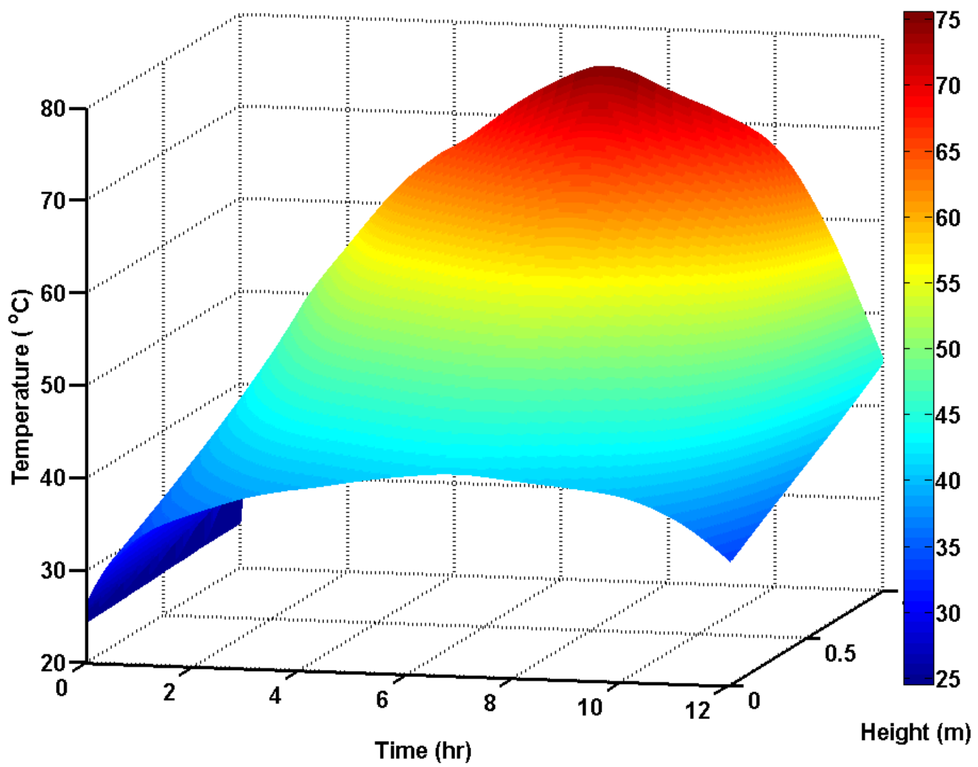


Time step=0.002 sec, grid size= 0.01 m

Numerical Solution-Evaporator

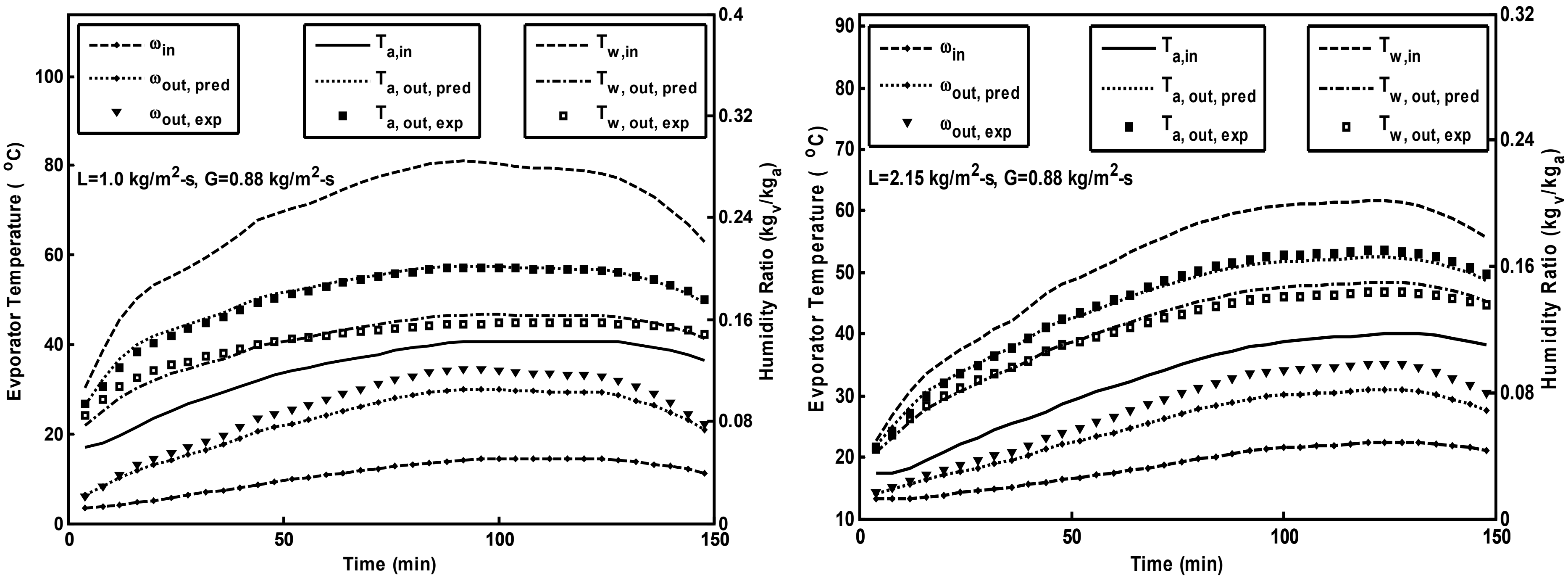
L=1.0 kg/m^2-sec, G=0.5 kg/m^2-sec

Packed bed Temperature



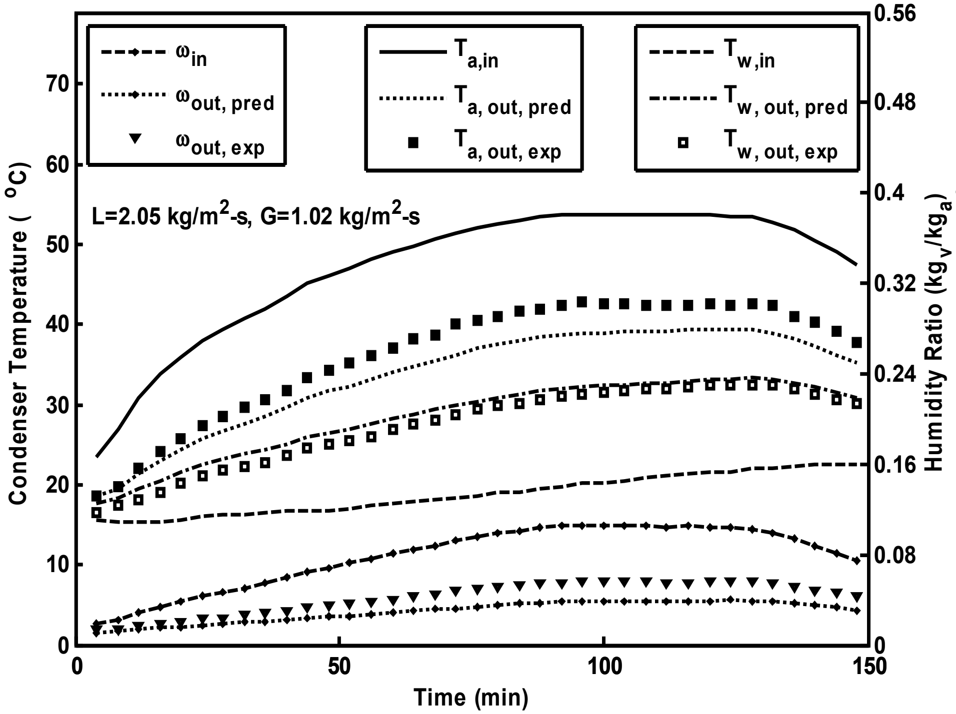
Evaporator- Num. vs. Exp.

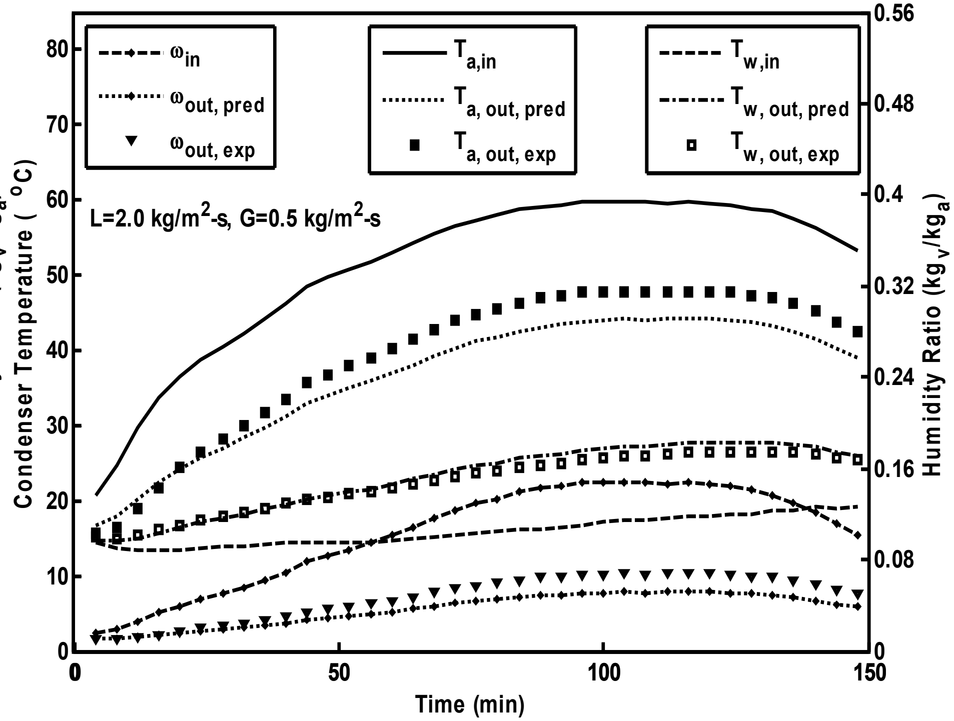
Water Flux: L=1.0, and 2.15 kg/m^2-sec



Condenser- Num. vs. Exp.

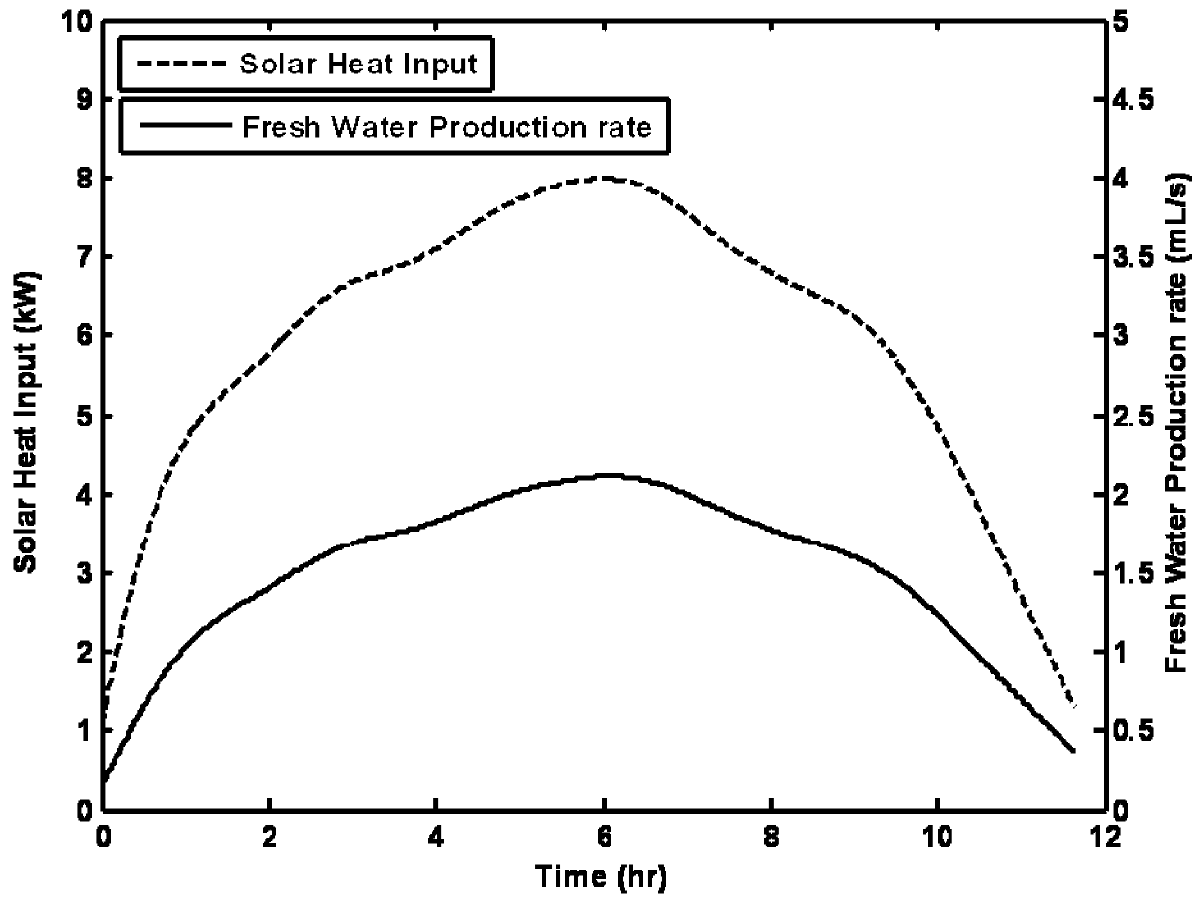
Gas Flux: G=0.5, and 1.02 kg/m²-sec





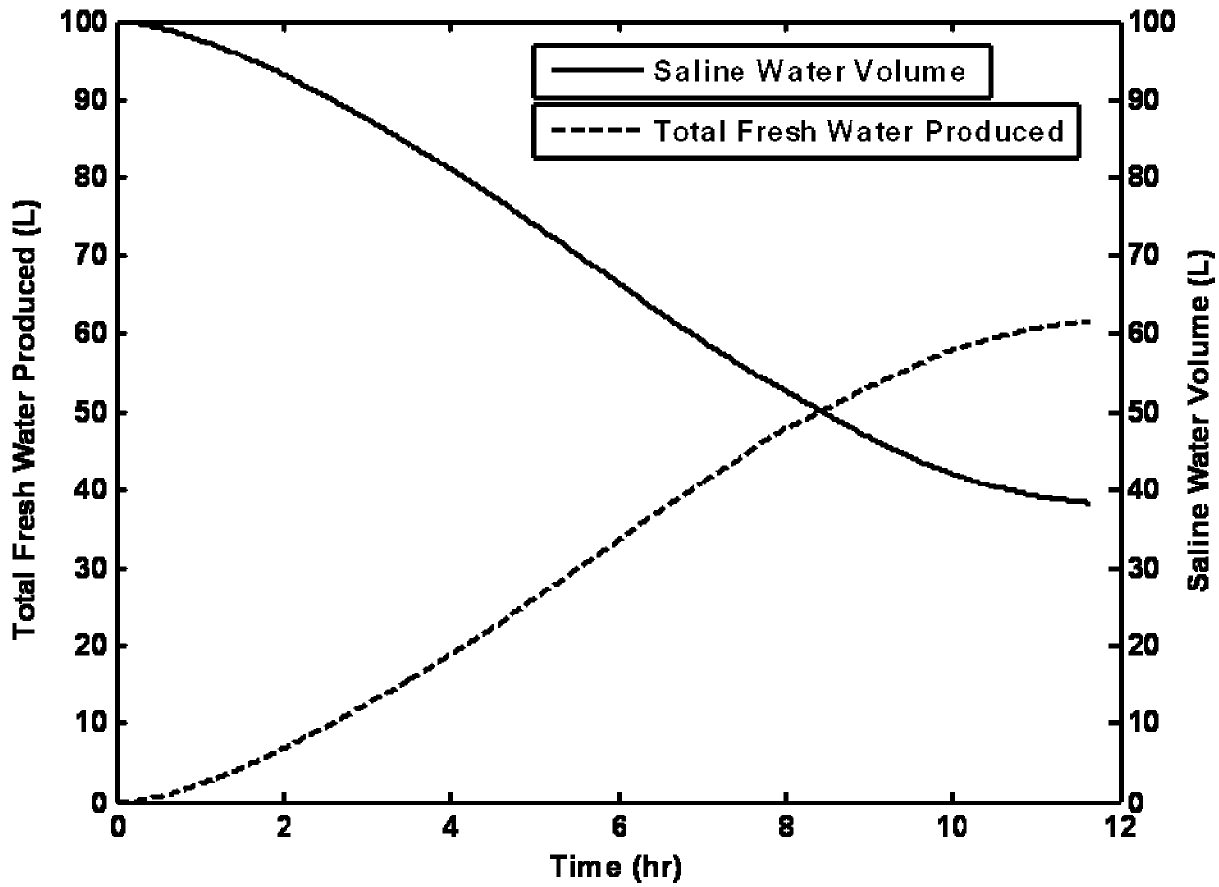
Water Production

L=1.5 kg/m^2-sec, G=1.5 kg/m^2-sec, $A_{solar,col}$=10 m^2,V_{tank}=100 L



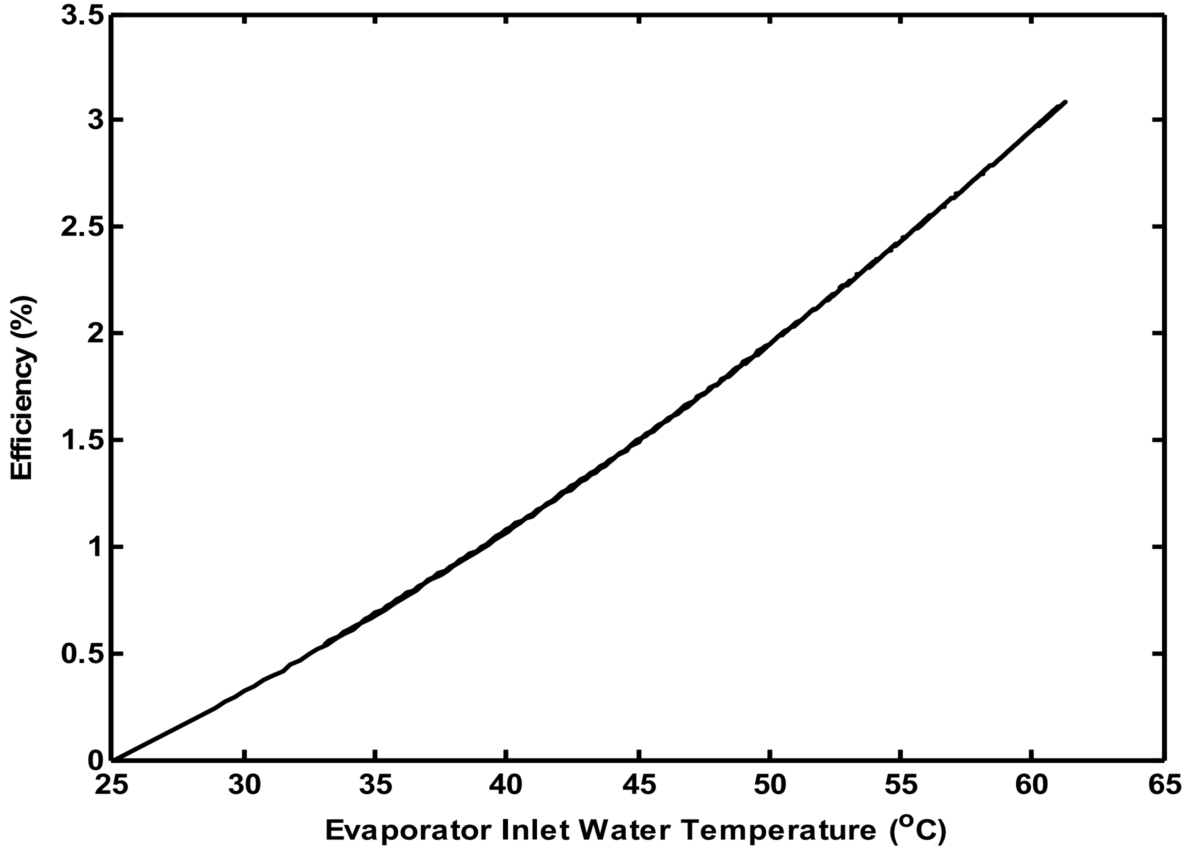
Water Production

L=1.5 kg/m^2-sec, G=1.5 kg/m^2-sec, $A_{solar,col}$=10 m^2, V_{tank}=100 L

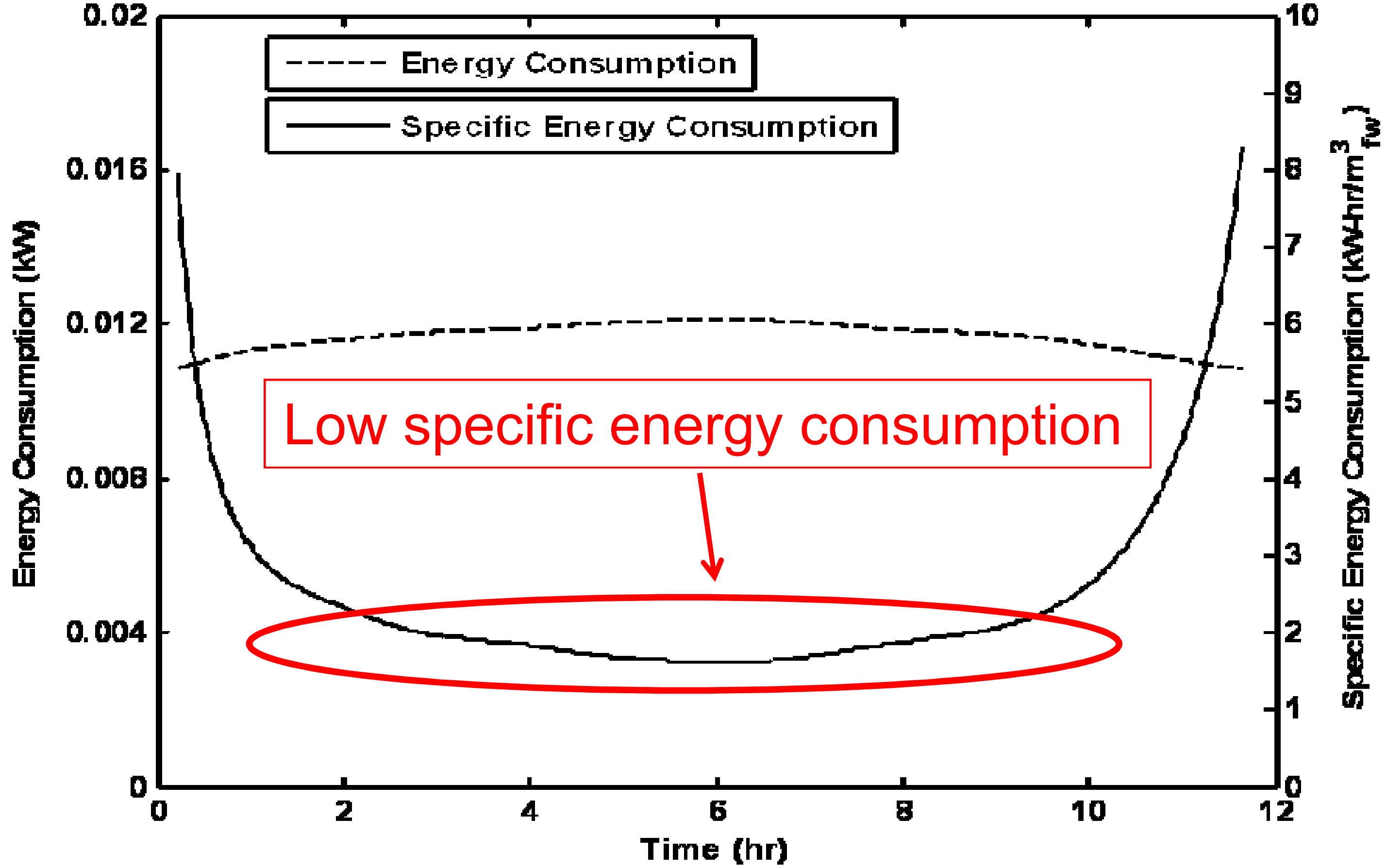


Water Production

L=1.5 kg/m^2-sec, G=1.5 kg/m^2-sec,
A_{solar}=10 m^2,V_{tank}=100 L



Energy consumption



1.9 kWh/m^3

Water Cost for Small Scale Unit

Solar DDD	PV-RO
1.9 kWh/m^3	>10 kWh/m^3
\$5.7/m^3	\$8-29 /m^3

No chemicals are required
No membrane replacement
No battery is required
Low energy consumption
Better water quality

Conclusion

- Theoretical model is developed for the evaporator and condenser
- Numerical solution is obtained for the models
- Evaporator and condenser models are validated by experimental data
- Energy consumption of the distillation unit is 1.9 kWh/m^3

Thanks for your attention

Questions?