Water Purification by the Dewvaporation Technique

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With

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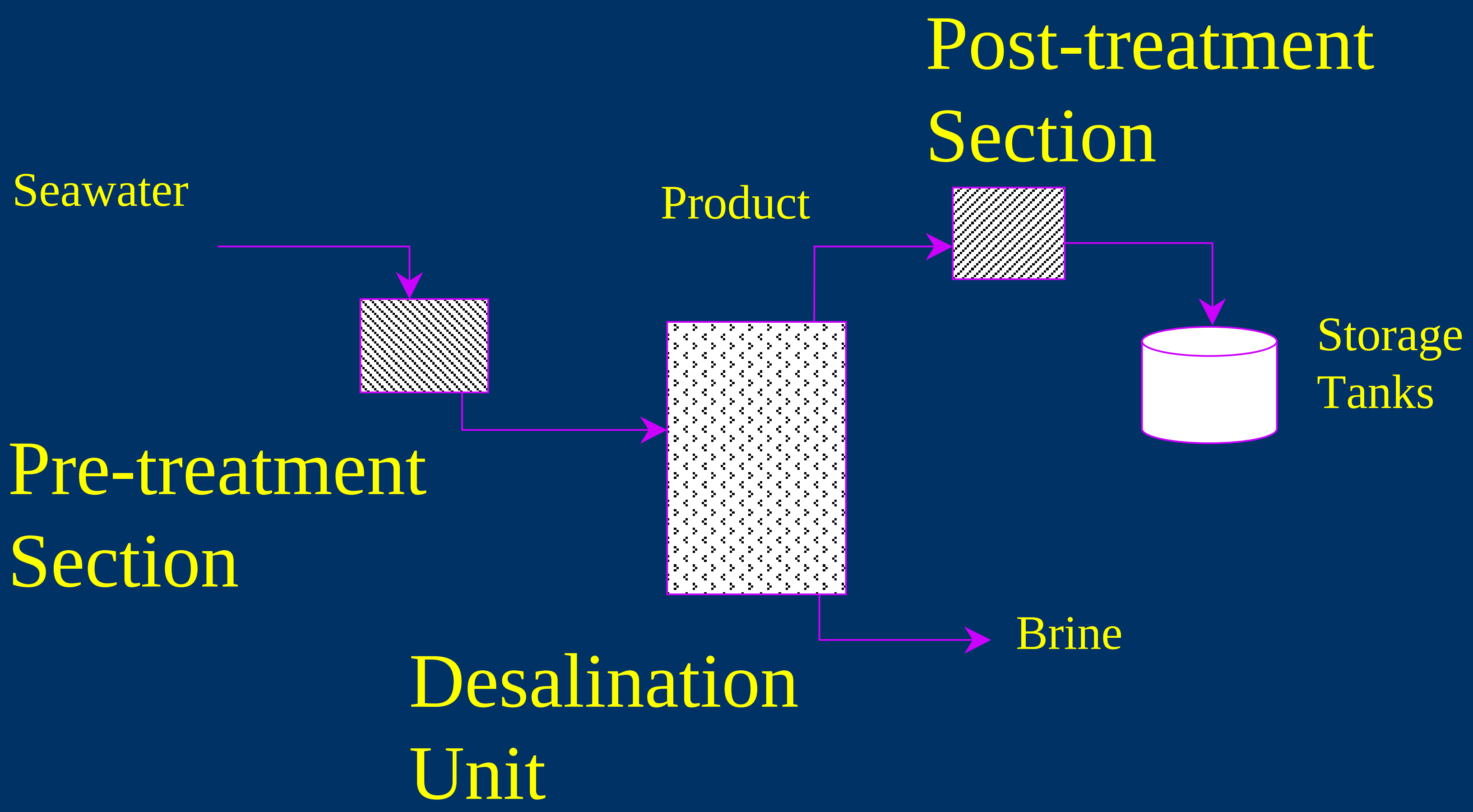
Overview

- ❑ Motivation
- ❑ Status Quo Technology
  - ✓ Thermal processes
  - ✓ Membrane processes
- ❑ DEWVAP Research
  - ✓ Design
  - ✓ Theoretical development
  - ✓ Experimental work
- ❑ Experimental Observations
- ❑ Cost Summary

Motivation

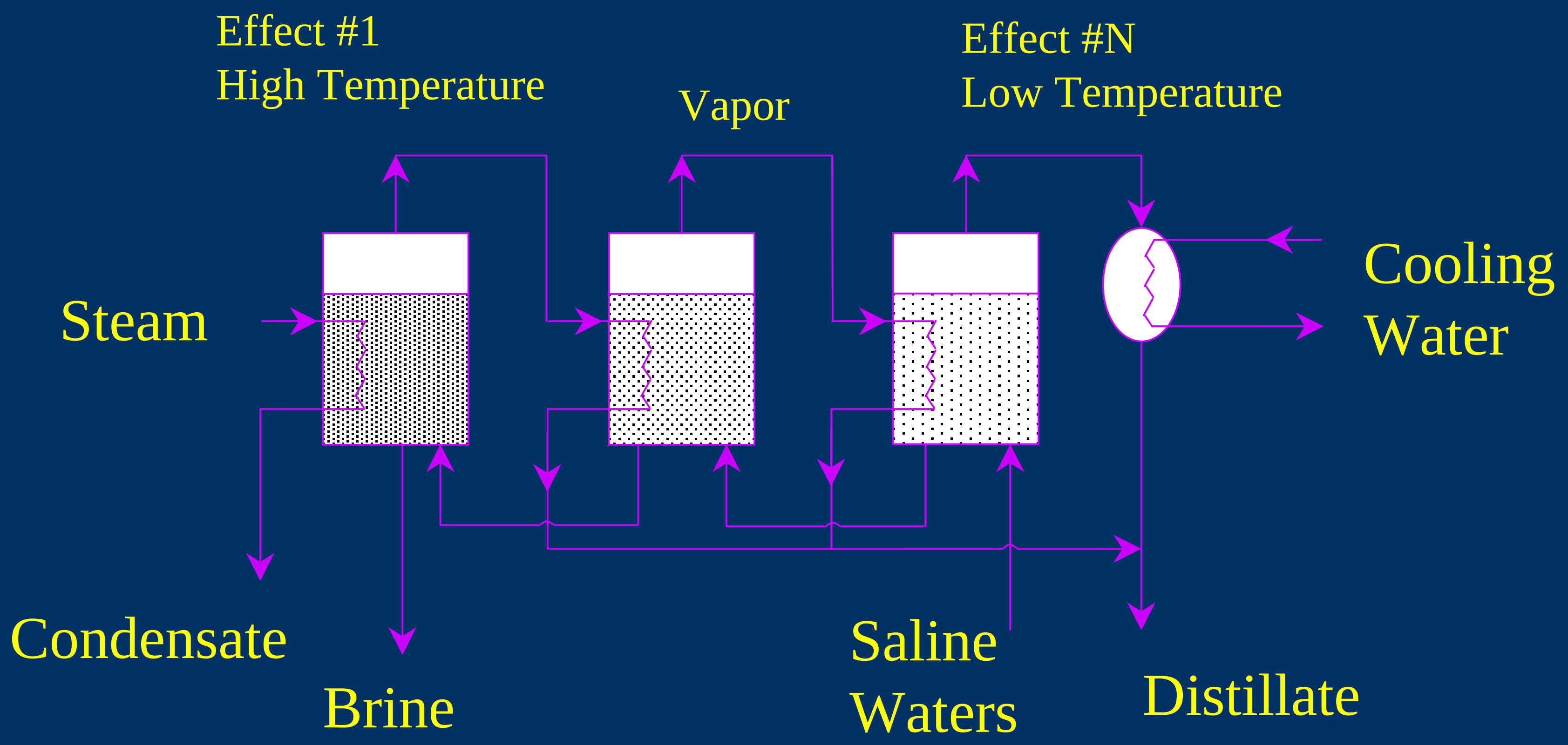
- Decrease in fresh water supply
- Increase of water cost by desalination due to high demand
- Seawater ,Brackish water, Evap Pond Waters
  - ✓ Salinity is defined as g of salt per kg of solution
  - ✓ Seawater
    - Salinity of the world oceans varies from 30-50 g/kg
  - ✓ Brackish water
    - Waters with salinity of 5 g/kg or less
  - ✓ Evaporative Pond Waters
    - Saturated salt solutions of 300 g/kg crystallized

Desalination Plant-General



Bakish, Robert. Practice of Desalination. New Jersey, 1973

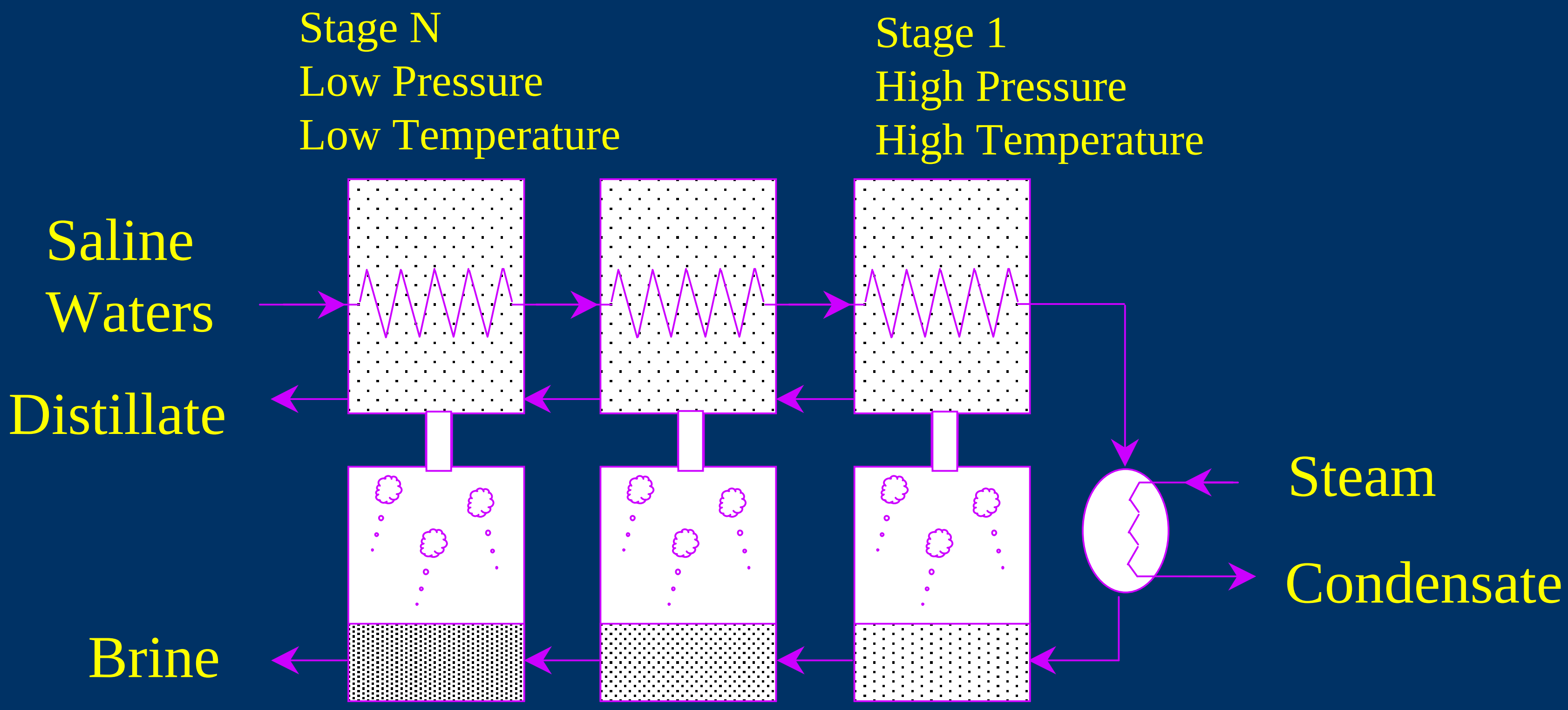
Background - MED



GOR = 0.8*Number of Effects

Spiegler, K.S. and Laird, A.D. K. <u>Principles of Desalination: Part A 2nd ed.</u> New York, 1980

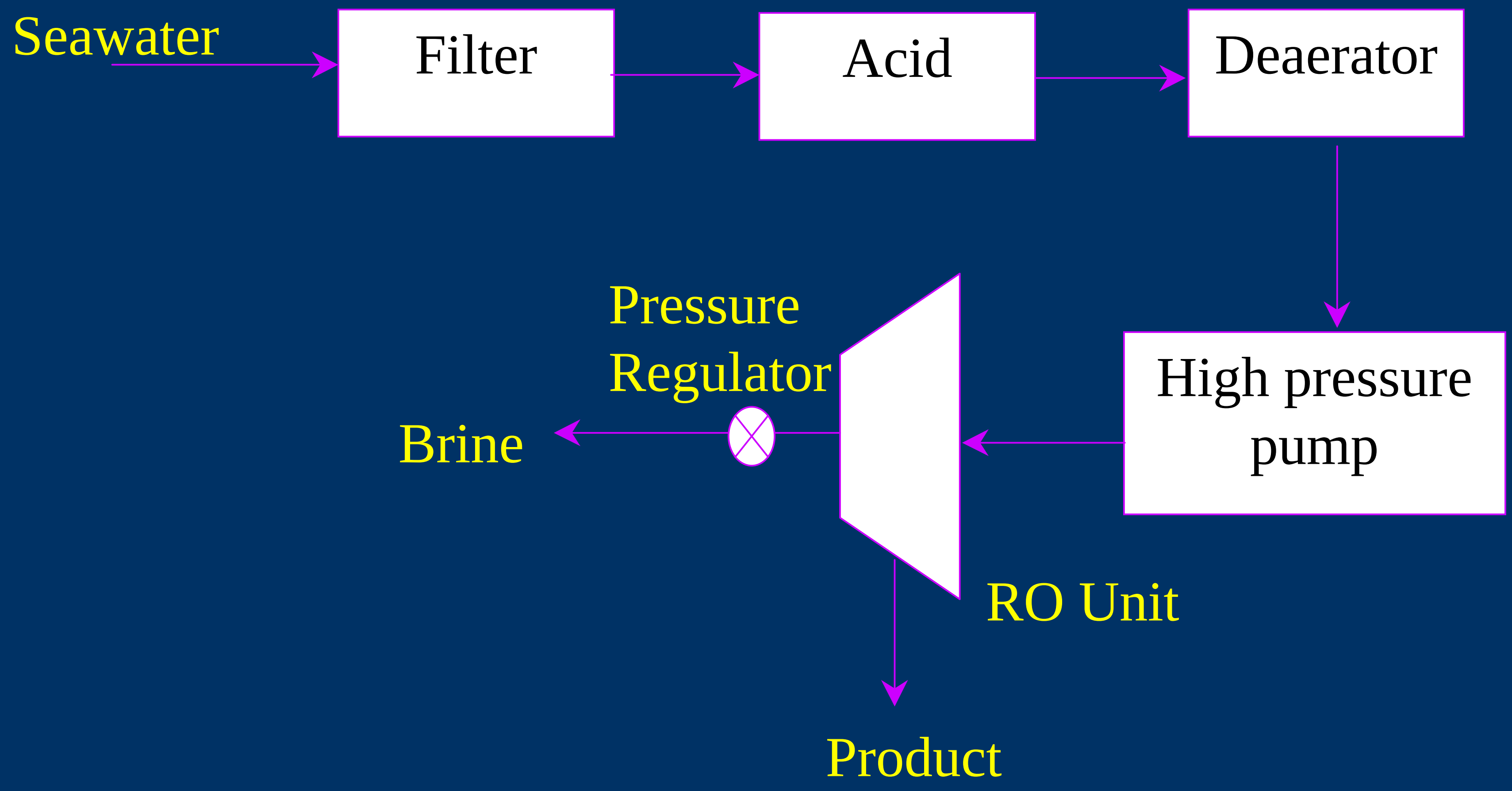
Background - MSF



GOR values range from 4-12

Howe, Everett D. <u>Fundamentals of Water Desalination</u>. New York, 1974

Background - RO

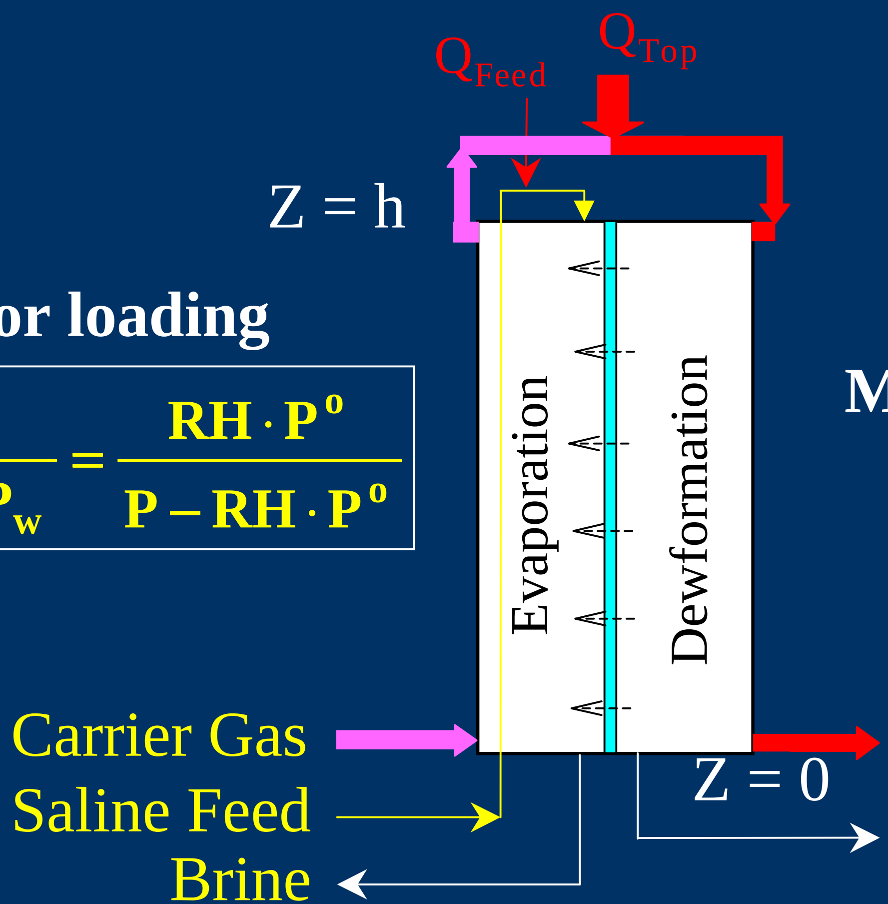


Spiegler, K.S. and Laird, A.D. K. Principles of Desalination: Part B 2nd ed. New York, 1980

Dewvaporation - Theory

Energy reuse factor

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



Vapor loading

$$V = \frac{P_w}{P - P_w} = \frac{RH \cdot P^o}{P - RH \cdot P^o}$$

Molar production density

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

Evap

Dew

Dewvaporation at ASU

- 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

Research Objectives at ASU

- Objective I
  - ✓ Minimum Gamma
  - ✓ Design a tower for the Dewvaporation technique
- Objective II
  - ✓ Develop a mathematical model for the Dewvaporation
  - ✓ Develop an approximate solution of the theory
- Objective III
  - ✓ Scaling phenomena
  - ✓ Different runs on few of the potential designs

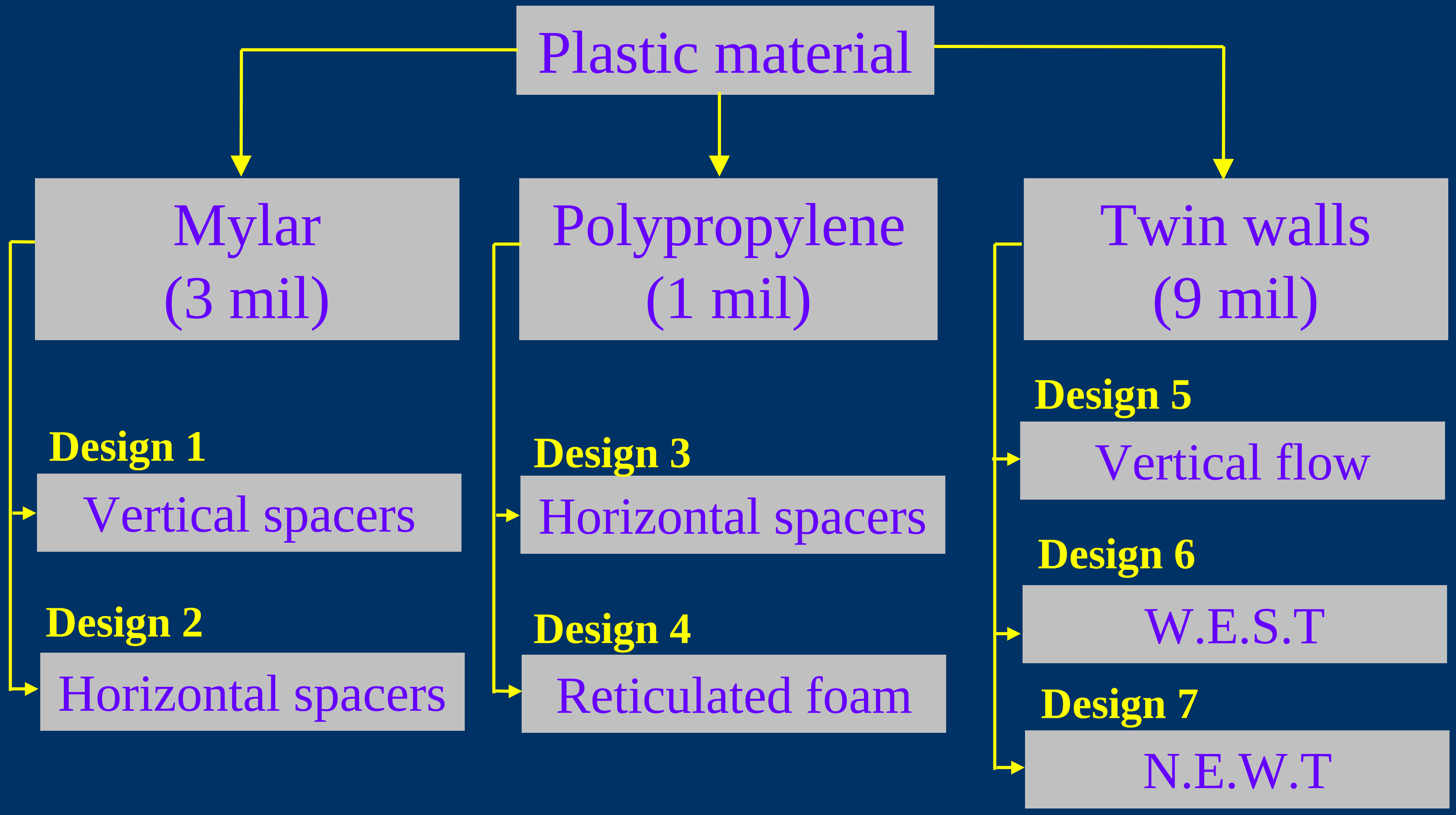
Surface wetting

- Minimum gamma (lb of feed liquid/hr. /ft of width)

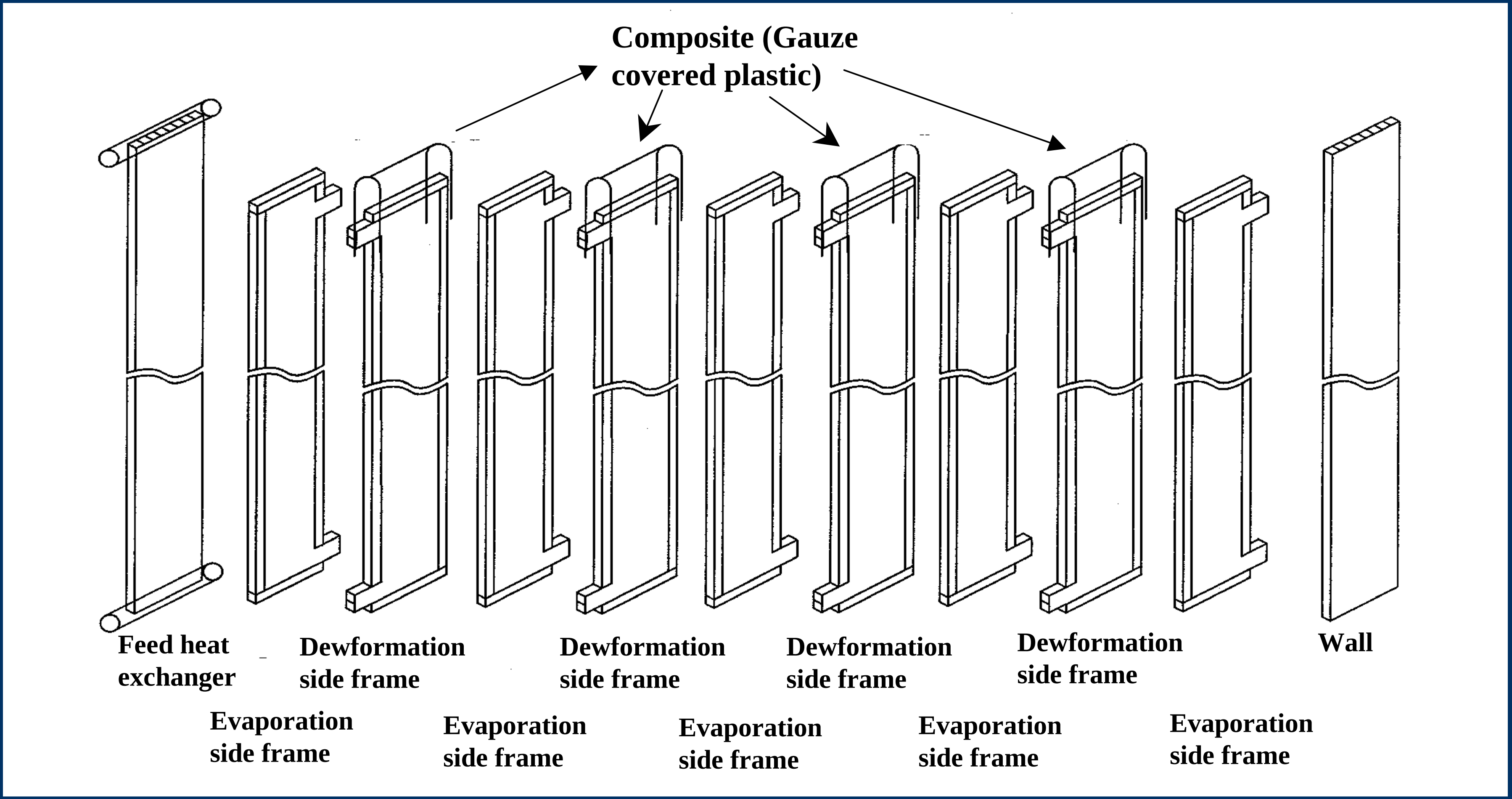
Percent Coverage	Without gauze	With gauze*
REXAM	12	~1
Polypropylene	>12	~1
Polypropylene twin wall	>12	~1

•Nylon

Plastic Design Choices



Dewvaporation - Tower Assembly



Dewvaporation tower – Design 1

- 20 ft^2 effective total heat transfer area
- 12 evaporation and 12 dewformation sides
- REXAM water wettable sheet

Design 2 - Spacers

Spacer for the Evaporation side

Spacer for the Dewformation side

Dewvaporation tower – Design 2

- Total area ~ 55 ft^2
- 5 evaporation sides
- 4 dewformation sides
- 1 liquid heat exchanger
- 19 passes per side

Dewvaporation tower – Design 3

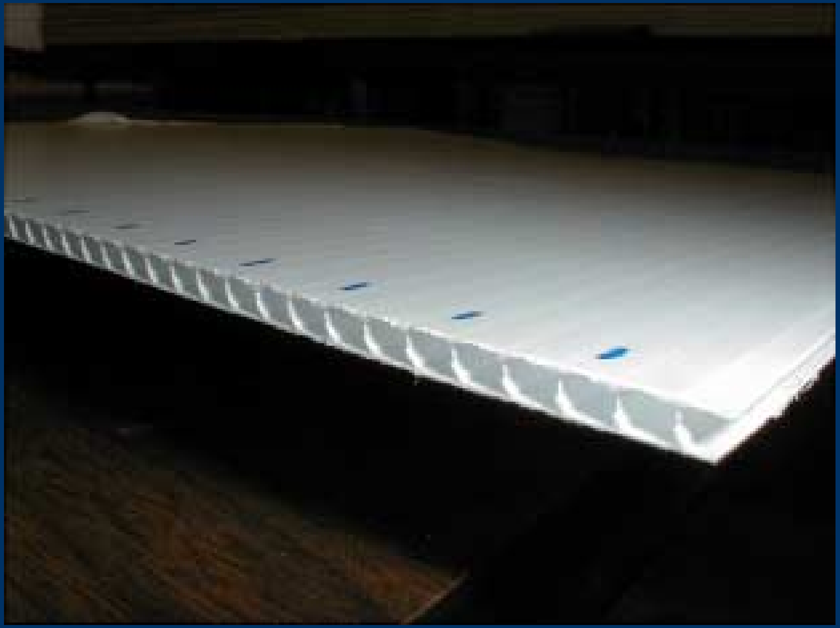
- 5 evaporation chambers
- 6 dewformation chambers
- 1 liquid heat exchanger
- 10 passes per side on evaporation and dewformation
- Thin plastic (1 mil) polypropylene
- Foam spacers
- Issues
  - ✓ Support

Dewvaporation tower – Design 4

- Thin plastic (1 mil)
- Reticulated foam
- Filled dew formation side(no collapsing)
- Issues
  - ✓ Pressure drop increase with wetting

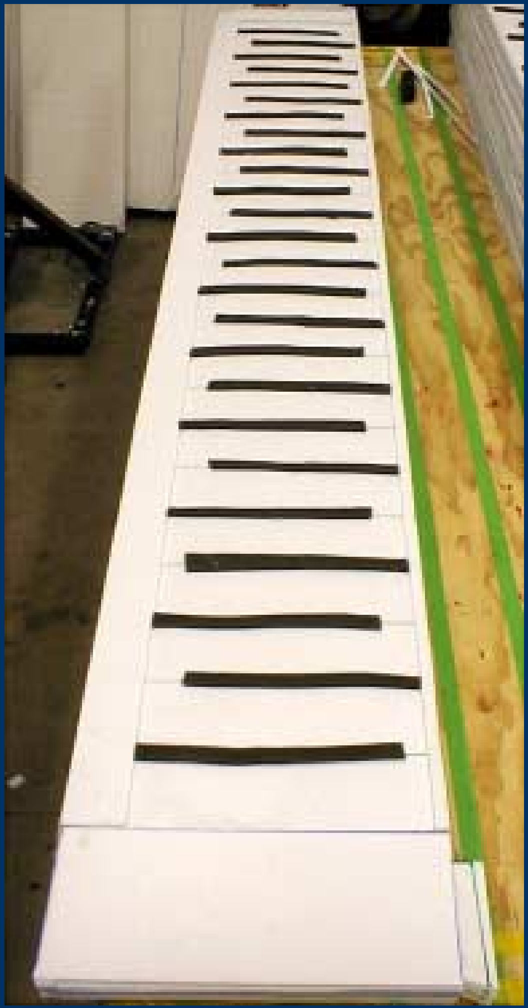
Dewvaporation tower – Design 5

- 9 mil wall thickness
- No horizontal/vertical spacers
- Issues
  - ✓ None



Dewvaporation tower – Design 6

- Horizontal spacers on the evaporation side only



Dewvaporation Tower-Design 7

- 850 square Feet
- W.E.S.T. Twin Design
- 45 lb/hr
- 1ftx2ftx7ft

PROJECTED FACILITY

100,000 gallon/day Plant

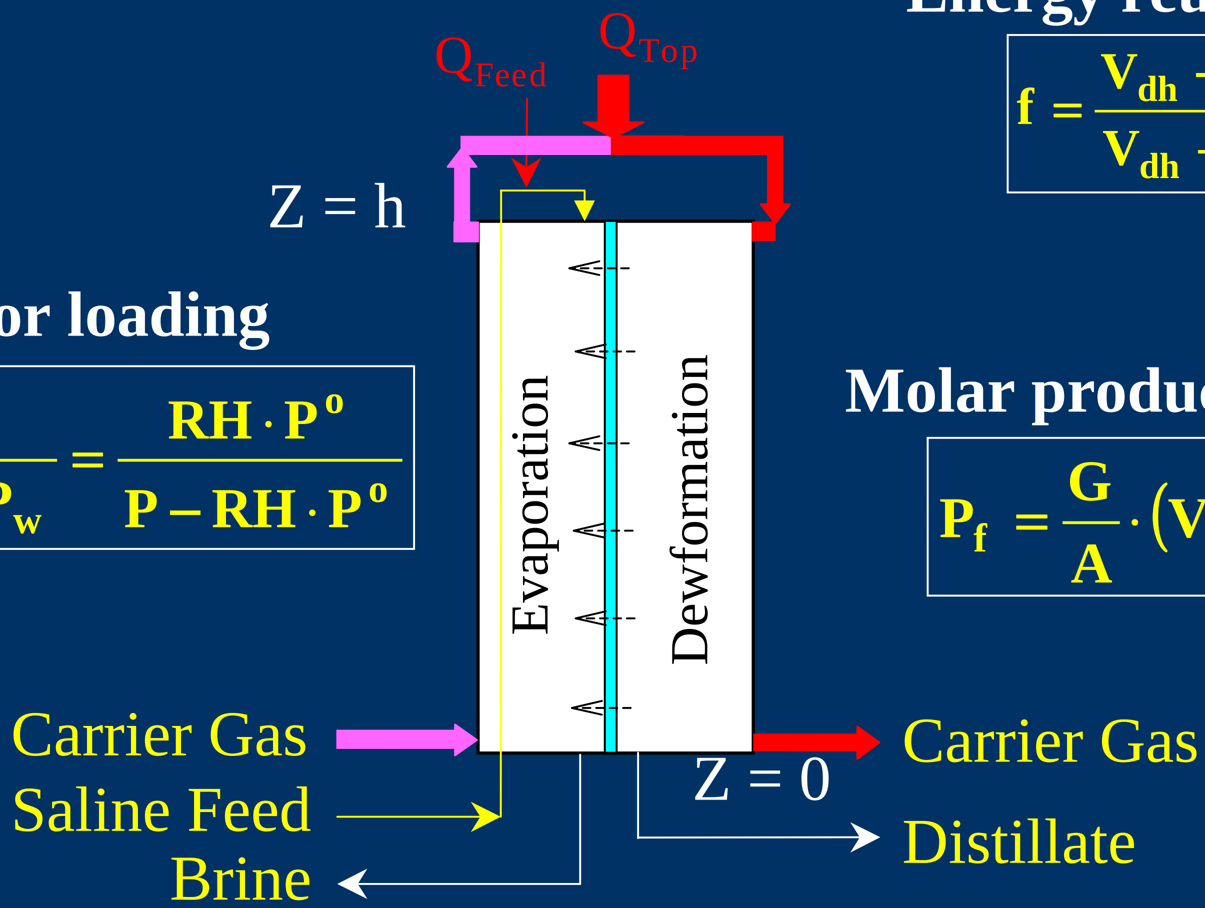
Footprint: 780 square feet

20 feet high

Dewvaporation - Theory

Energy reuse factor

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



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Molar production density

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

Evap

Dew

Dewvaporation - Theory

Overall Heat Transfer Coefficient

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

Resistances

Heat Transfer Coefficient

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

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

Plastic Thickness

Liquid Film Thickness

$$\delta = \left(\frac{3 \cdot \mu \cdot \Gamma}{\rho^2 \cdot g}\right)^{1/3}$$

Theory - Approximation

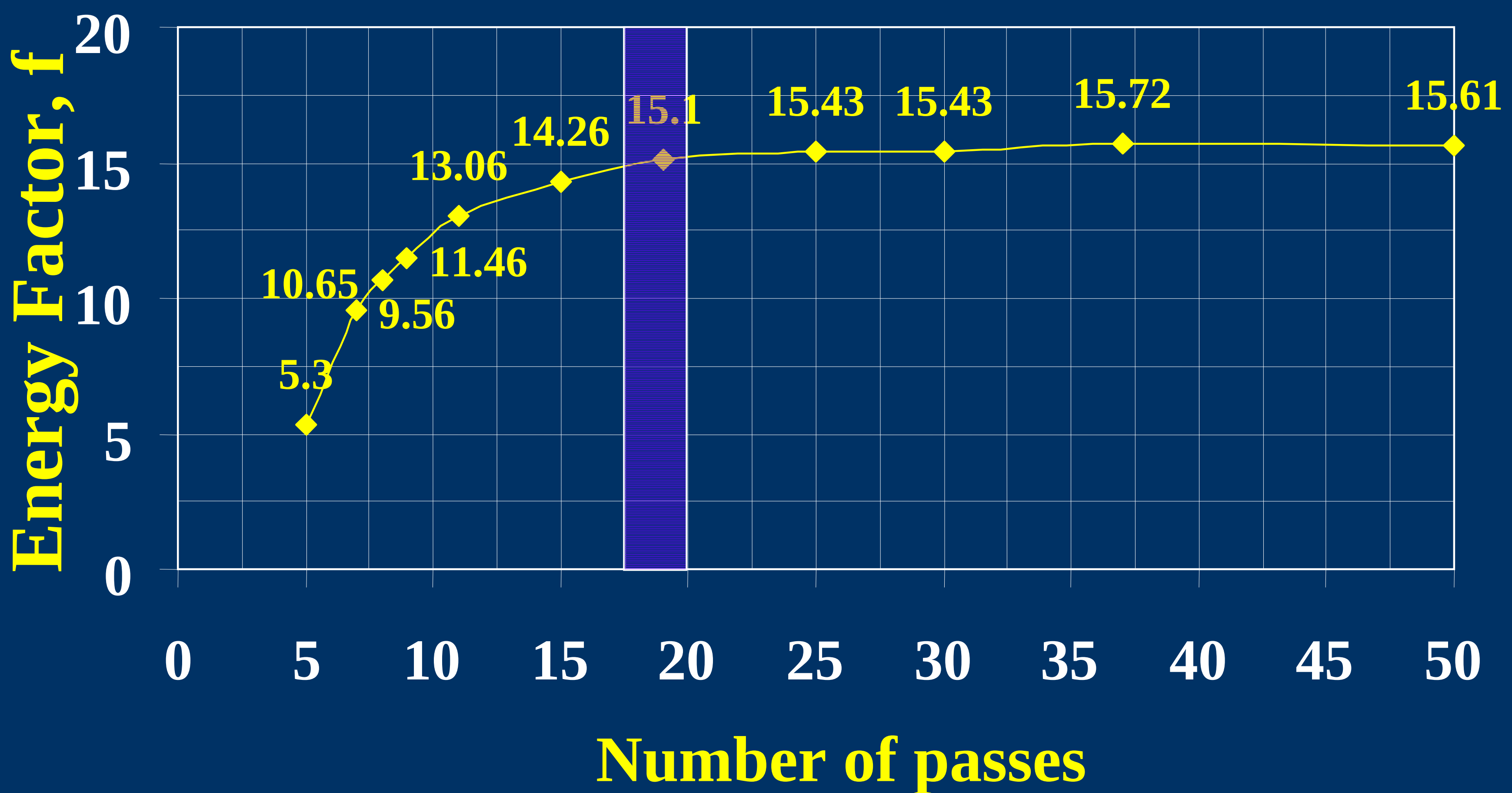
Assumption: **Energy terms of liquid and air are small compared to latent heat of vaporization**

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

$$F = \frac{1}{1 + F_{RH} + F_{\varepsilon} + F_{RH} \cdot F_{\varepsilon} \cdot \left(\frac{6 + 3 \cdot V_{eh}}{3 + 2 \cdot V_{eh}}\right)}$$

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

Cross flow Reduction Effect



Scale

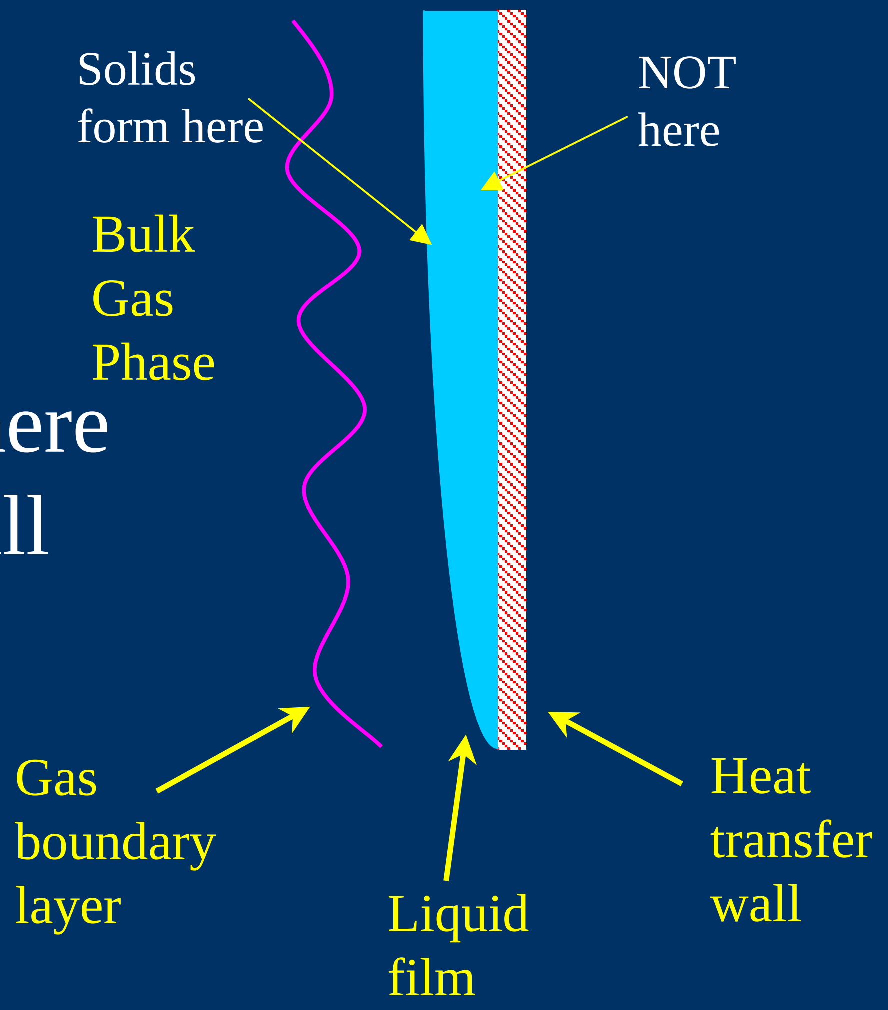
- Defined as a deposit that forms on solid surfaces by enhanced species concentration
- Problem: Reduction of heat transfer coefficient

Preliminary Data - Scale

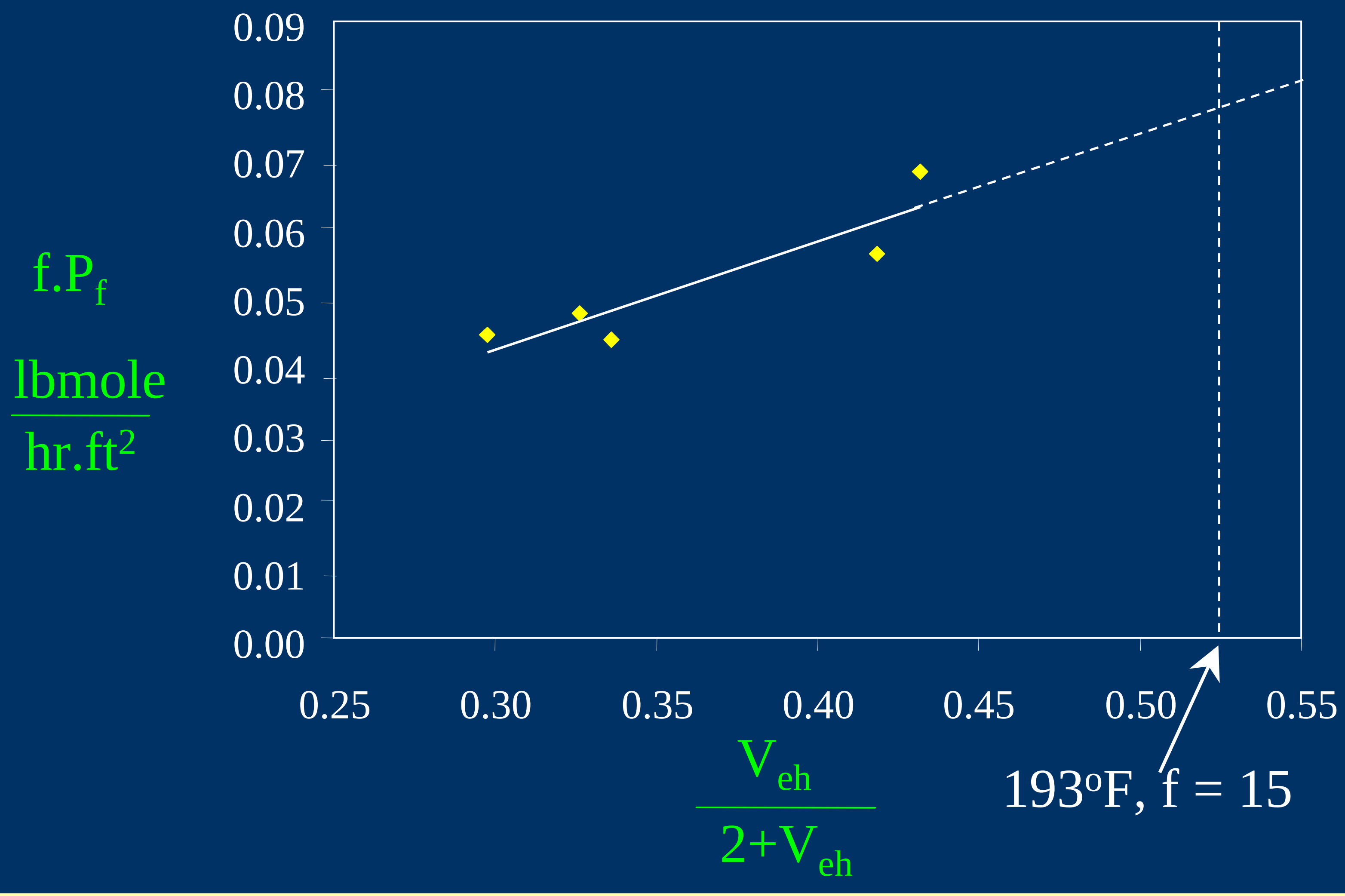
- 85% recovery
- Solids were observed but did NOT adhere to the surface
- No potential scaling problem

Data - Seawater Scaling

- 85% recovery
- Crystals formed at the gas/liquid interface
- Crystals did NOT adhere to the heat transfer wall



Preliminary Data based on Design 1



Sea & Brackish Water Data:Design 2

Run #	Distillate (lb/hr)	Steam (lb/hr)	GOR	GOR (no heat loss)
729	**3.04**	**0.37**	**8.96**	**17.74**
805c	**2.22**	**0.29**	**7.69**	**19.34**
806*	**2.60**	**0.27**	**9.46**	**28.25**
809*	**1.98**	**0.37**	**5.29**	**13.34**

* seawater with 42000 ppm

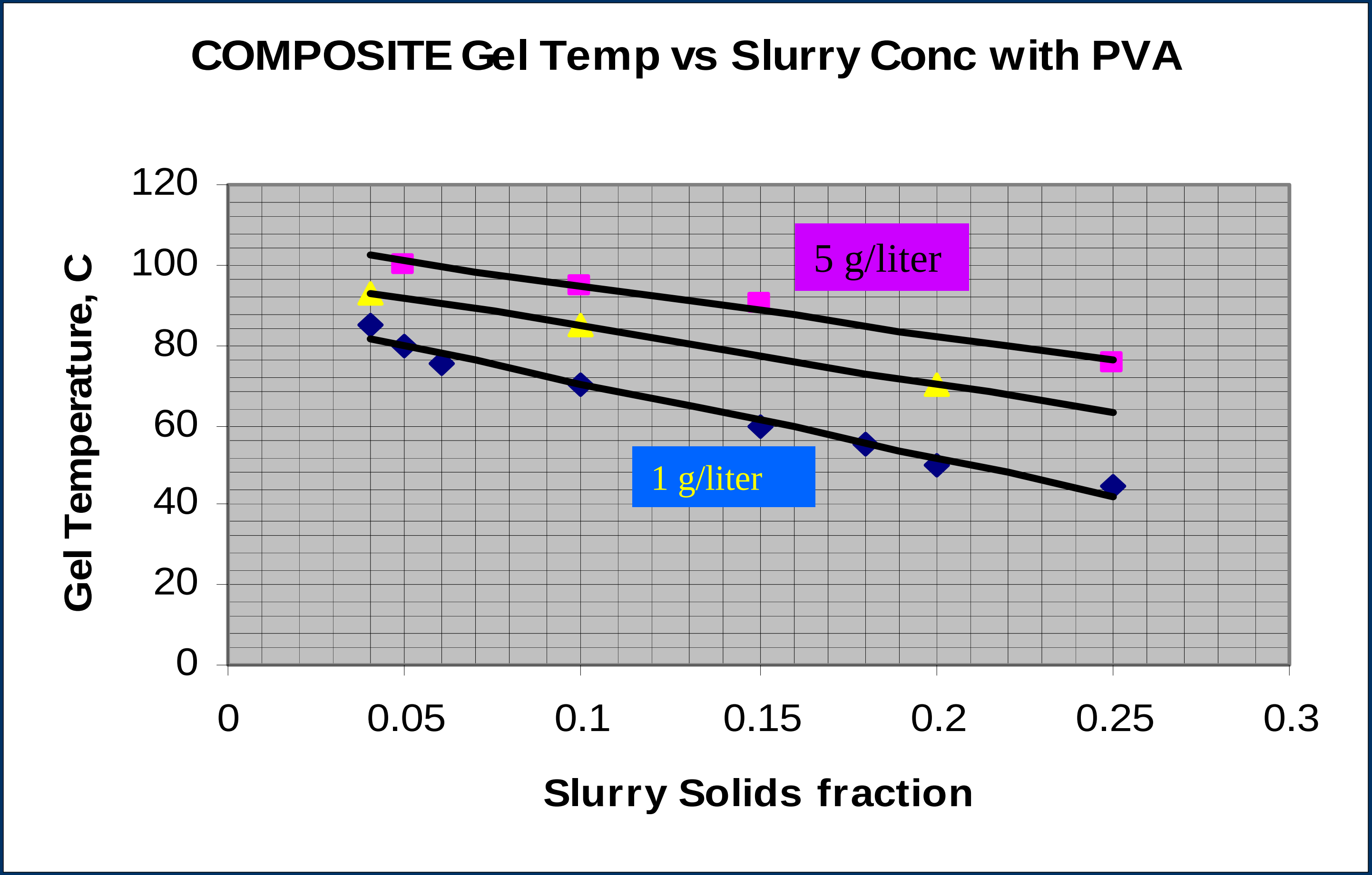
CMP Slurry Operational Data

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

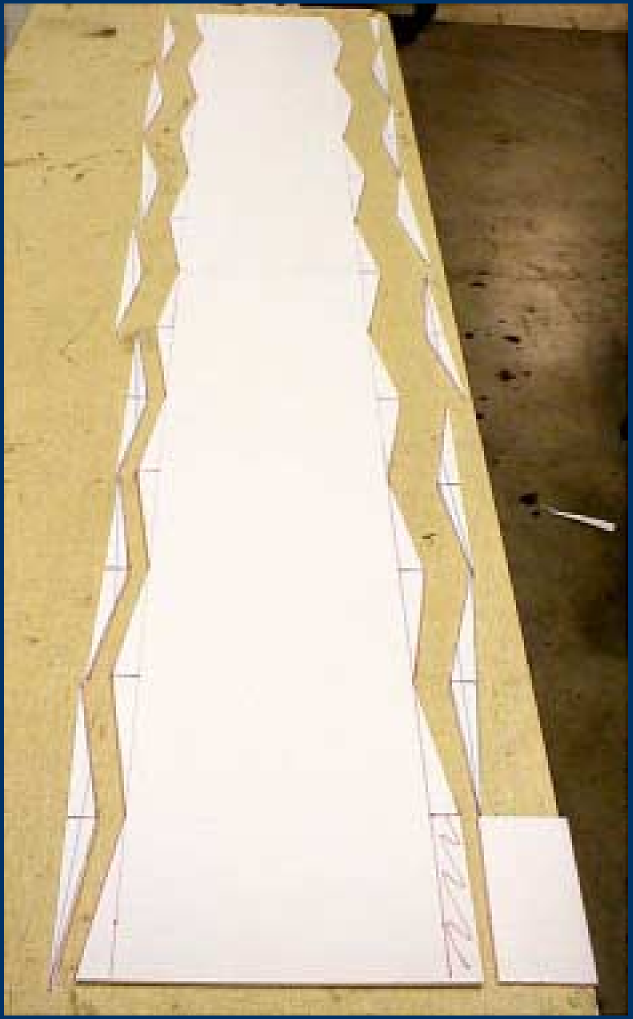
CMP : PVA GEL SUPRESSION



PVA will Prevent Gel Formation in the Dewvaporation Towers

Air flow correction - Design 7

- Improved design (N.E.W.T) where cross flow occurs on the dewformation side instead of the evaporation side
- Eliminates spacers on Dew formation side



Economics (100,000 gallons per day)

Design Heat Source	Capital Cost ($)	Operating Cost ($/1000 gallons)
Natural Gas @ $0.36/therm	$100,900	3.67
Desiccant Enhanced	$97,400	2.67
Waste Heat @ $1/1000 lb steam	$85,900	1.39

Summary

- ✓ No potential scaling
- ✓ Operated at atmospheric pressure and below boiling point
- ✓ No clogging of membranes (no additional cost for cleaning / replacing membranes)
- ✓ Demonstrated CMP water reclamation
  - (at least 90% more with PVA)
- ✓ Potential Ultra-Pure Water Preparation
  - (leaks 10 ppm less with manufactured units)
- ✓ Potential Plating & Post etch Clean Reclamation
  - (like evaporation Pond Waters)

Acknowledgements

- United States Department of Interior, Bureau of Reclamation (Brackish & Sea Water)
- Salt River Project(Evap Ponds Crystallizer)