Optimum Design of a Solar Desalination Process

IPRO 304-e

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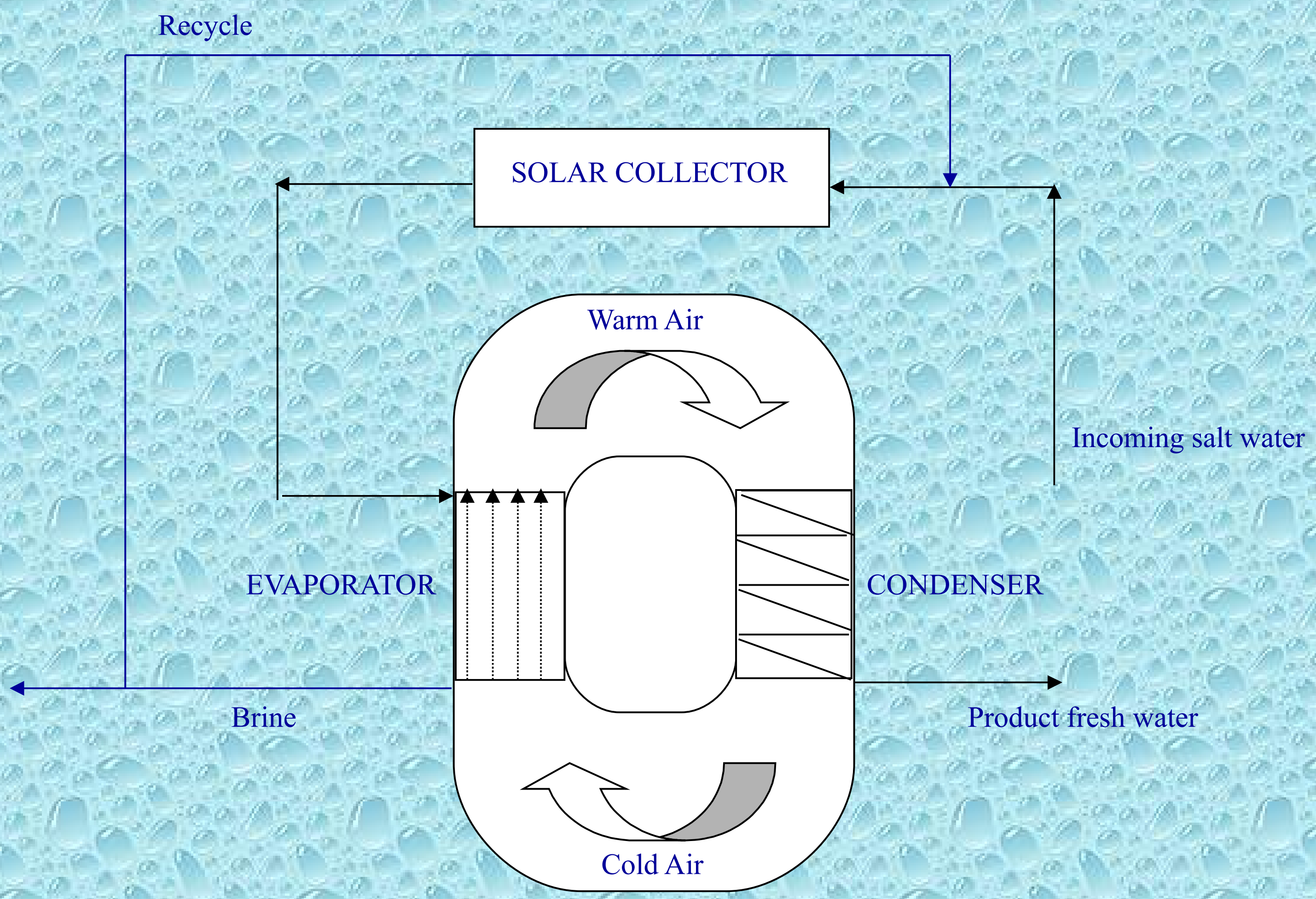
Project Background

- Global Water Shortages
- Project Focus

Process Schematic

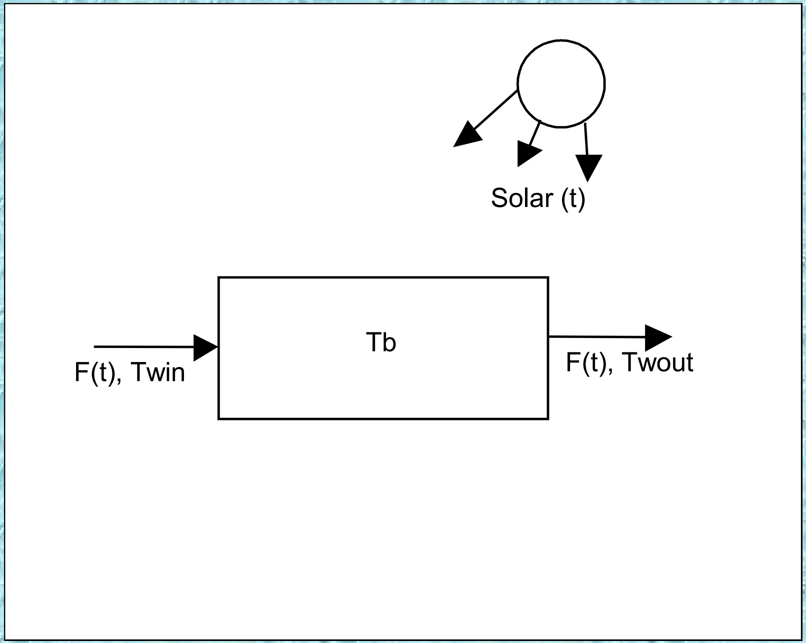


Project Outline

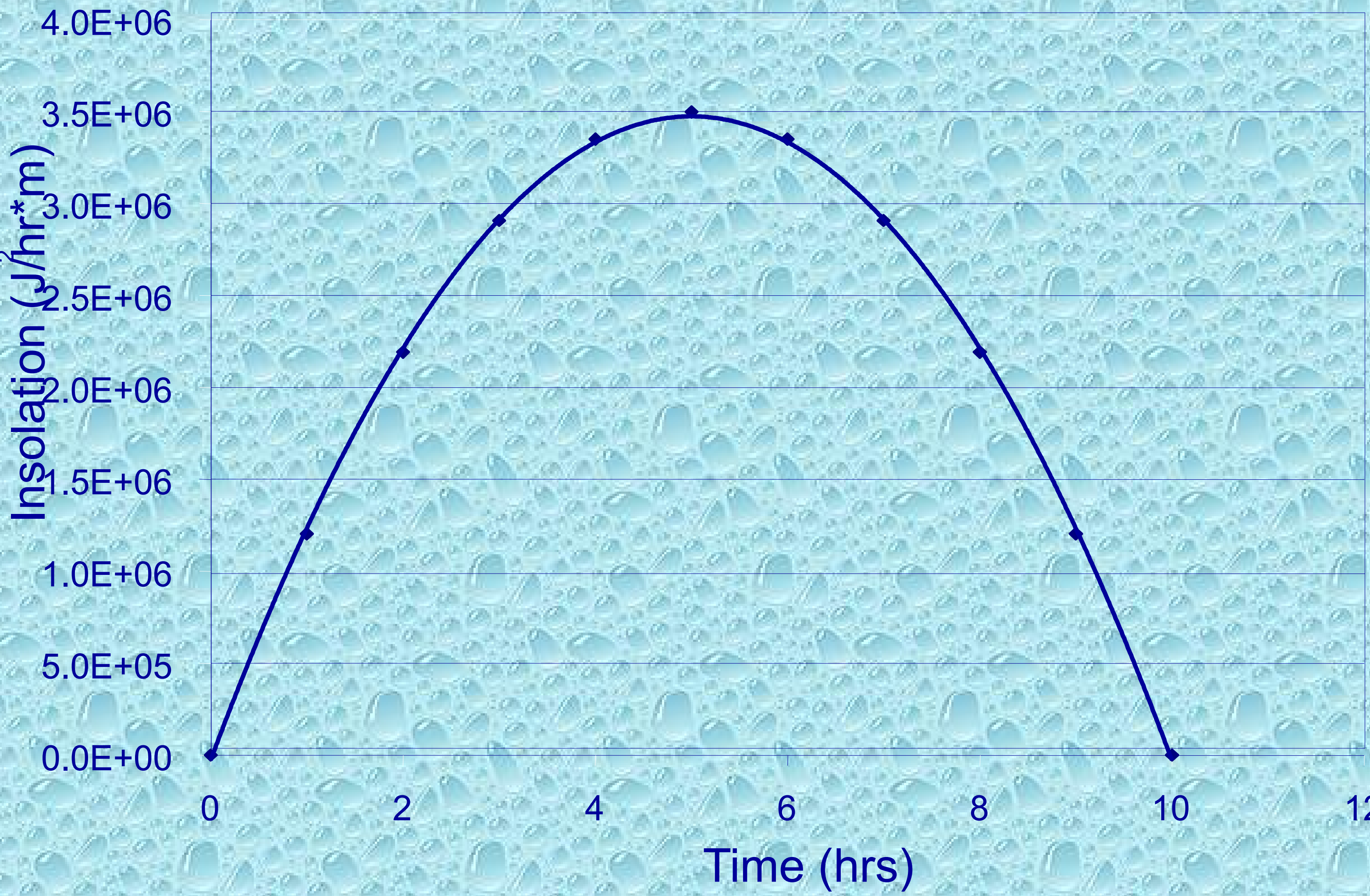
- Solar heater
- Evaporator
- Condenser
- Cost and sustainability
- Conclusion

Solar Collector

- Convert solar energy
- Constant exit temperature
- Minimize wasted energy

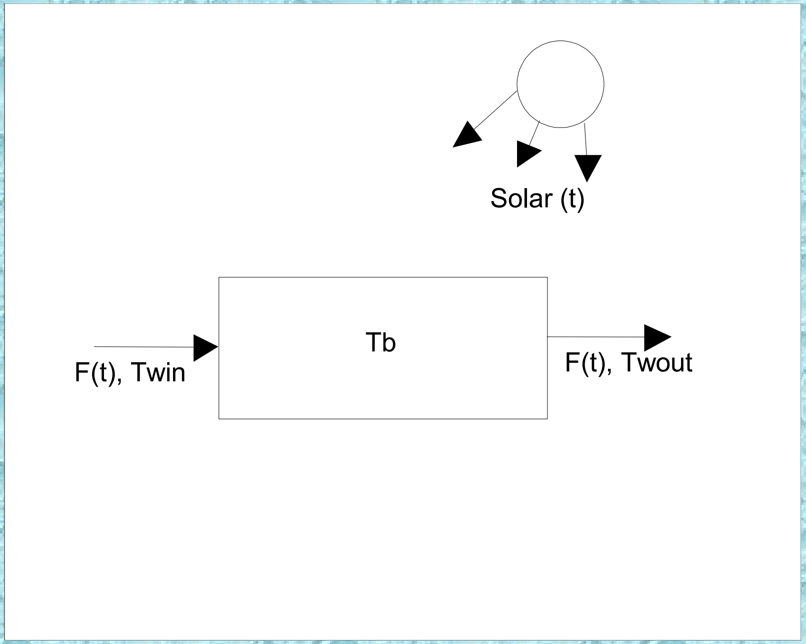


January Insolation

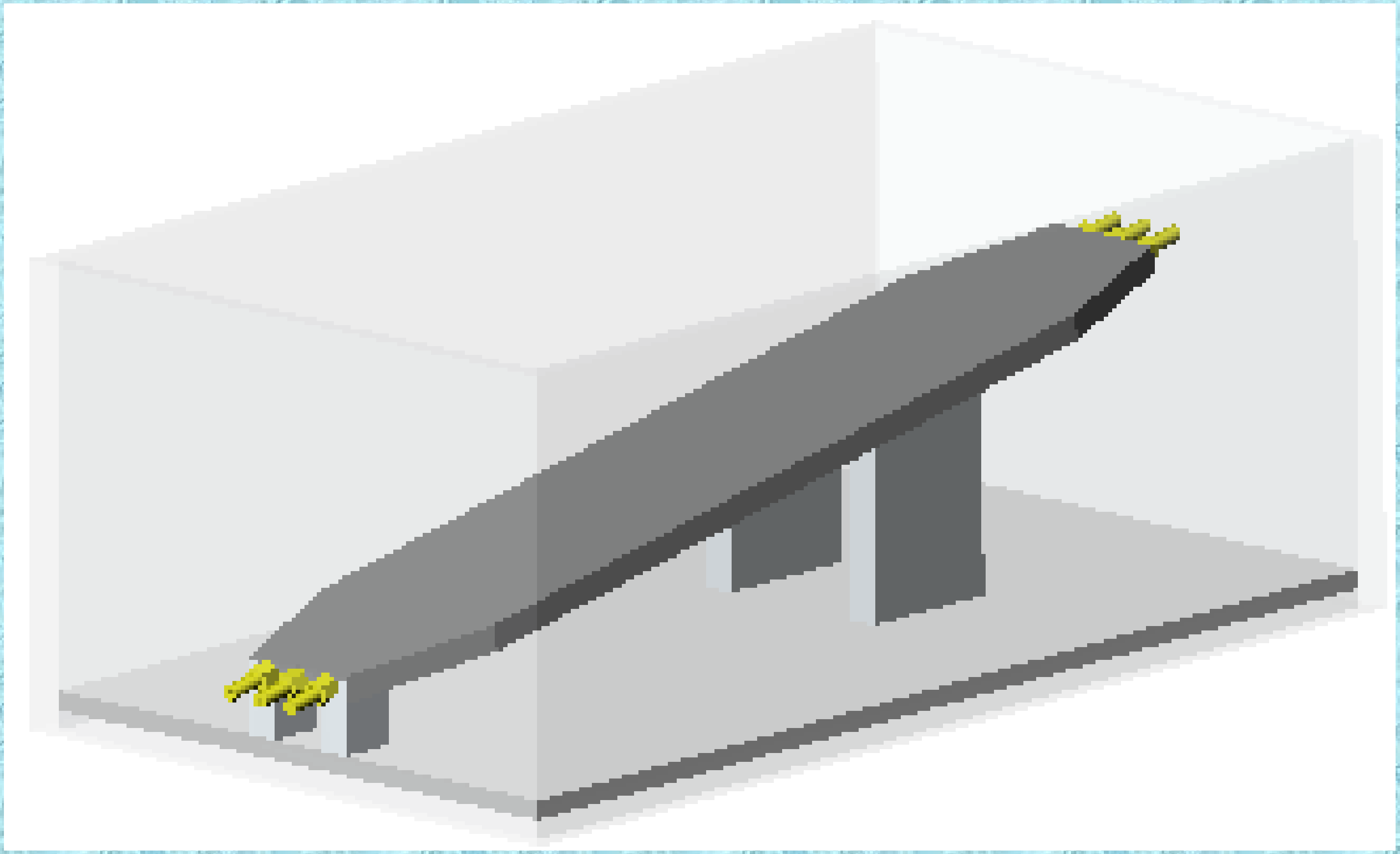


Solar Collector

- Convert solar energy
- Constant exit temperature
- Minimize wasted energy



Solar Unit



Assumptions

- No insolation losses
- No convective or radiative heat losses
- At start-up $T_{bulk}=T_{win}$
- No temperature gradient in bulk
- Quasi steady-state heat transfer coefficient

Mathematical Model

- Bulk heating

$$V_b C_{pb} \rho_b \frac{dT_b}{dt} = A_b * Solar(t)$$

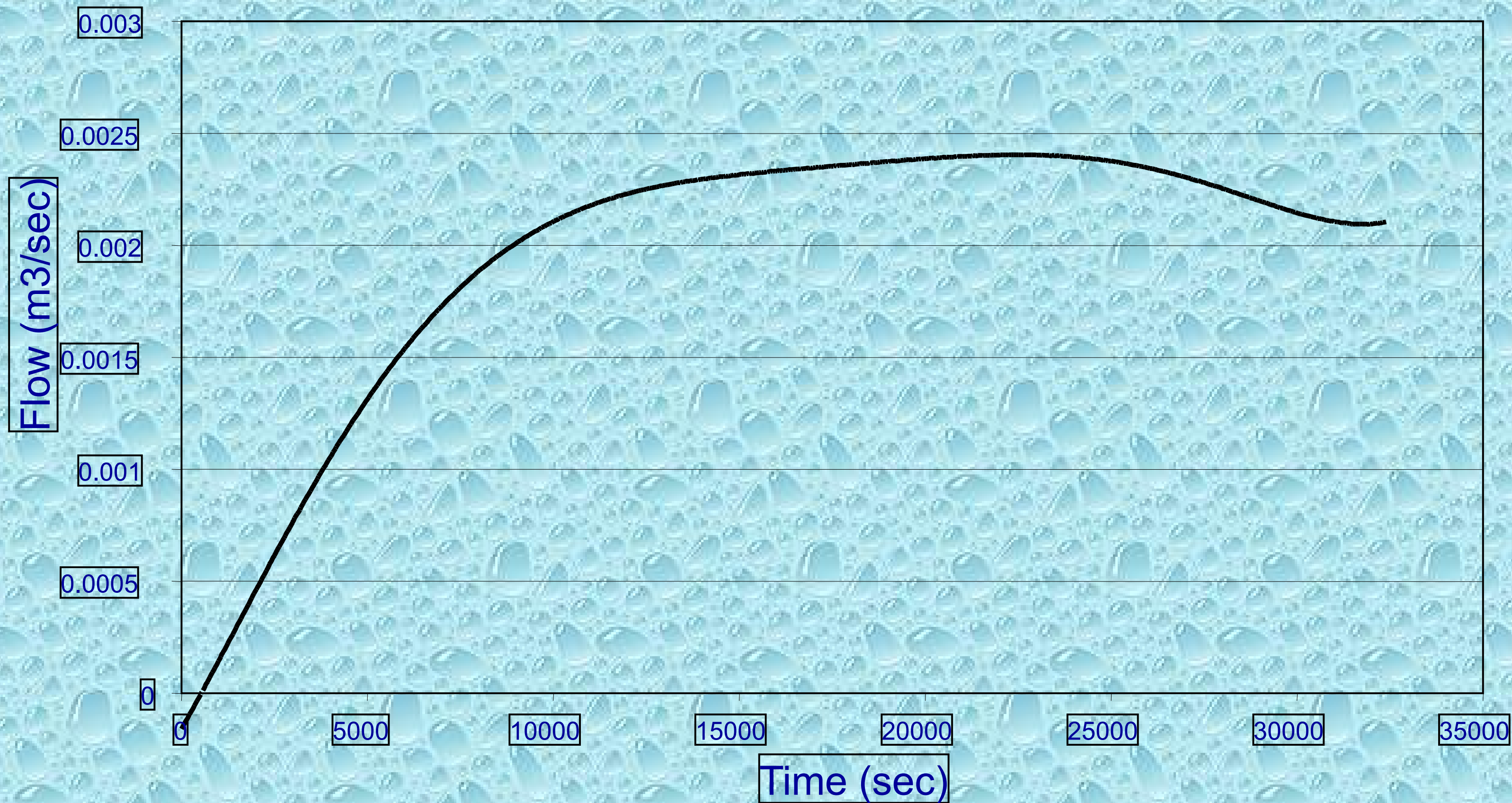
- Bulk temperature

$$V_b C_{pb} \rho_b \frac{dT_b}{dt} = A_b * Solar(t) - hA(T_b - T_{\ln})$$

- Exit water temperature

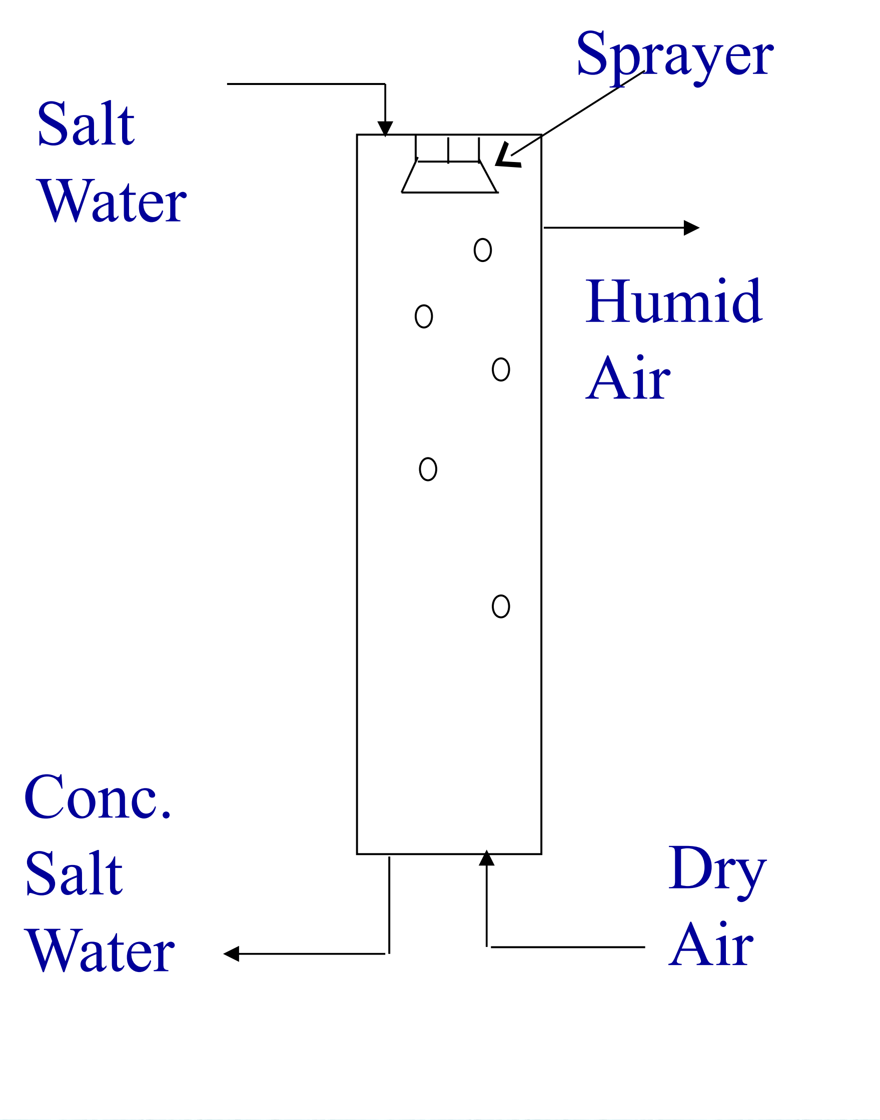
$$0 = C_{pw} \rho_w F(t) * (T_{win} - T_{out}) + hA(T_b - T_{\ln})$$

Total Daily Flow

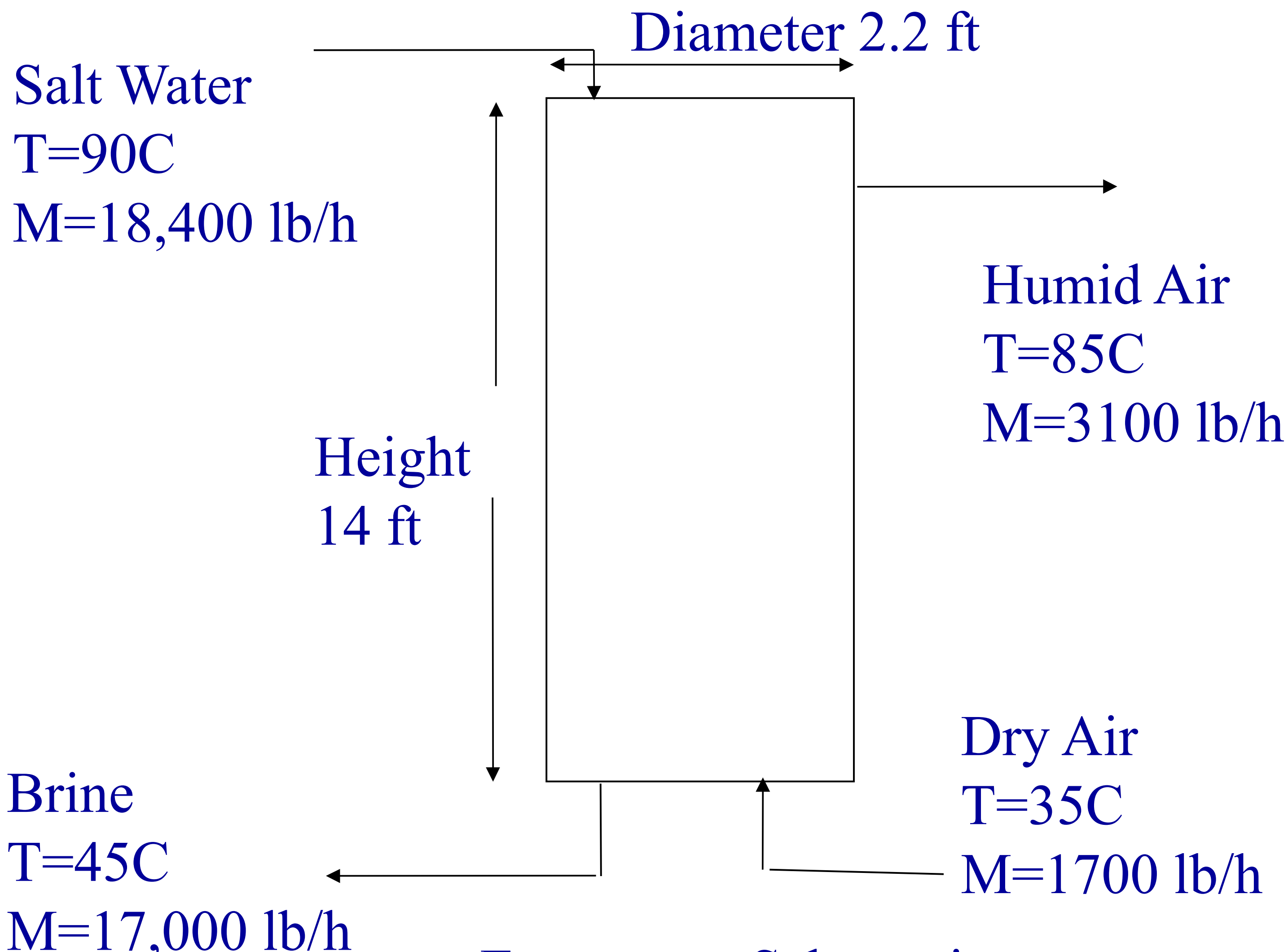


Evaporator Design

- Salt water enters, sprayed in tiny drops
- Pure water evaporates, leaves as water vapor
- Concentrated salt water exits
- Air flows countercurrent



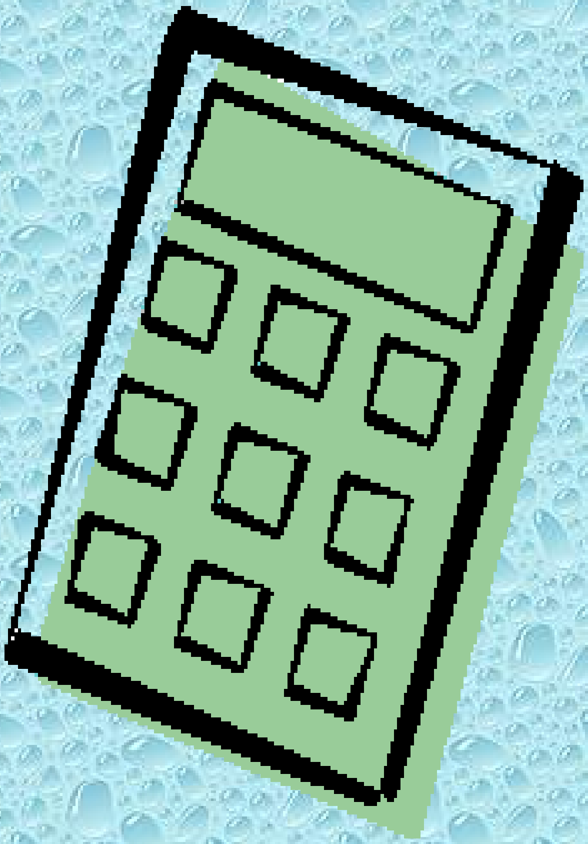
Evaporator Design



Evaporator Schematic

Evaporator Design

- Select tower diameter
- Solve for height and cost
  - Heat transfer properties
  - Mass balance
- Adjust diameter to optimize cost and feasibility
- Results
  - Diameter: 2.2 ft
  - Height: 14.5 ft
  - Stainless steel

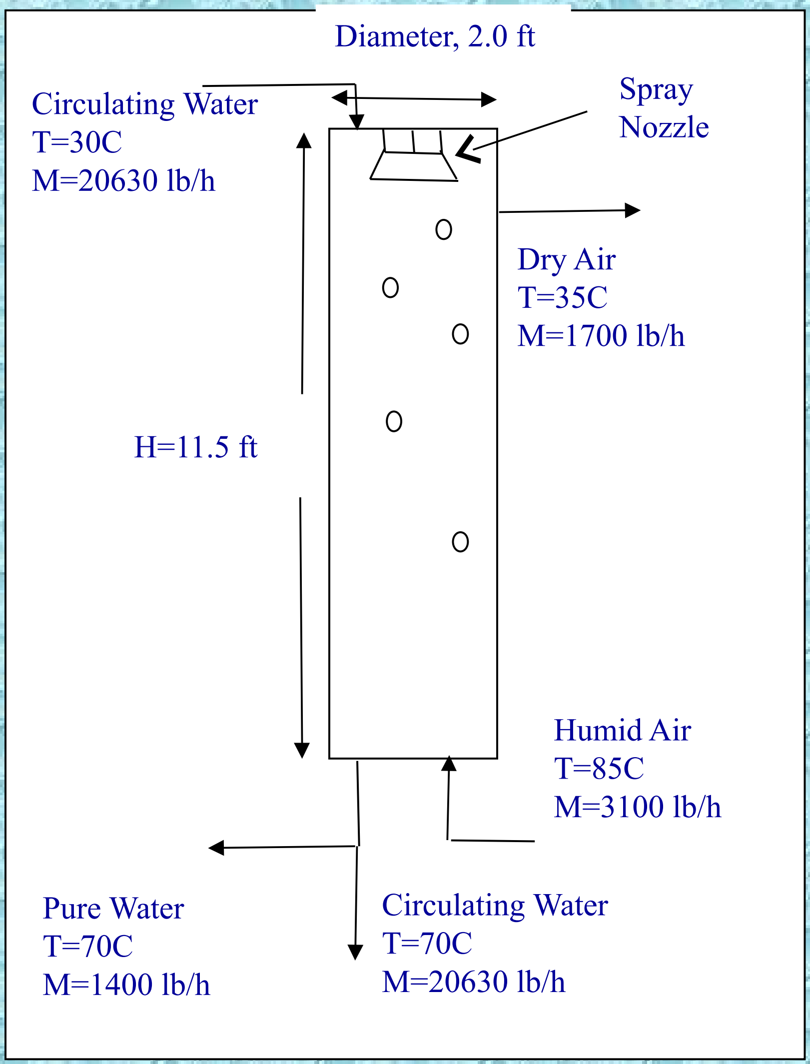


Condenser Design General Information

- Transformation of water vapor to liquid by mechanical means

- Types
  - Shell and tube condenser
  - Spray condenser

- Spray Condenser
  - 1. Water inlet
  - 2. Spray
  - 3. Incondensables outlet
  - 4. Inlet of humid vapor
  - 5. Condensate outlet



Condenser Design
Specific Design Considerations

- Co-current flow
- Condensed water recycle stream used for spray water
  - Extra water only for start up
- Additional heat exchanger needed
  - Preheat salt water while cooling spray water

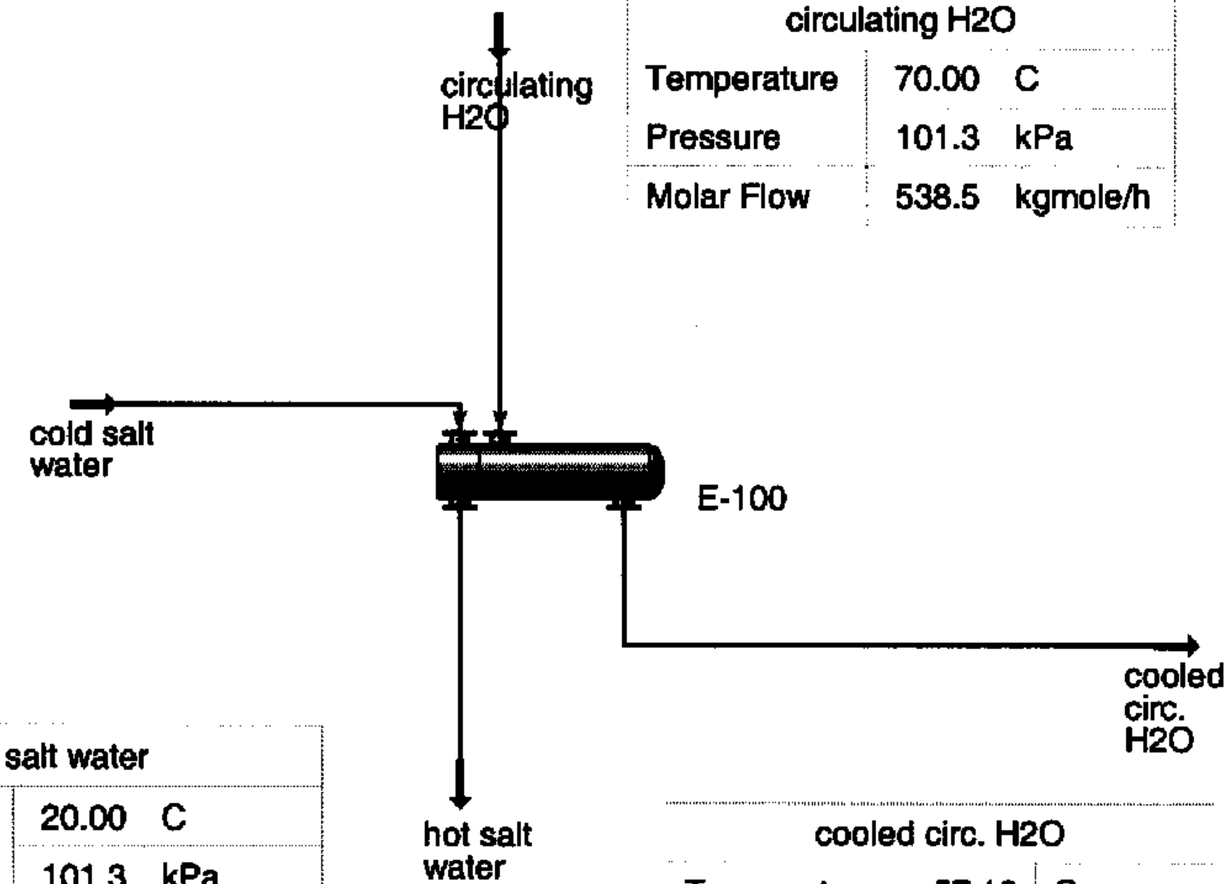
Parameter	Optimal Value
Minimum Height	11.45 ft (3.5m)
Diameter	2.0 ft (61 cm)

Condenser Design Calculations

- Volumetric air flow rate = 65534 ft^3/hr
- Mass air flow rate = 1731 lb_m/hr
- Volumetric flow rate of circulating water = 343.3 ft^3/hr
- Mass flow rate of circulating water = 20630 lb_m/hr
- **Mass flow rate of produced water:**

$$\dot{m}_{water\ produced} = \frac{\dot{m}_{circulating\ water} * c_{pl} * \Delta T_{water}}{\lambda_o} = 1432 lb_m / hr$$

Heat Exchanger



circulating H2O		
Temperature	70.00	C
Pressure	101.3	kPa
Molar Flow	538.5	kgmole/h

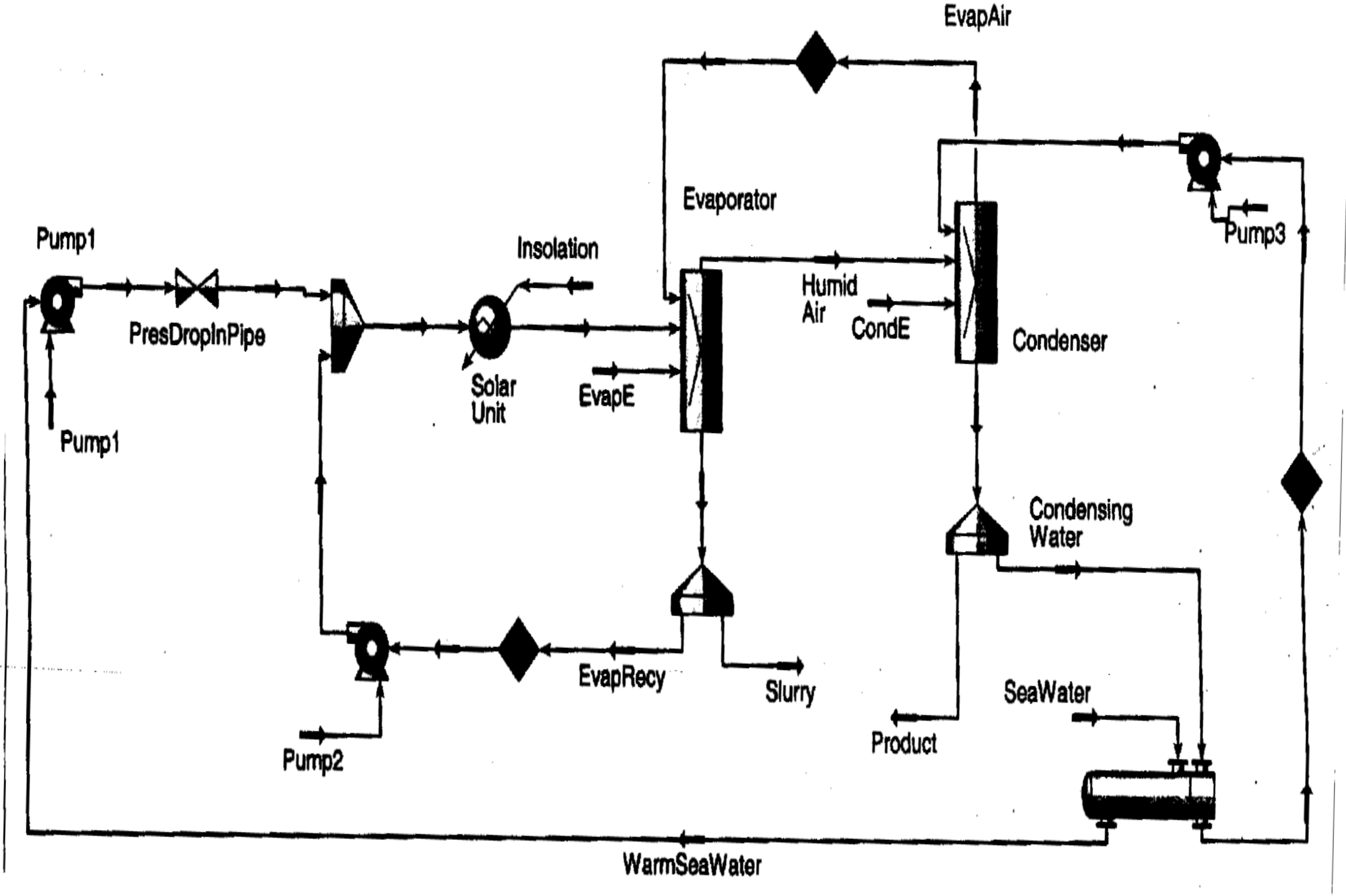
cold salt water		
Temperature	15.00	C
Pressure	101.3	kPa
Molar Flow	1396	kgmole/h

hot salt water		
Temperature	20.00	C
Pressure	101.3	kPa
Molar Flow	1396	kgmole/h

cooled circ. H2O		
Temperature	57.10	C
Pressure	101.3	kPa
Molar Flow	538.5	kgmole/h

Cost Analysis

- Used Seider's *Process Design*
- Cylindrical process vessels and heat exchanger models
- Principal equipment cost (C_P) estimated
  - C & E : height & diameter
  - HE : heat exchange area
- Materials factor (F_M)
  - Carbon steel
  - Stainless steel
  - Titanium
- Compare costs


EvapAir
Evaporator
Pump1
Insolation
Pump3
Humid
Air
PresDropInPipe
CondE
Condenser
Solar
Unit
EvapE
Pump1
Condensing
Water
EvapRecy
Slurry
SeaWater
Pump2
Product
WarmSeaWater

Comparative Costs & Investment

- Investment for project

Our Investment:	
Heat Exchanger	$41,881.97
Condenser: Carbon Steel	$98,187.94
Evaporator: Stainless Steel	$390,537.75
Miscellaneous Materials	$10,000.00
Total	$540,607.66

Cost in the long run?

- Life of unit: 25 years
- Water producing days: 180

$$\frac{5670 liters}{day} \times \frac{180 day}{year} \times 25 years = 2.55 \times 10^{7} liters$$

- Price of our water (worst case scenario)
  - January flow
  - ½ year production time

$$\frac{\$540,607.66}{2.55 \times 10^{7} liters} = \$0.02 / liter$$

Feasibility & Sustainability

- Typical person uses 250 liters/day
  - Single person: $5/day or $160/month
- Current costs are lower in U.S.

- Q: Is this technology sustainable?
  - Green energy
  - Minimal impact on environment
  - Raw material plentiful
  - Cost still too high
- A: Yes, with **water conservation** and **further development** to make unit more **cost effective**

Conclusion

- Production: 5,670 L/day for test case
- Prohibitively expensive
- Model development and cost reduction

www.iit.edu/~ipro304es02

SOLAR DESALINATION UNIT
(Temperatures for January)