CMP WATER RECLAMATION by *"DEWVAPORATION™ "*

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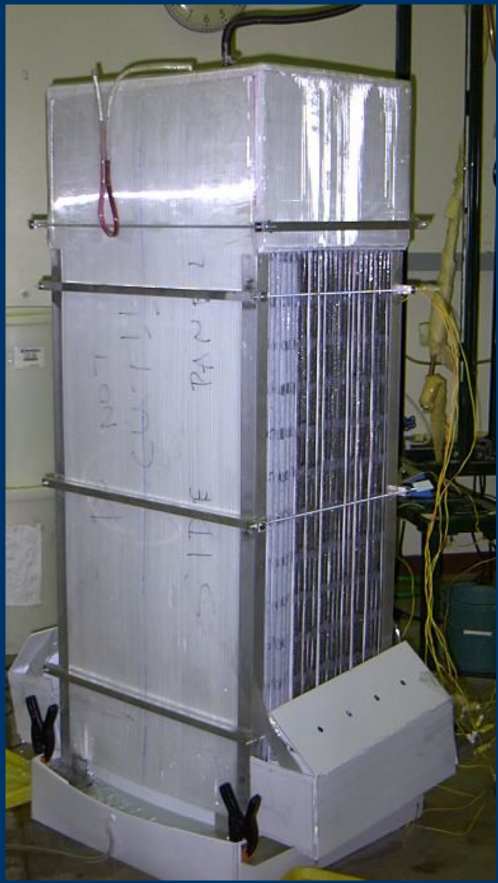
PRESENTATION OVERVIEW

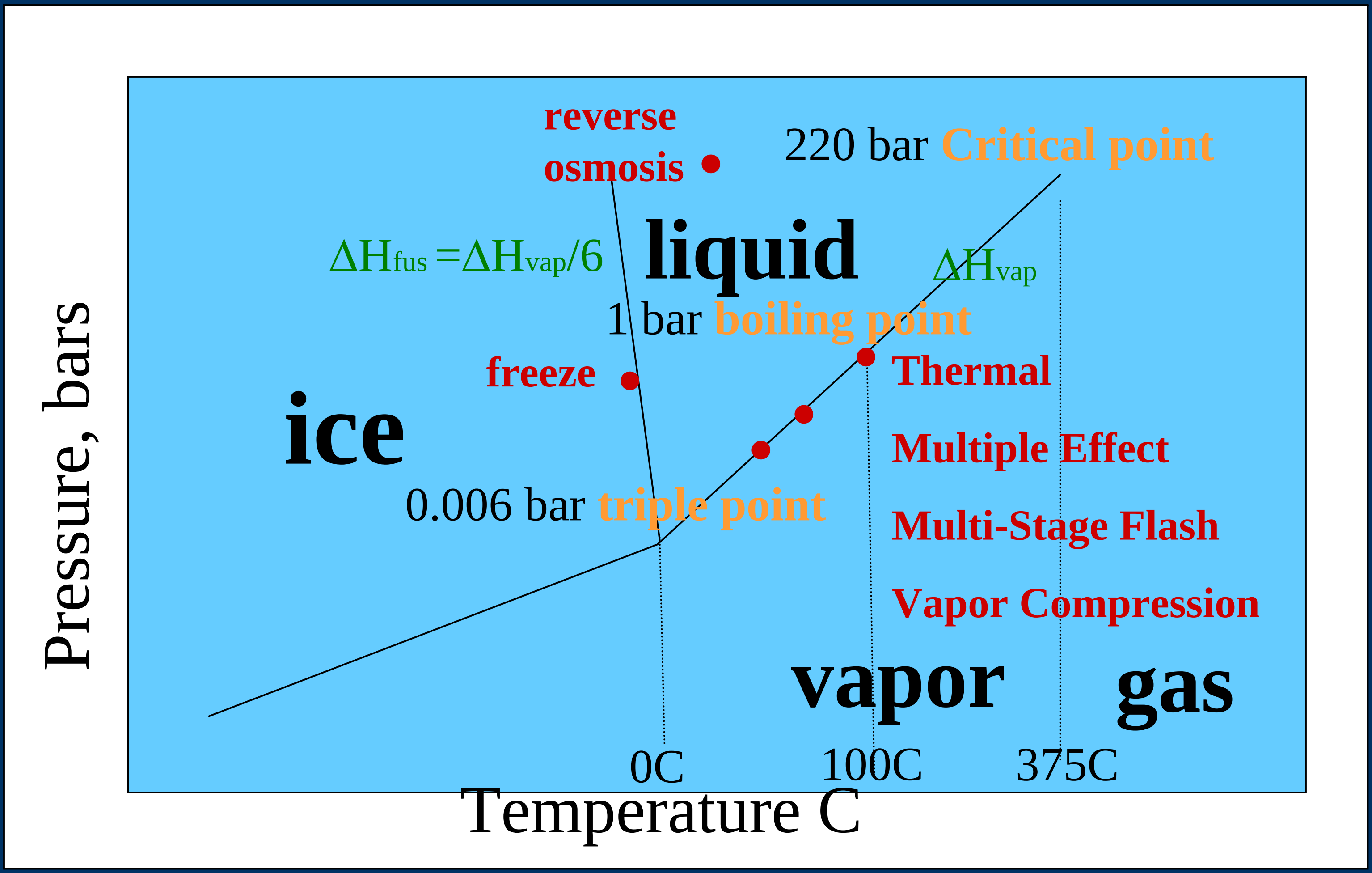
- **Overall Desalination Practices**
- ***DEWVAPORATION***
  - ✓ **Theory**
    - **Thermo, fluids, heat & mass transport, unit operations, design**
  - ✓ **Applications (presented)**
    - **Desalination-seawater, waste water**
      - **Steam**
      - **Desiccant heat pump**
      - **Ultra-effect**
    - **Crystallization – waste water**
    - **CMP water reclamation**
    - **Distillation**
  - ✓ **Potable Distillates - certification**



SEAWATER DESALINATION TECHNIQUES

- **FREEZING-crystallization, filtration**
  - ✓ Ice
- **PRESSURE- membranes, compressors, heat exchangers**
  - ✓ Reverse Osmosis
  - ✓ Vapor Compression
- **VACUUM Thermal- heat exchangers**
  - ✓ Multiple Effect Distillation
  - ✓ Multi-Stage Flash
- **ATMOSPHERIC Thermal- fans, boilers, sprays, desiccants, Humidification/Dehumidification**
  - ✓ **DEWVAPORATION**

THE BIG PICTURE
WATER PHASE DIAGRAM

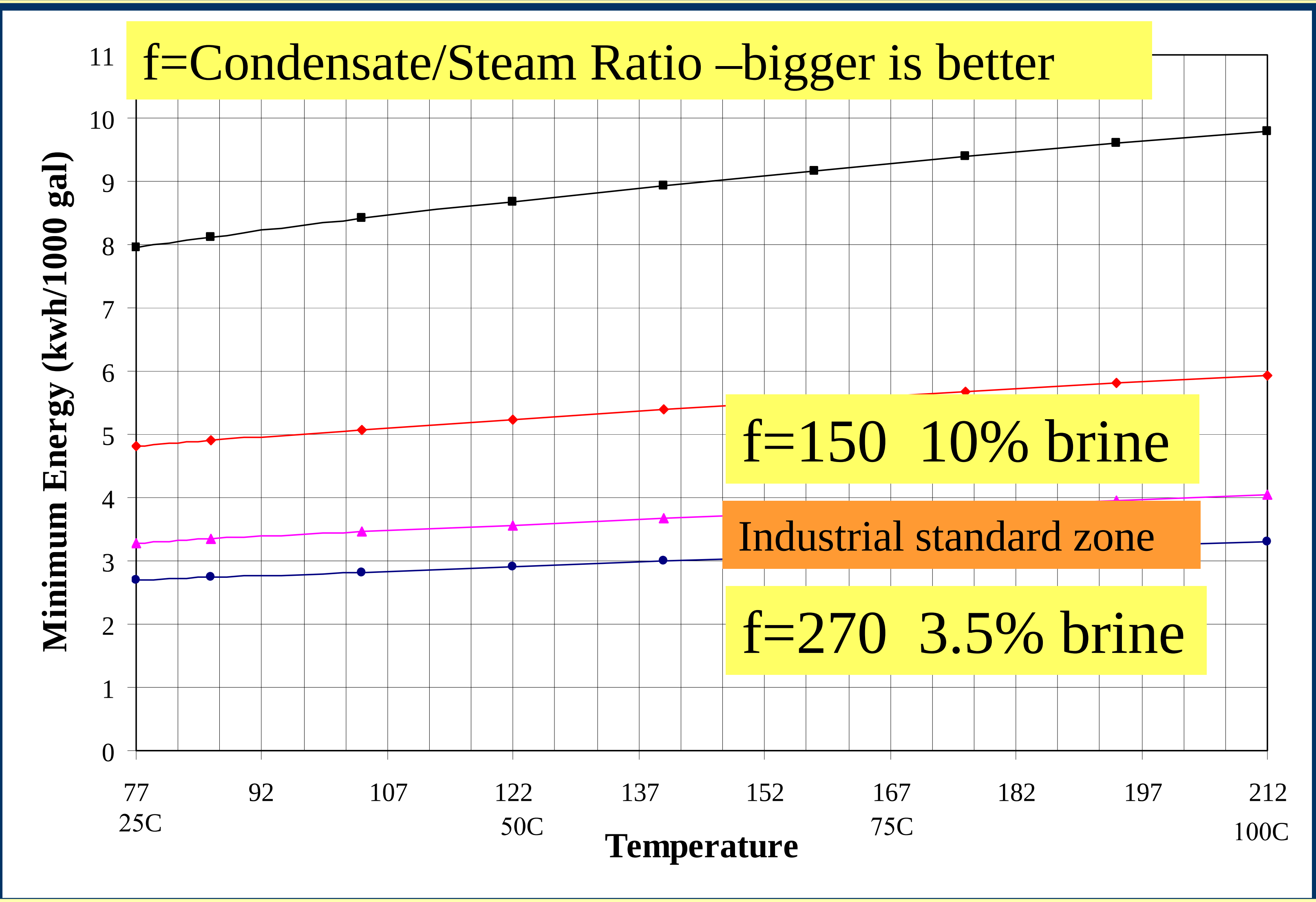


Seawater Desalination: f

- **DEWVAPORATION** f = 5 to 500
- Vapor Compression Evaporation f =50
- Reverse Osmosis f = 30 (90 shaft work)
- Multiple Effect Distillation f = 8 to 12
- Multi-Stage Flash f = 8 to 12
- Freeze f = 6

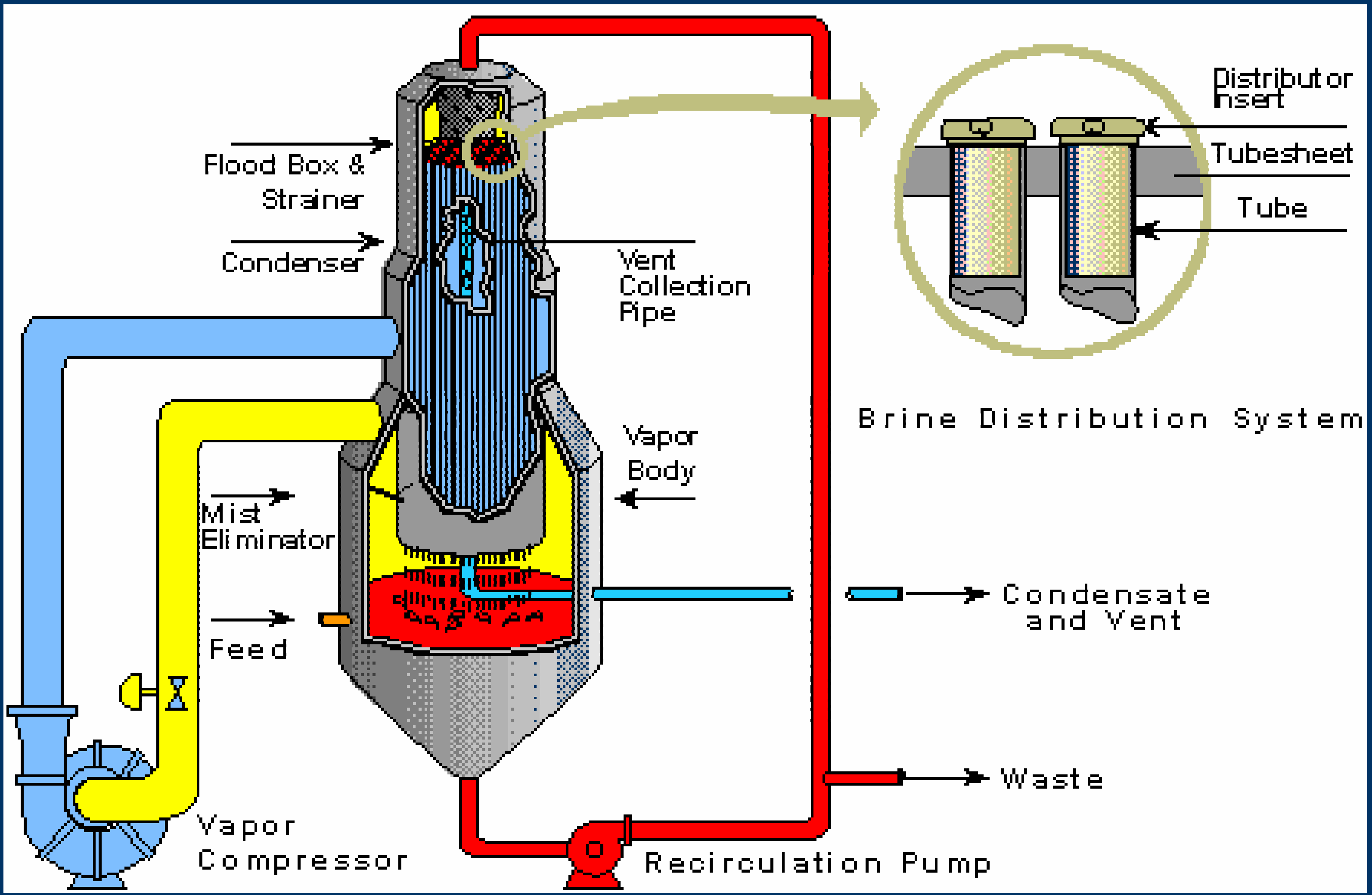
f = # effects = condensate/steam equivalent heat

SEAWATER THERMAL DESAL – Max Efficiency



R.O. RACK : MODULAR

VAPOR RECOMPRESSION EVAPORATOR

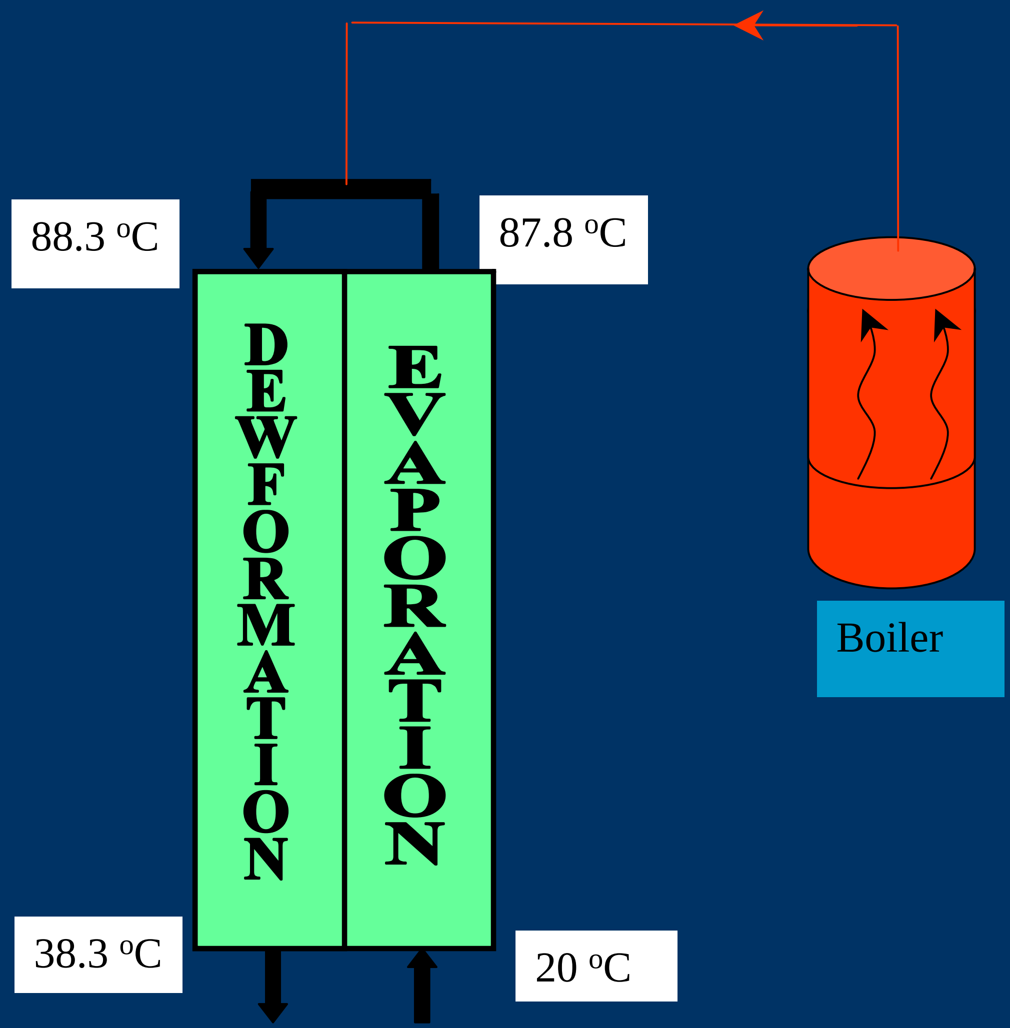


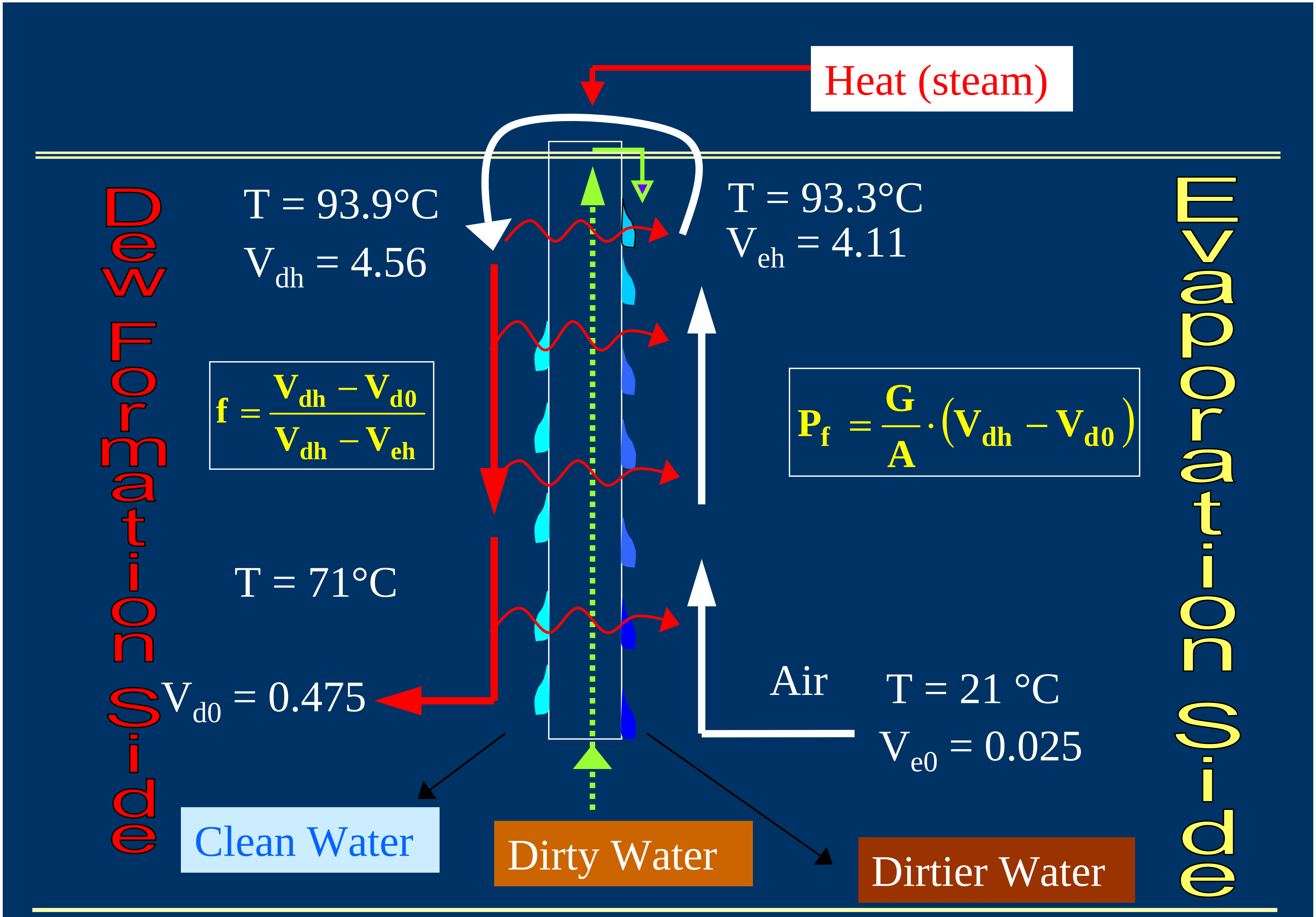
DEWEY TOWER

Dewvaporation

- Uses air as a carrier gas in a contact tower
- Operates at atmospheric pressure and below boiling point
- Air Fan and Feed Pump
- Towers are composed of :
  - ✓ Polypropylene and nylon plastic materials
  - ✓ evaporation and dewformation side separated by thin inexpensive non-corrosive plastic heat transfer walls

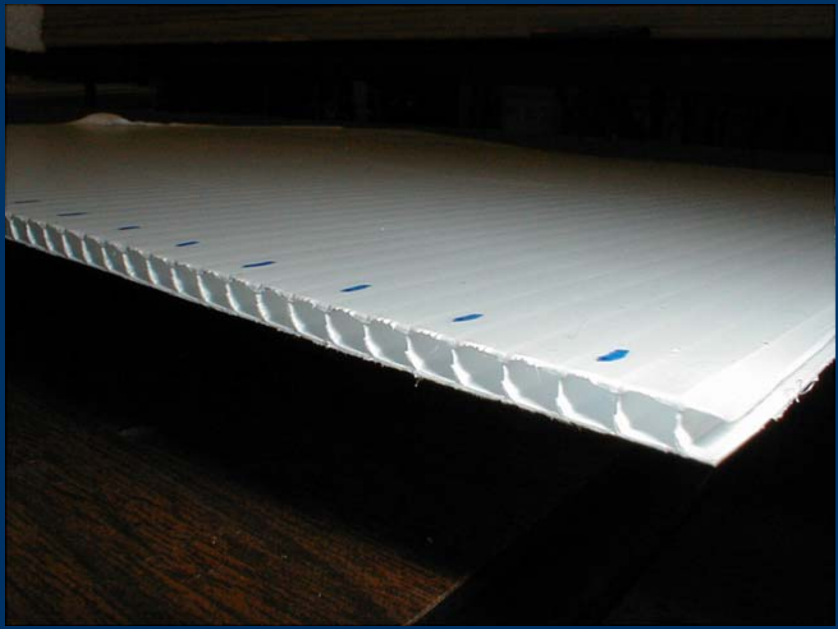
Standard Boiler Regeneration




Heat (steam)
Dew Formation Side
T = 93.9°C
V_{dh} = 4.56
$f = \frac{V_{dh} - V_{d0}}{V_{dh} - V_{eh}}$
T = 71°C
V_{d0} = 0.475
T = 93.3°C
V_{eh} = 4.11
$P_f = \frac{G}{A} \cdot (V_{dh} - V_{d0})$
Air
T = 21 °C
V_{e0} = 0.025
Evaporation Side
Clean Water
Dirty Water
Dirtier Water
f = clean water/steam = 9

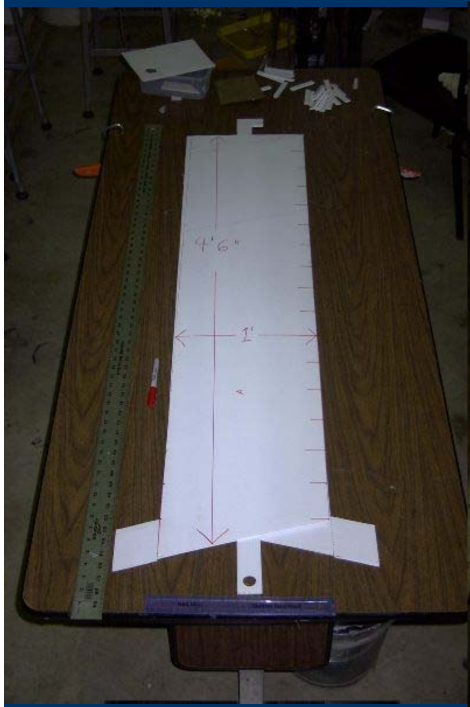
Twin Wall Extrusion Design

- 4mm total dimension
- 0.2mm plastic wall thickness
- Cost $0.05/sqft
- Easily constructed
- Off the shelf



250 SQFT N.E.W.T. Tower Assembly

DOUBLE HELIX

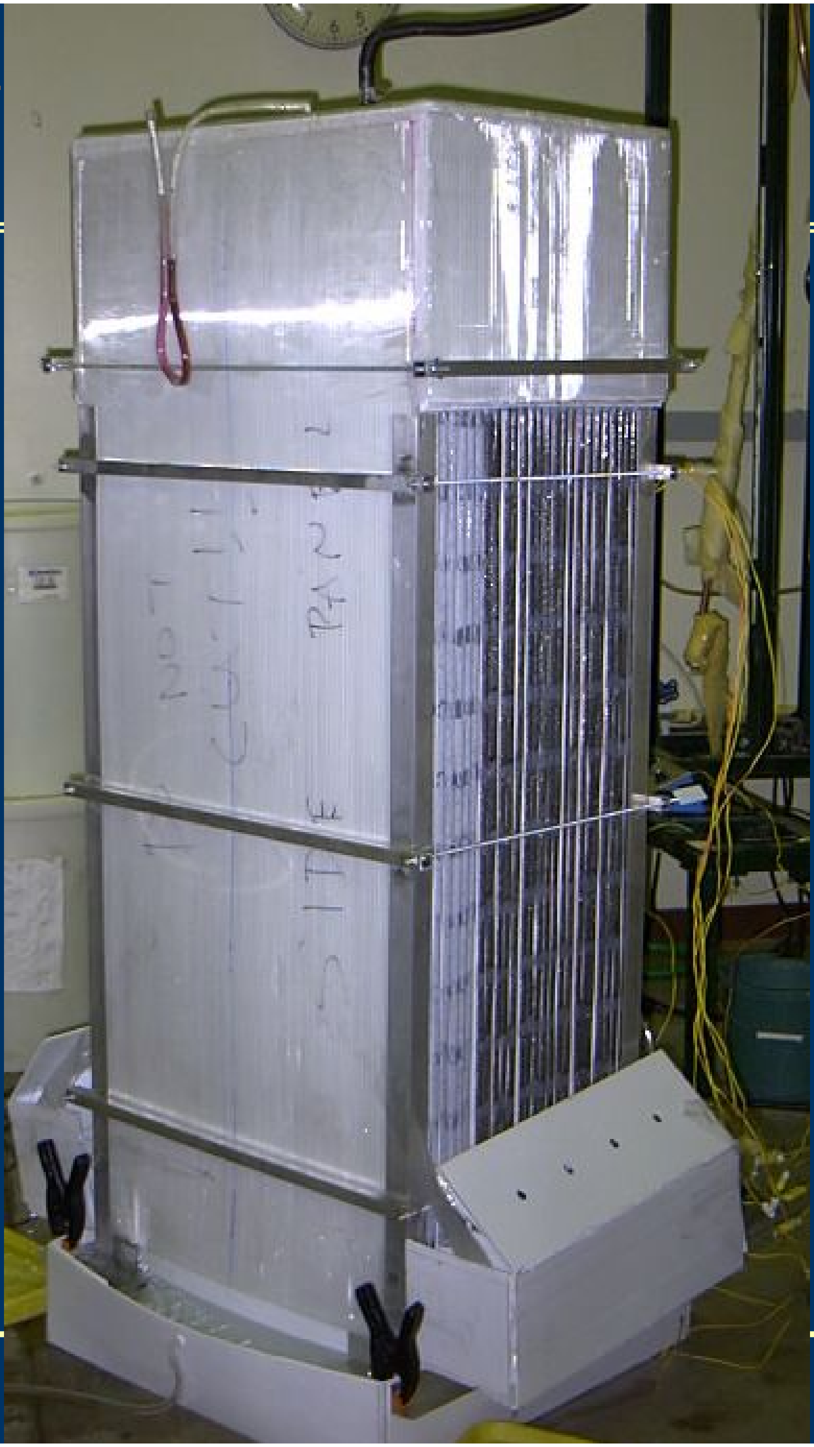


Feed Hex Bottom Inlet

Feed Hex Top Outlet

DEWEY TOWER

$$P_f = \frac{G}{A} \cdot \left(V_{dh} - V_{d0}\right)$$



$$f = \frac{V_{dh} - V_{d0}}{V_{dh} - V_{eh}}$$

1.5ft x 1.5ft x 8ft

250 gal/day

Dewvap :Heat /Mass Transfer Theory

Overall Heat Transfer Coefficient

$$\frac{1}{U|_z} = \frac{1}{h_{fe}|_z} + \frac{1}{h_{fd}|_z} + \frac{t_{plastic}}{k_{plastic}} + \frac{\delta_e|_z}{k_{water}} + \frac{\delta_d|_z}{k_{water}}$$

$$h_f|_z = h_g|_z + k_c \cdot (C_A - C_{A-wall}) / (y_{airLM}(T - T_{wall}))$$

$$C_A = K\exp(-\lambda / RT) / RT$$

Taylor Series Expansion wrt T = Twall

And Lewis # =1 yields:

$$h_f|_z = h_g|_z \cdot (1 + M|_z)$$

$$M = \left(\frac{\lambda}{RT}\right)^2 \cdot \left(\frac{R}{c_p}\right) \cdot V$$

Theory – Integral Results

Assumption: Sensible heat terms of liquid and air are small compared to latent heat of vaporization

Simple (thin wall)

$$P_f \cdot f = \left(\frac{\lambda}{B \cdot R \cdot T}\right)^2 \cdot \left(\frac{h_g}{c_p}\right) \cdot \left(\frac{V_{eh}}{2 + V_{eh}}\right)$$

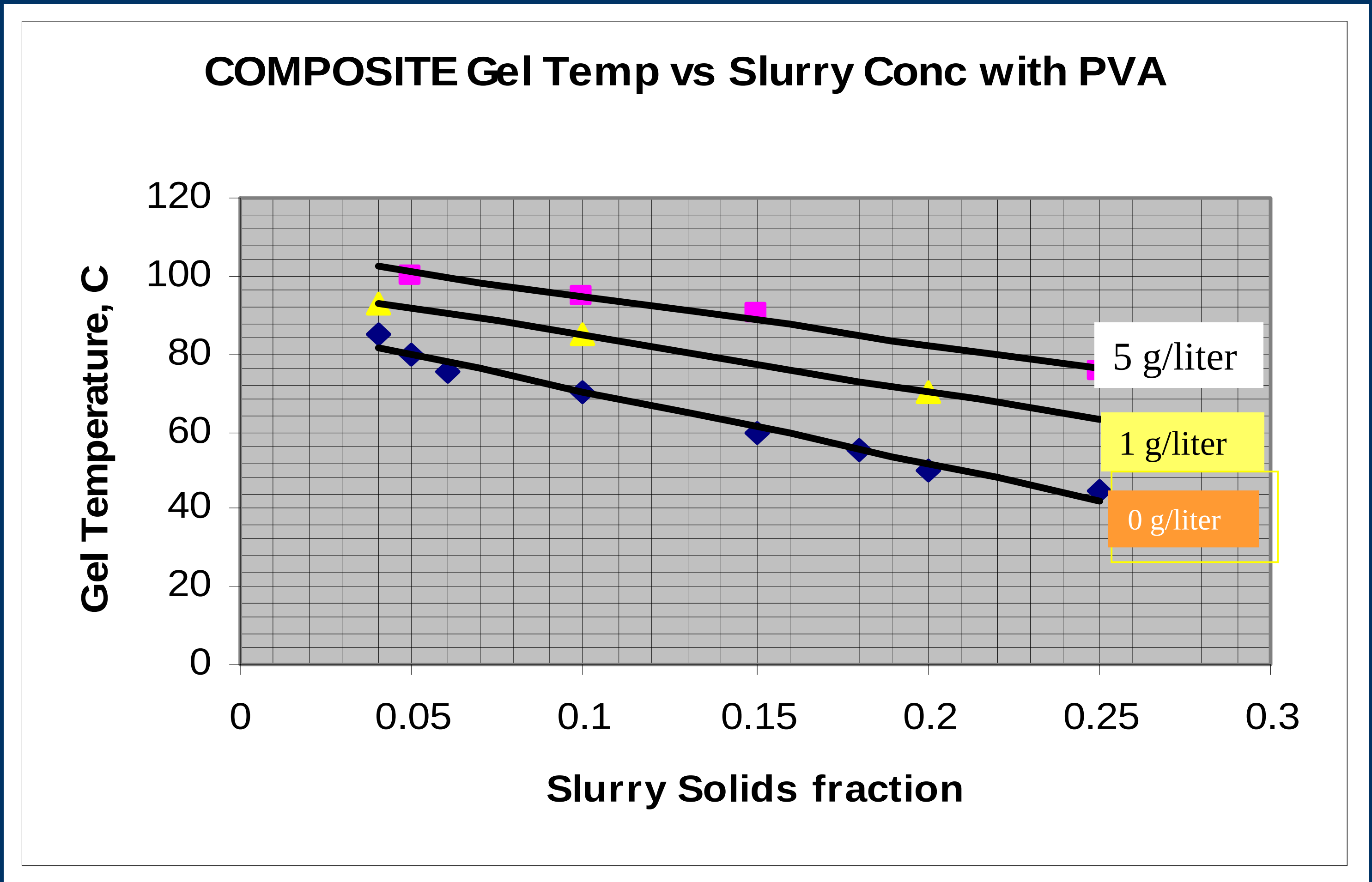
Less Simple for 0.2mm plastic wall

$$\frac{1}{(3 + 2 \cdot V_{eh}) P_f \cdot f} = \left[\left(\frac{R}{h_g}\right) \cdot \left(\frac{B \cdot R \cdot T}{\lambda}\right)^2 \cdot \left(\frac{c_p}{R}\right)\right] \cdot \left(\frac{2 + V_{eh}}{3 \cdot V_{eh} + 2 \cdot V_{eh}^2}\right) + \frac{B^2 \cdot R}{6} \cdot \sum \frac{t}{k}$$

Air Boundary Layer Wall&Liquids

DEMONSTRATIONS
with
DEWVAPORATION

CMP : PVA GEL SUPRESSION



PVA will Prevent Gel Formation in the Dewvaporation Towers

CMP Slurry Operational Data

Run #	Feed* (lb/hr)	Distillate (lb/hr)	% Reclaimed	f Reuse** Factor
1	**8.0**	**3.30**	**41**	**20.0**
2	**8.0**	**3.63**	**45**	**14.1**
3	**6.0**	**3.30**	**55**	**20.8**
4	**4.0**	**3.52**	**88**	**7.3**

* CMP Slurry 1 wt% solids

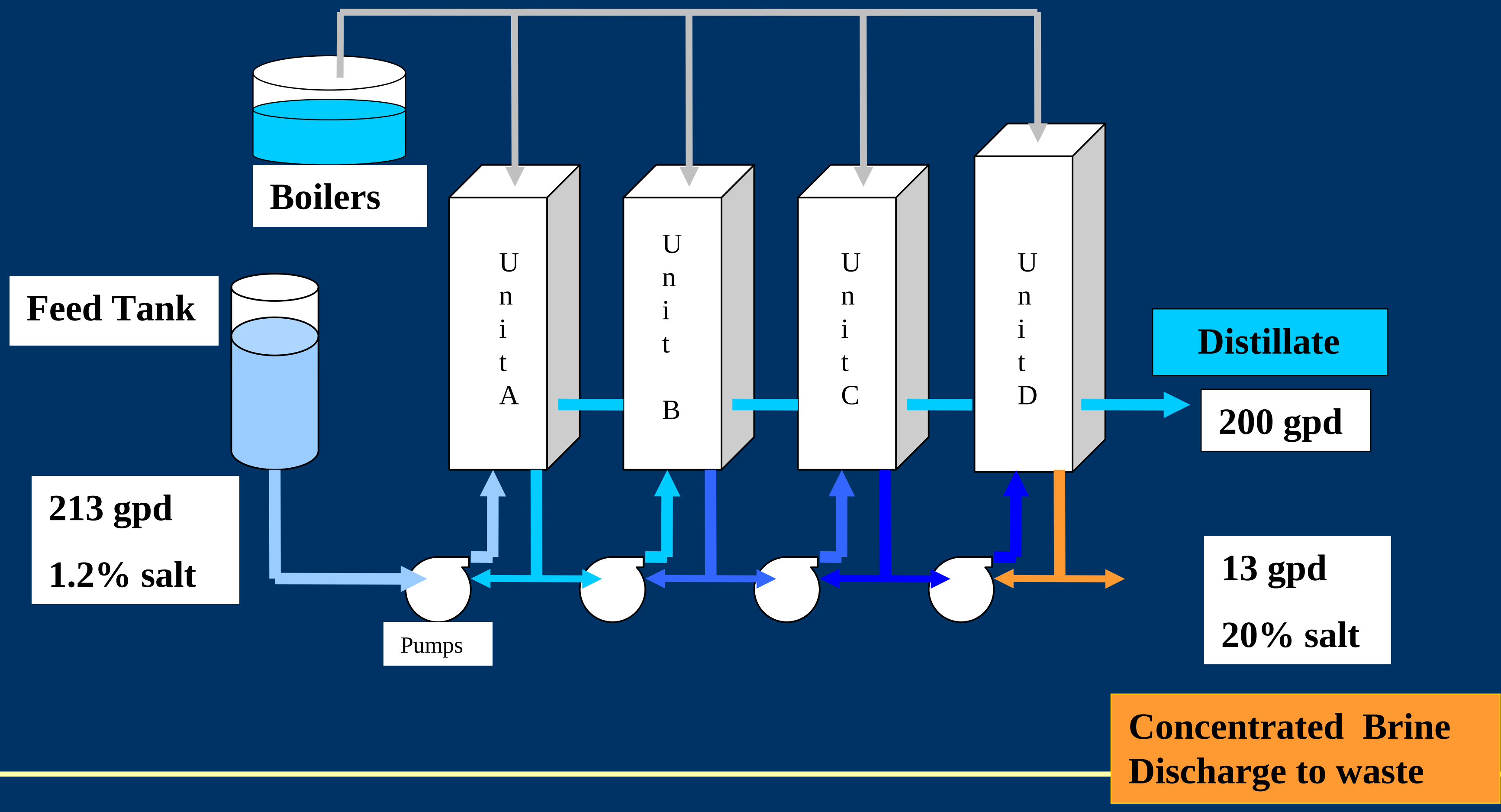
** Behaves Like Brackish Water but some gel in tower

Dewvap Units

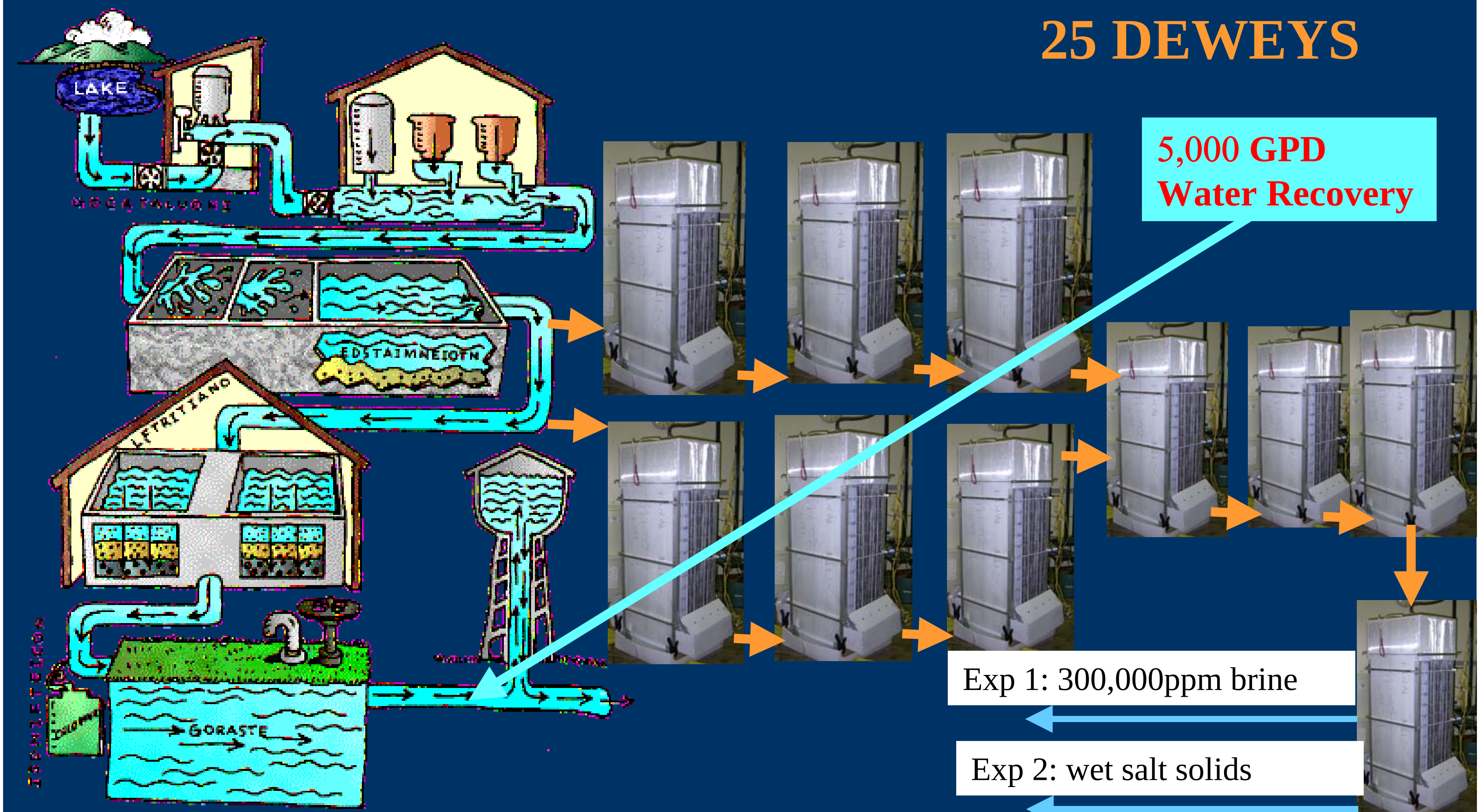
COOLING TOWER BLOWDOWN

CGS Evaporation Pond Demo

- Reduced Volume by 90%
- Reduced Cost from $15/1000 gal to $3.50/1000 gal



5,000 GPD PILOT PLANT: PHOENIX



waste discharge

1500 GPH Tactical Water Purification System (TWPS)

Future Energy Efficiency

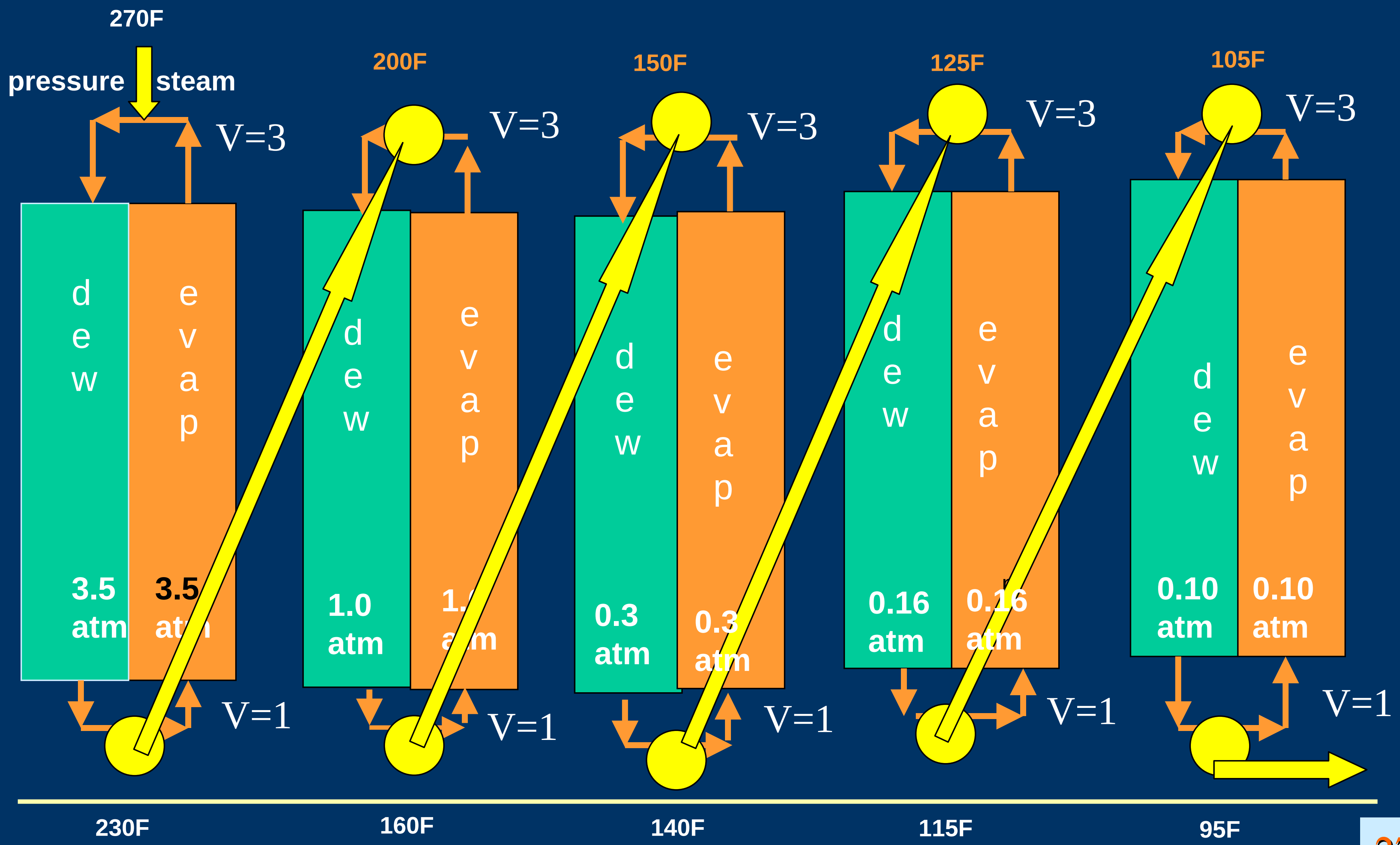
Energy Efficiency Improvement by

- **Desiccant Regeneration Techniques:**
  - Dry Air Evaporating
  - Low temperature waste heat
  - Solar Water Heating
- **Ultra-Effect Dewvaporation**

Ultra-Effect Evaporation

- V= moles water/mole air=$P_{sat}/P_{total}-P_{sat}$
- Set Tower Pressure to >1 atm say 40 atm
- Set Succeeding Tower Pressures to < 40 atm
- Thermally Attach Towers :High to Low Pressure
- Input Heat to Top of High Pressure Tower Only
- f = 50+
- Continue from 1Atm to 0.1Atm for f = 40+
- **Total f ~ 100**

Ultra-Effect Dewvaporation :Example f = 40



Waste Heat Ultra-Effect Evaporation

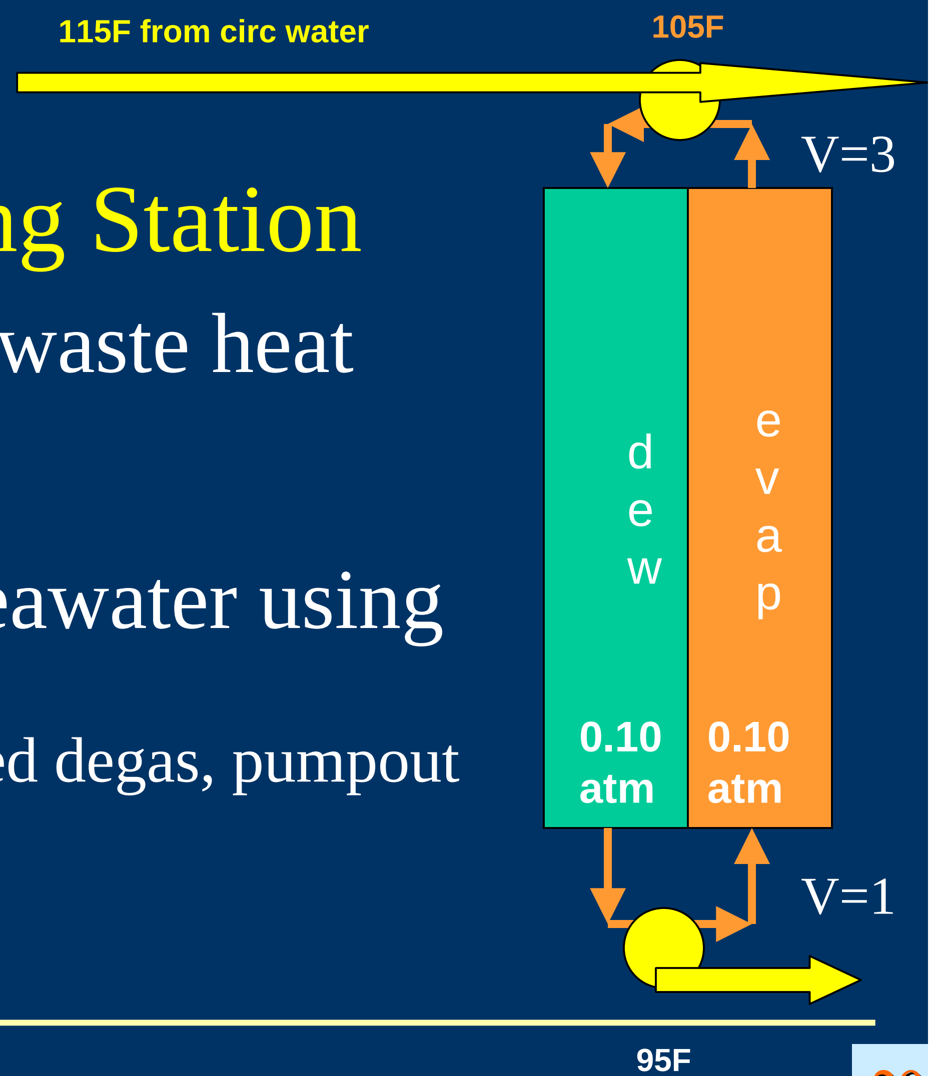
- Input 120 F Waste Heat to Top of Vacuum Tower : electric power plants, solar collector

- f = 8 but it's a free 8!

Waste Heat Ultra-Effect Dewvaporation : f = free 8

900 MWe

Generating Station



1800 MWh cooling tower waste heat desalinates:

150 million gallons/day seawater using

0.8kWhe/1000 gallons- feed degas, pumpout

Effective f = 500

PRESENTATION CONCLUSIONS

DEWVAPORATION

- ✓ **Versatile**
  - **Desalination-seawater, waste water**
  - **Crystallization – waste water**
  - **CMP water reclamation**
- ✓ **Modular : 200GPD - 100,000GPD**
- ✓ **Energy Efficient: f = 5 to 500**
- ✓ **Potable Certification: distillates**