



Humidification Dehumidification (HDH): From Theory to Plant

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Water Arabia 2015

Introduction

The solar Still

The Idea:

Simple

Old Technology

Low Productivity

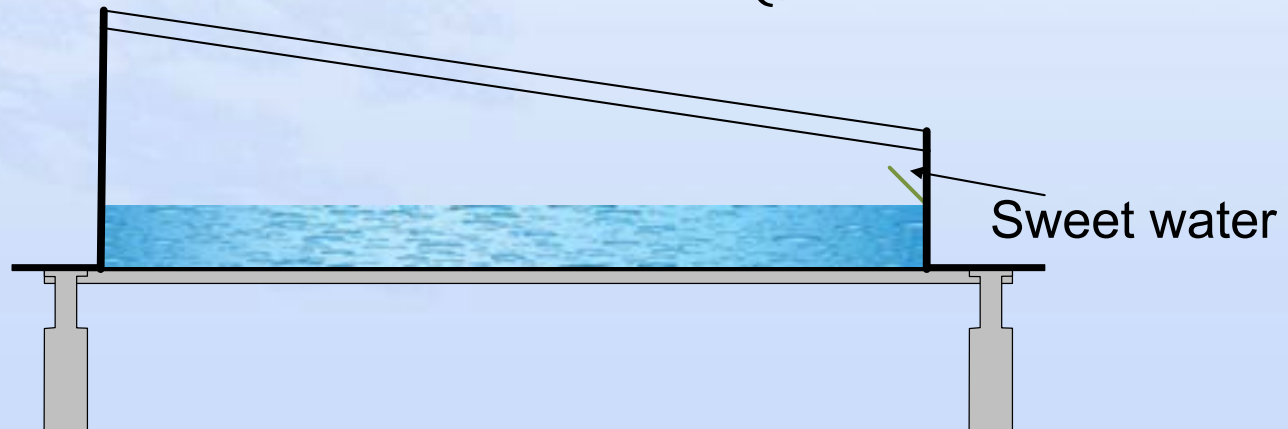
Maintenance

Low GOR

Easy to build

Energy Recovery

Convenient



Introduction

The HDH

- ✿ It uses separate components for each of the thermal processes,
- ✿ This allows each component to be independently designed
- ✿ Much greater flexibility in design of thermodynamic cycle for vaporizing water into air and subsequently condensing vapor

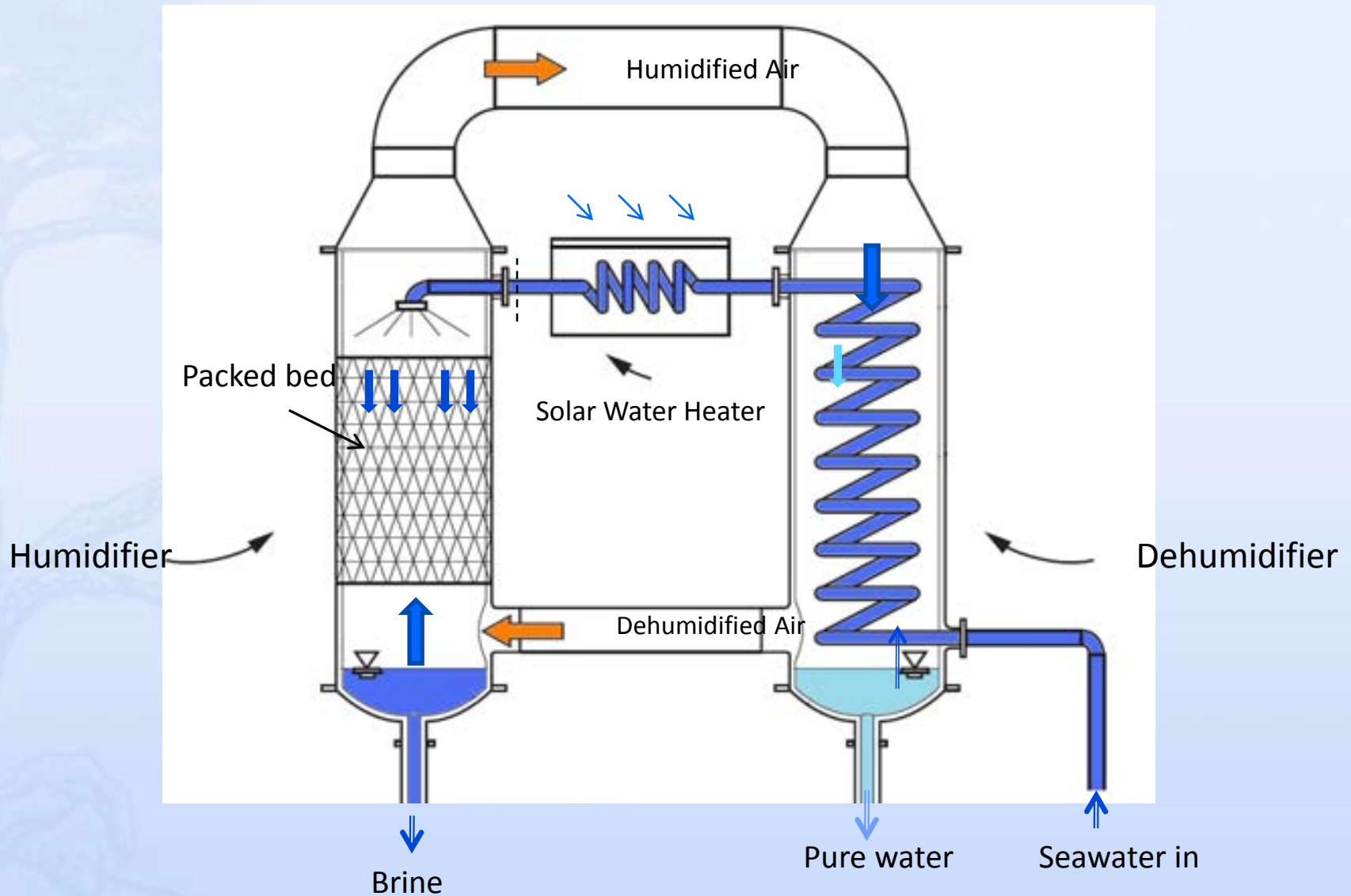
Introduction

- * The advantage of HDH over a solar still is a significantly
 - * Higher GOR
 - * Smaller total area of solar collector for a given water demand.
- * More broadly, HDH systems are regarded as having an advantage over some other technologies, such as reverse osmosis,
 - * they involve relatively simple, inexpensive components and
 - * can operate over a wide range of raw water quality without the need for complex maintenance operations.

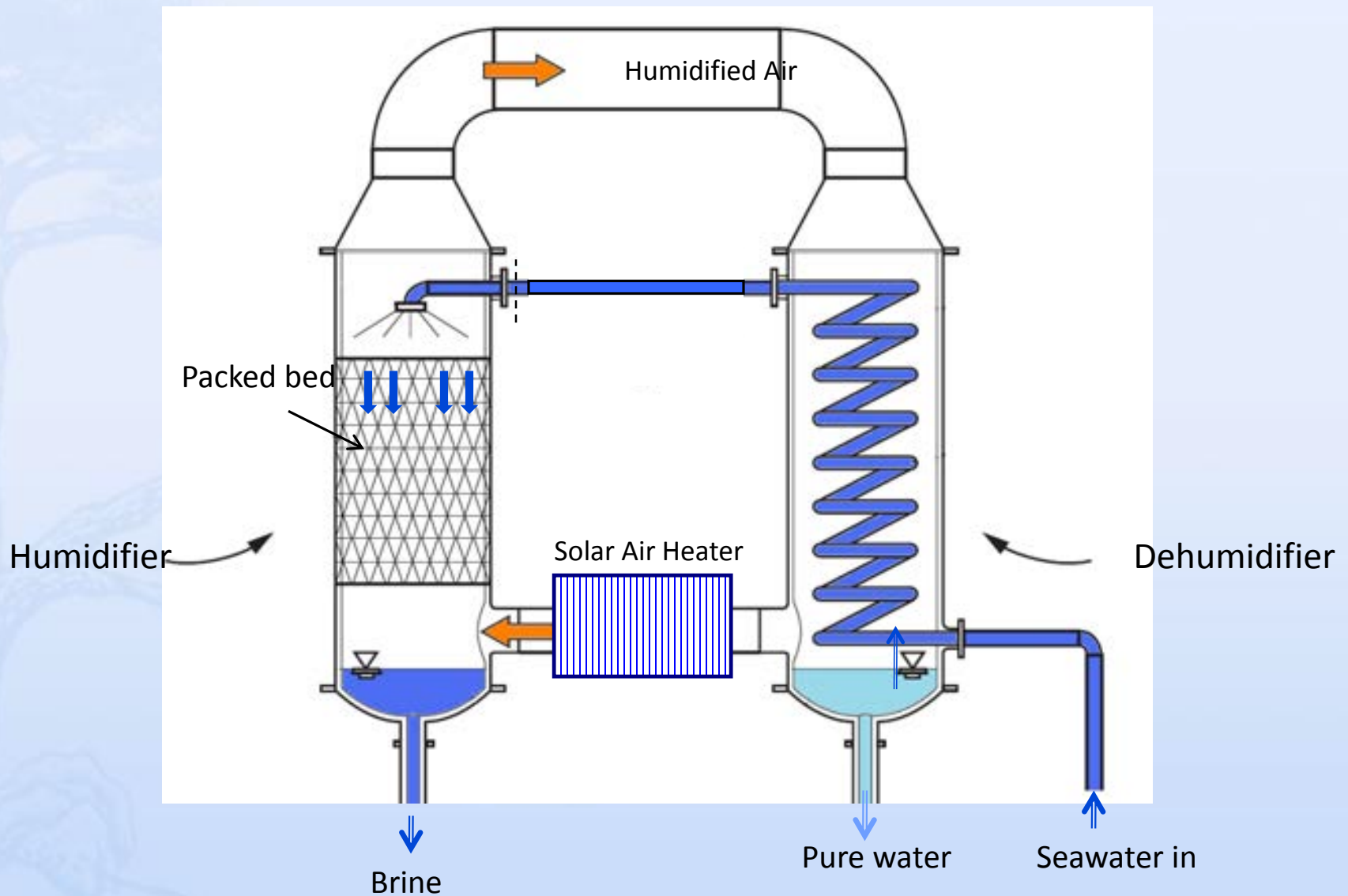
Introduction

- ✿ This makes HDH more suitable for deployment in the developing world, where capital investment and technical support may be limited.
- ✿ Flexibility with water intake *Quality*
- ✿ The basic drawback of the HDH system is that the thermal energy requirements are still relatively high in comparison to other technologies.

How HDH system works?

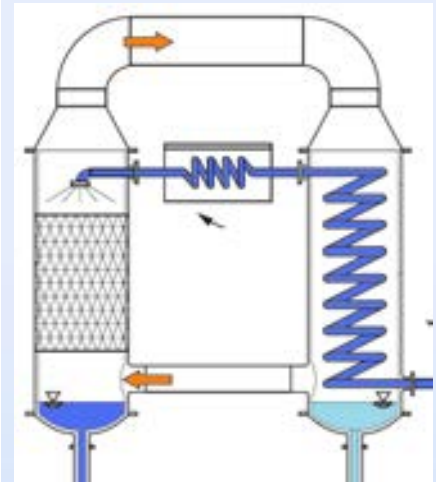
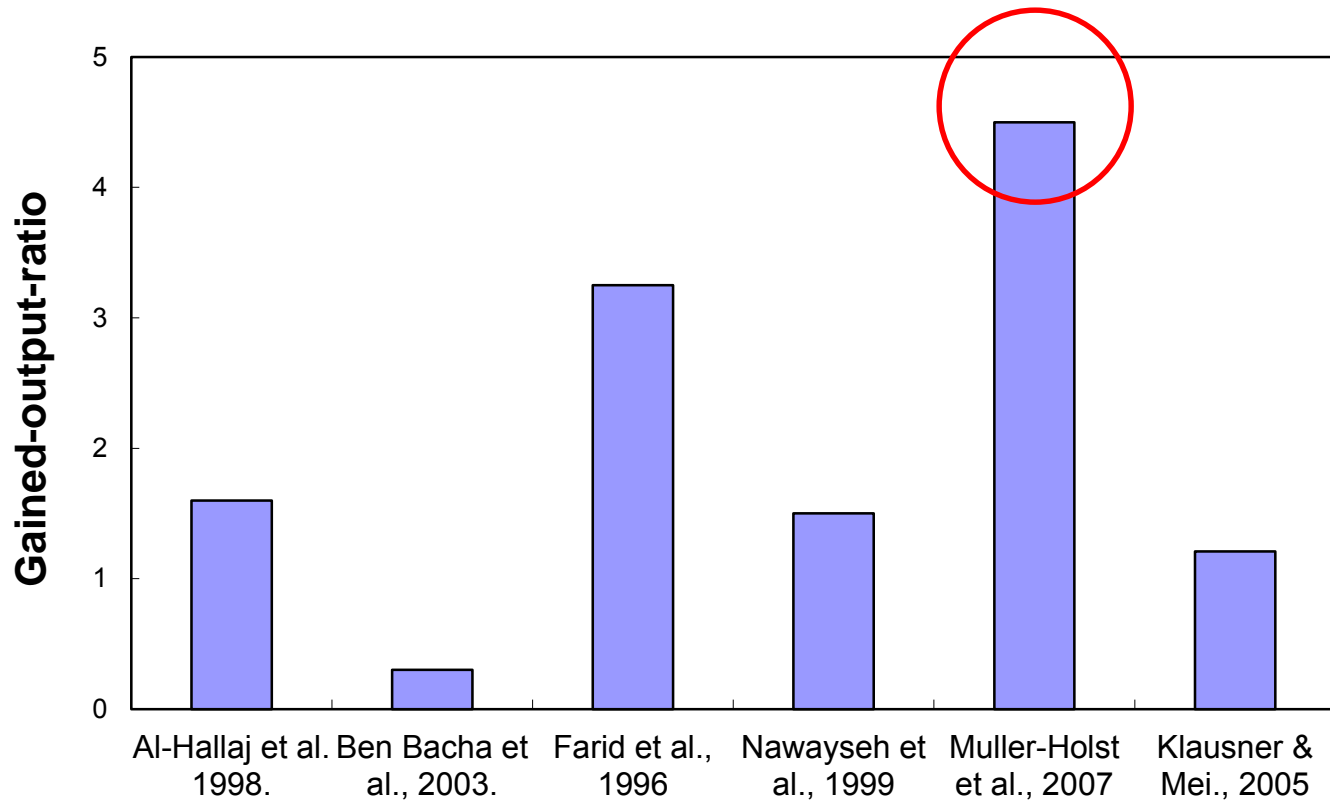


How HDH system works?



Best HDH system has GOR of 4.5

Less than the worst desalination system ...



G. Narayan, M. Sharqawy, K. Summers, J. Lienhard, S. Zubair and M. Antar, "The Potential of Solar-Driven Humidification-Dehumidification Desalination for Small-Scale Decentralized Water Production", *Renewable and Sustainable Energy Reviews* 14(4), pp. 1187-1201, 2010.

Improvements in HDH system

Can HDH compete with RO and MED?

Cycle Components

Seawater properties
Humidifiers models
Dehumidifiers models
Solar Heater models
Solar Heater design
Solar Heater tests
Thermal storage

HDH Cycle Analysis

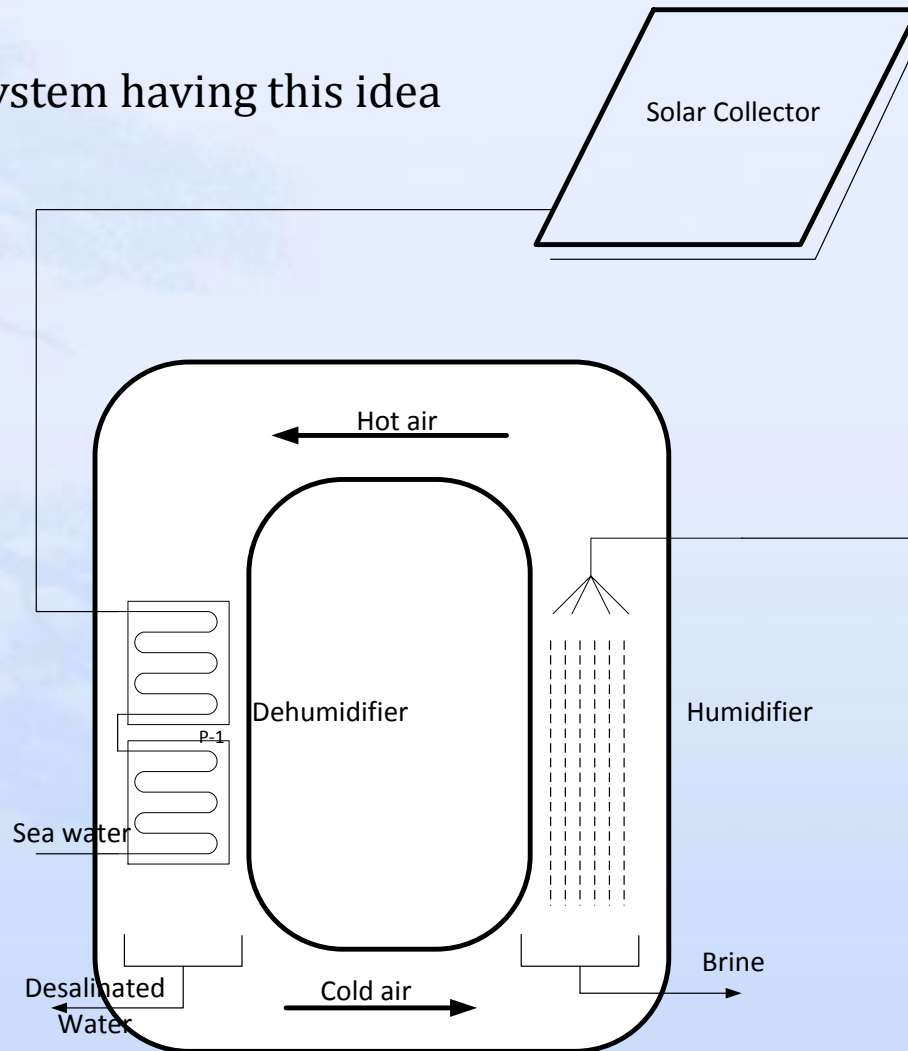
Energy analysis
Exergy analysis
Cycle configurations
Cycle optimization
New cycles (2 US patents)

Classification

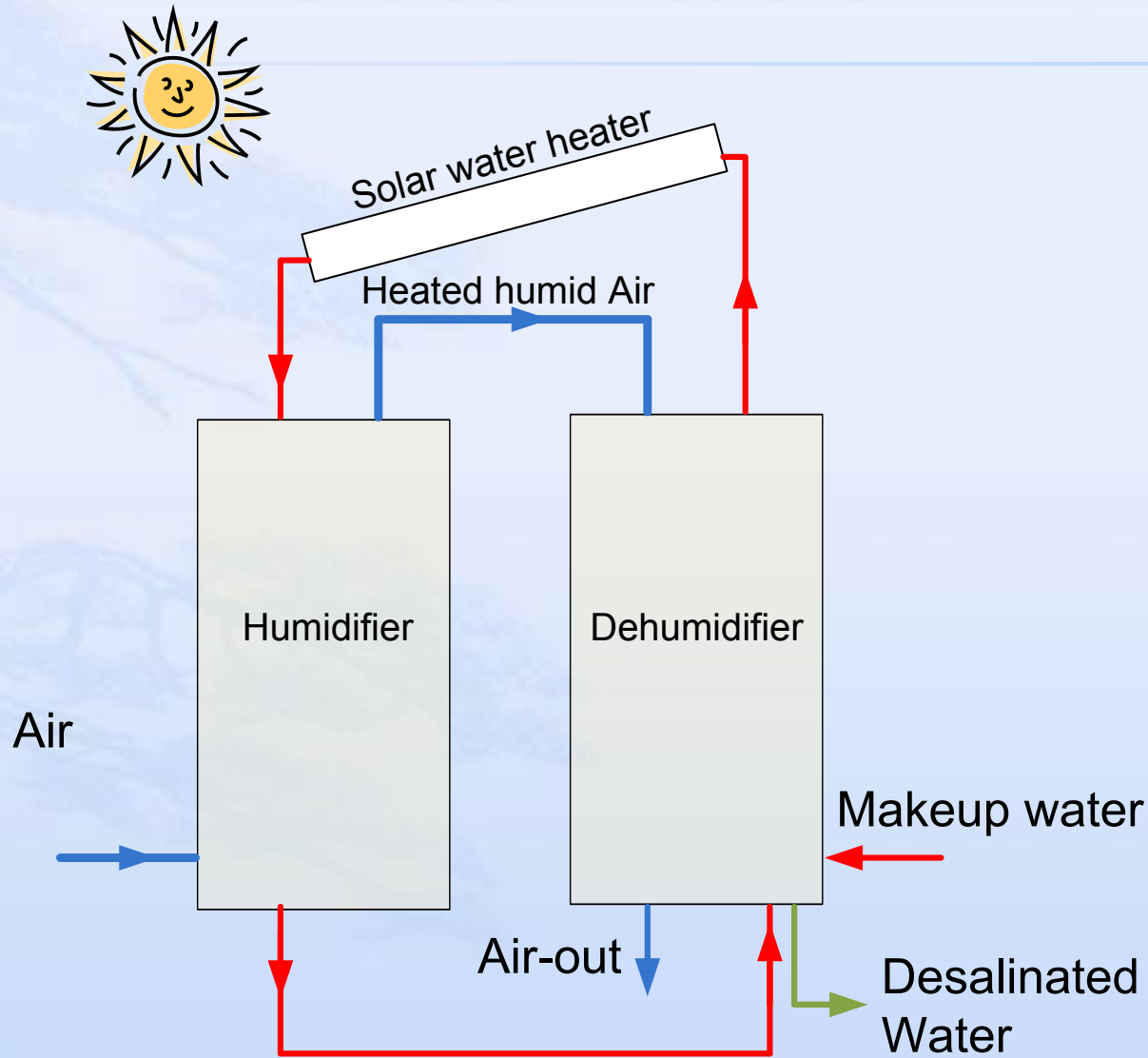
- ✿ HDH cycles may be classified according to whether air or water is heated
- ✿ According to whether the air or water circuit is open or closed loop.
- ✿ A water heated, open-air closed-water cycle is shown in Fig.1.
- ✿ Air heated cycles with open loop water and air, closed-air and open-water loops, and closed-water with open-air loops are shown in Figs. 2, 3, and 4, respectively.

Water heated cycle

El-Hallaj et al. built a system having this idea

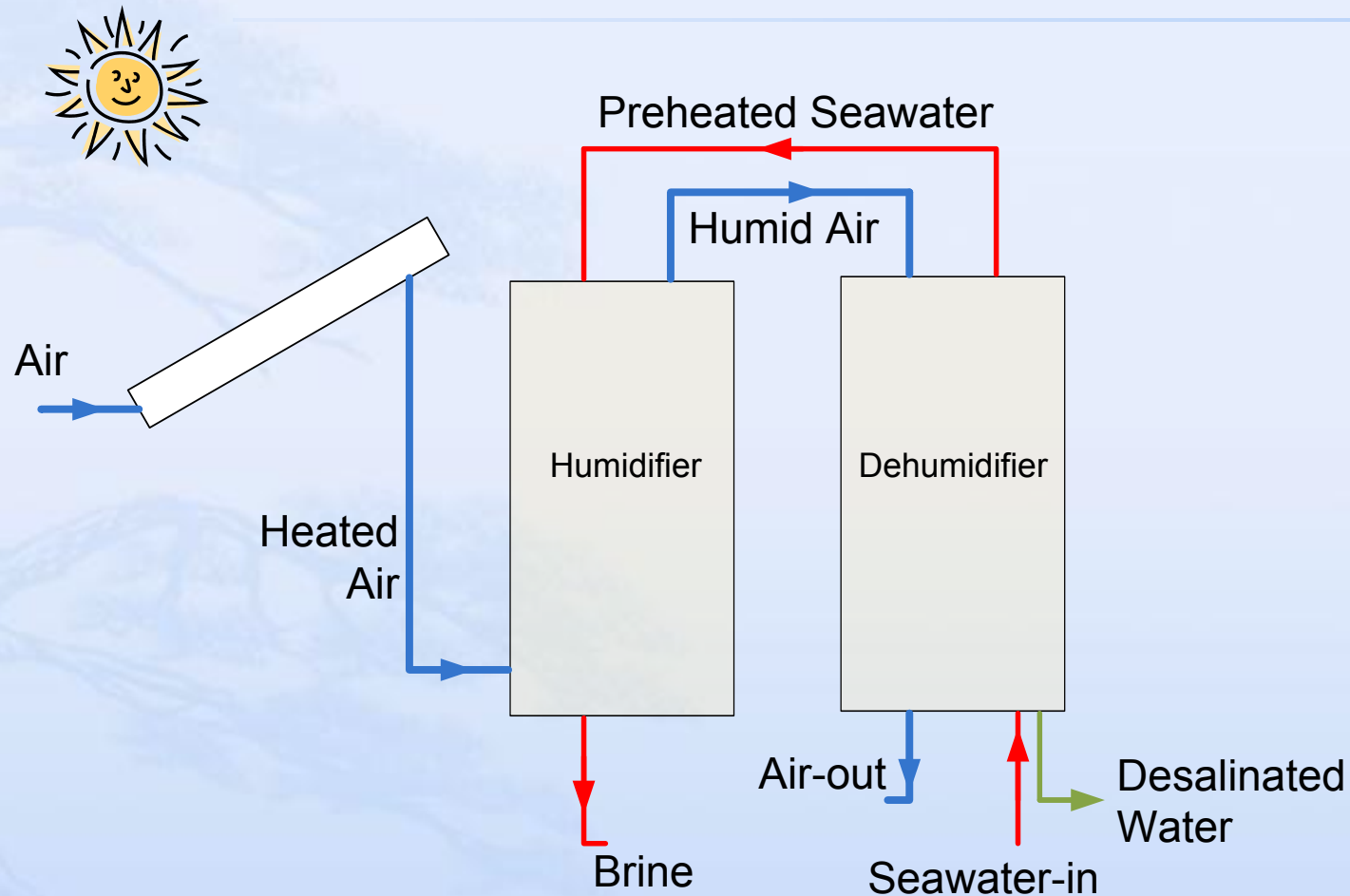


Classification



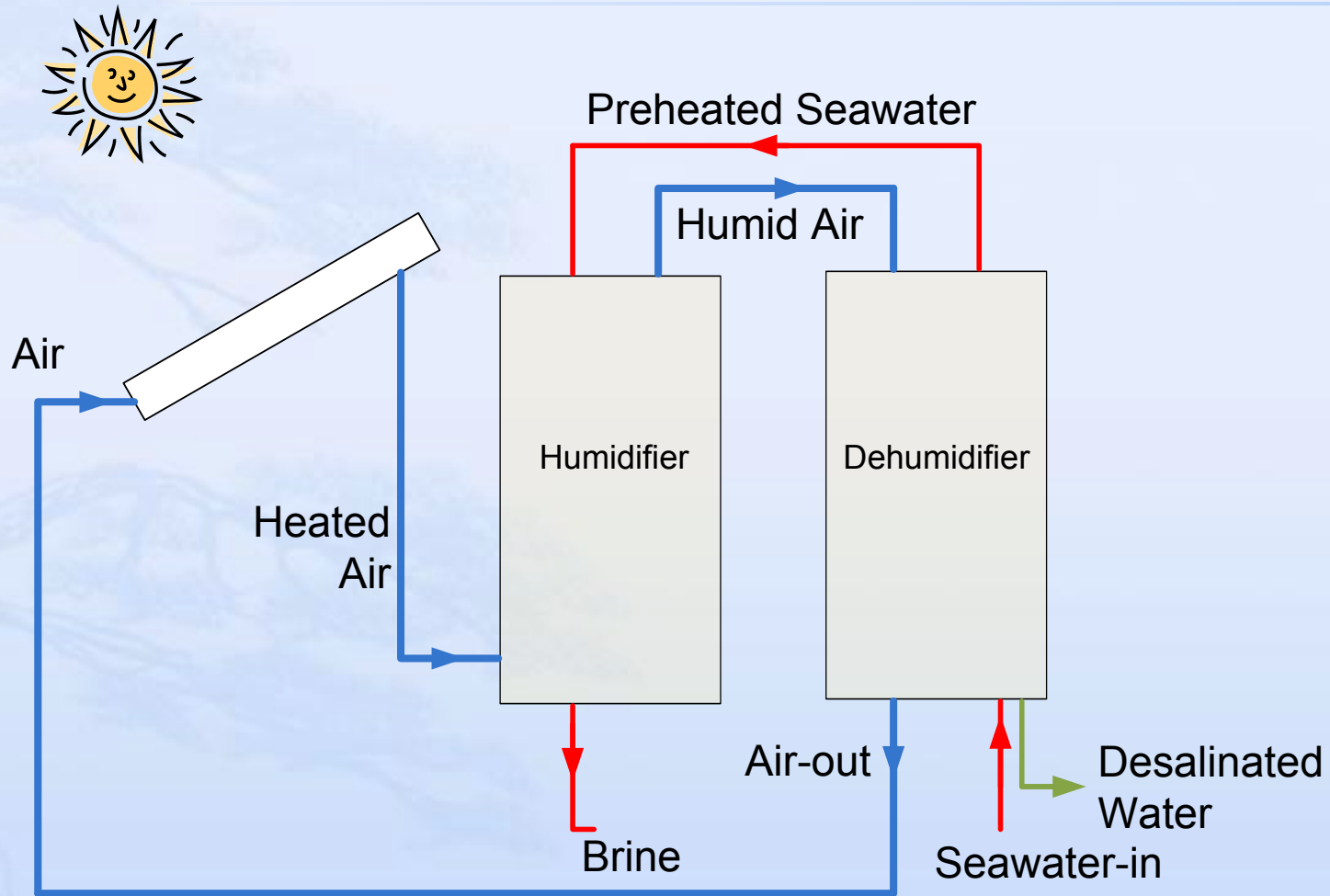
Water heated system with open air and closed water loops

Classification



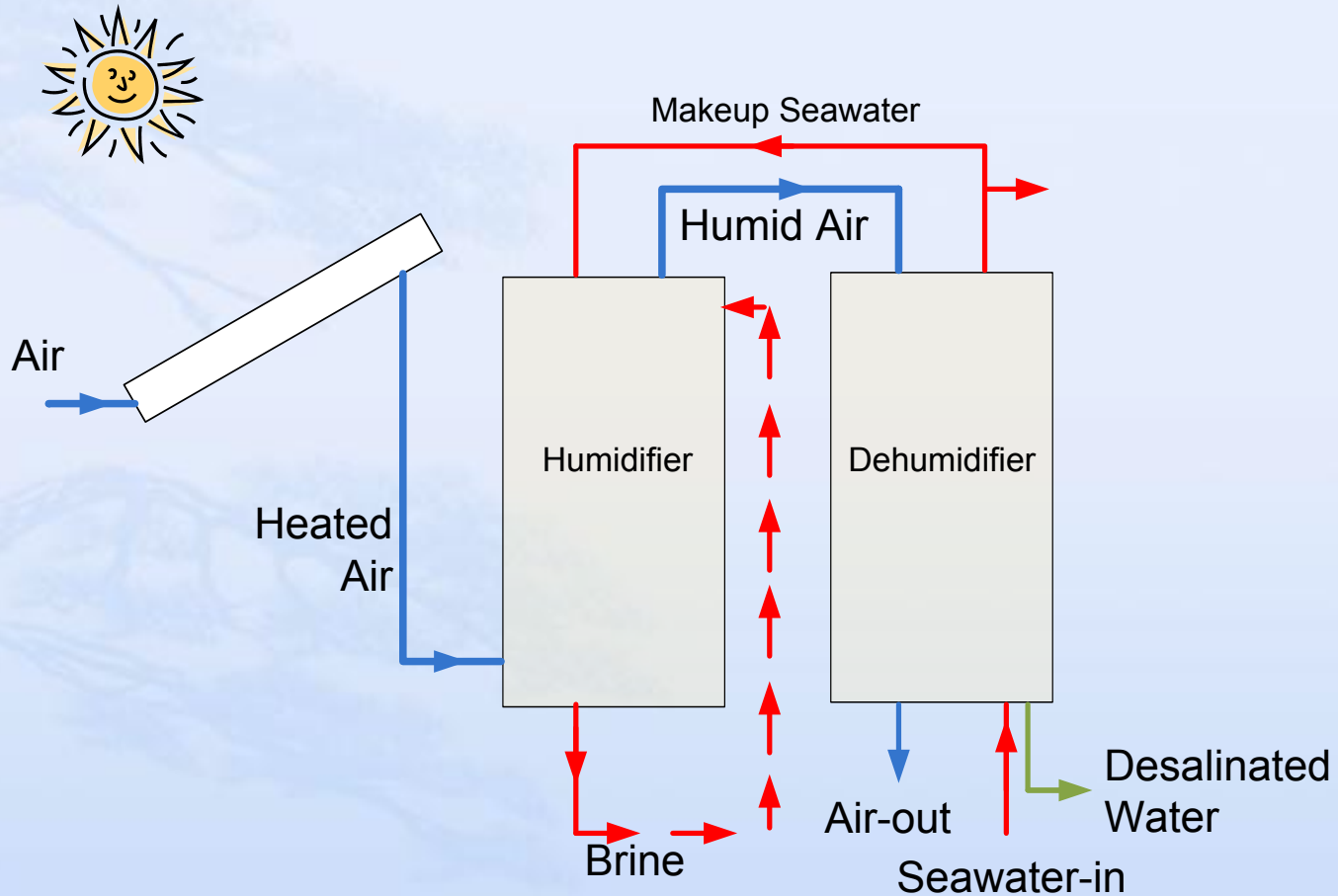
Air-heated cycle with both air and water streams open.

Classification



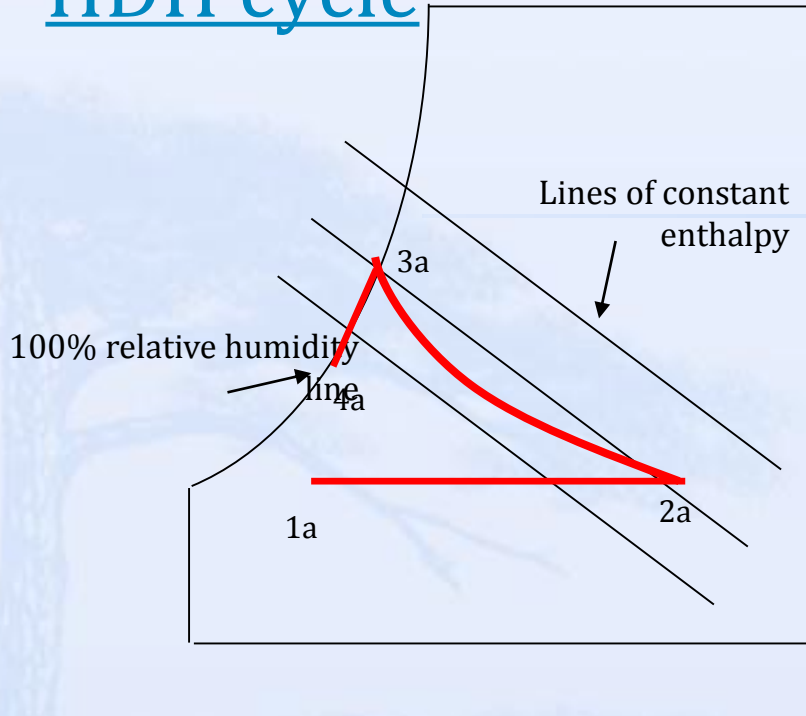
Air heated cycle with closed-air loop

Classification



Air heated cycle, closed water loop

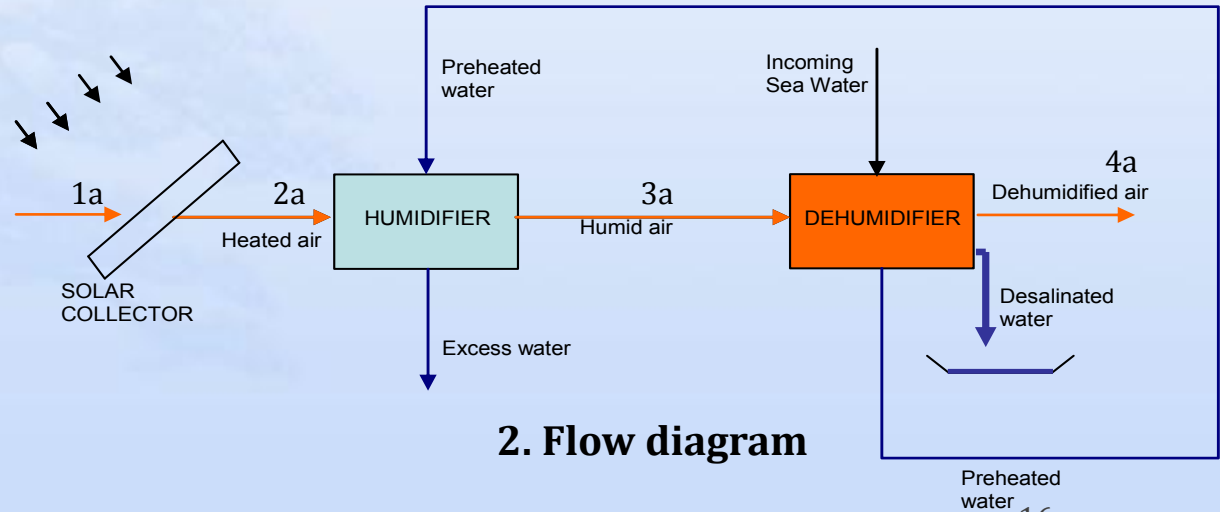
HDH cycle



Humidity ratio
(kg/kg of dry air)

1. Psychrometric Processes

Humidification process is very similar to that of a cooling tower



2. Flow diagram

Preheated water

Multi Stage System (Chafiq)

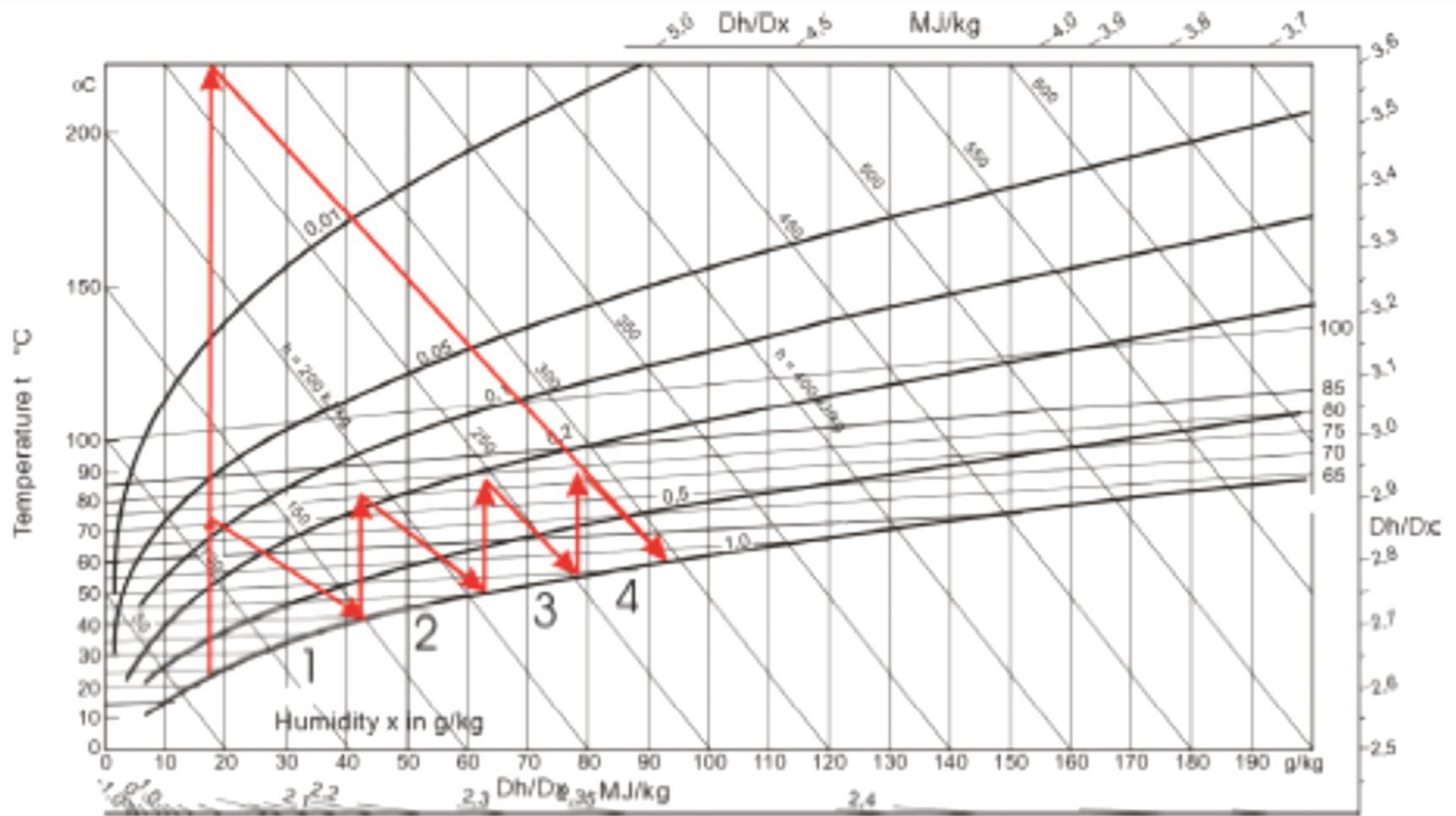


Fig. 1. $h-x$ diagram with stepwise heating/humidifying process.

Multi Stage System (Chafiq)

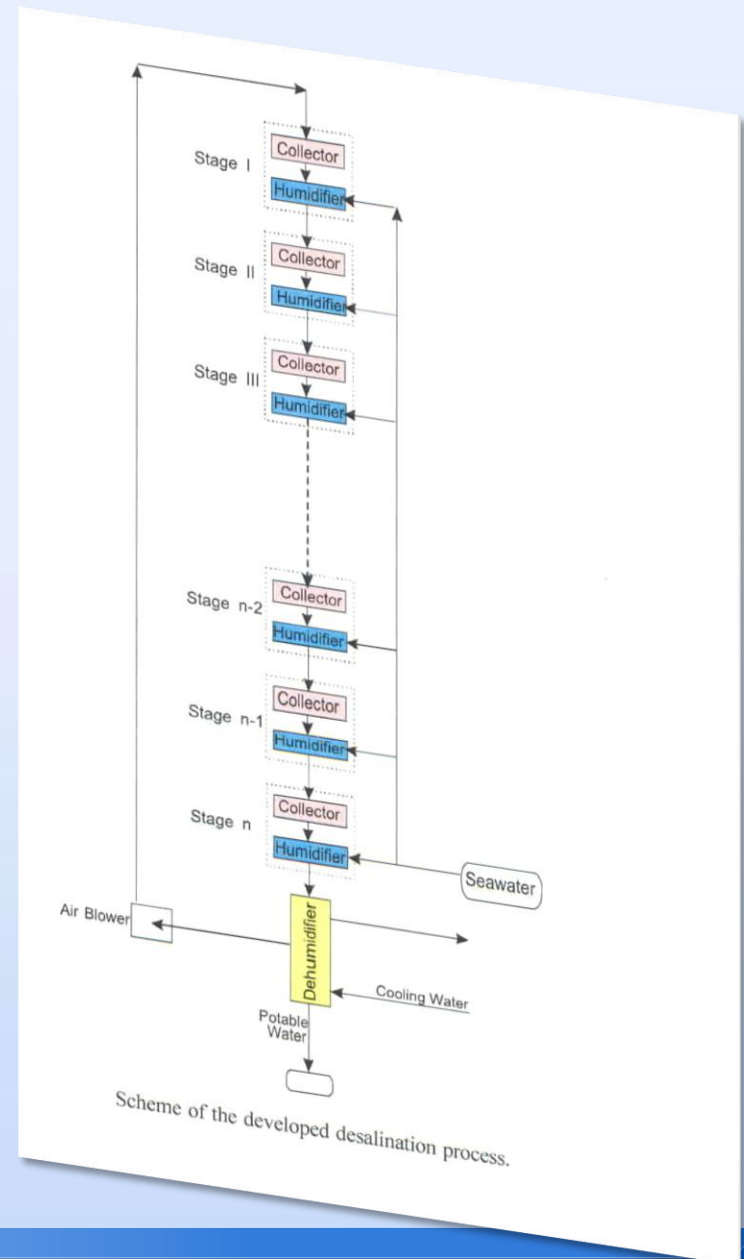
- * The main idea is to utilize solar energy to heat air (about 80°C) and humidify it through passing it over a pool of seawater.
- * This process is done on multiple stages (humidifying, heating cycles).
- * Different types of solar collectors and different ideas of solar heating are

Multi Stage System (Chafiq)

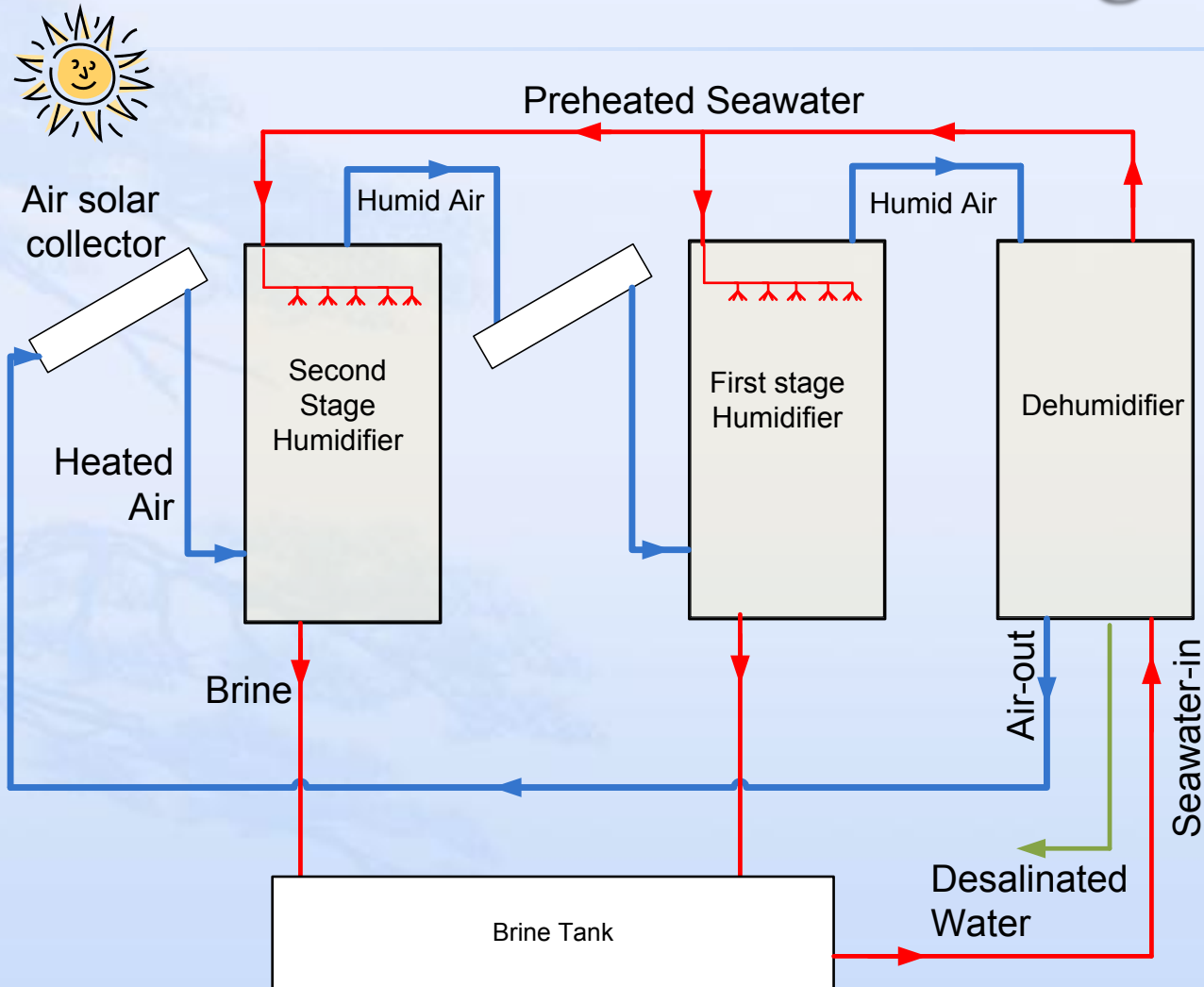
- ✿ Then, humid air is dehumidified in a condenser cooled by the seawater to extract fresh water.
- ✿ The theoretical analysis will include detailed feasibility study that determines the optimum number of stages, solar air heaters types, configuration and surface area (and of course, number), dehumidifier surface area and type, and effective system parameters.

PROCESS

- Multiple stages for distillate water production
- Seawater is used for humidifying the air
- It is also used to dehumidify the air in the heat exchanger as a cooling medium
- An air blower draws the air through different stages

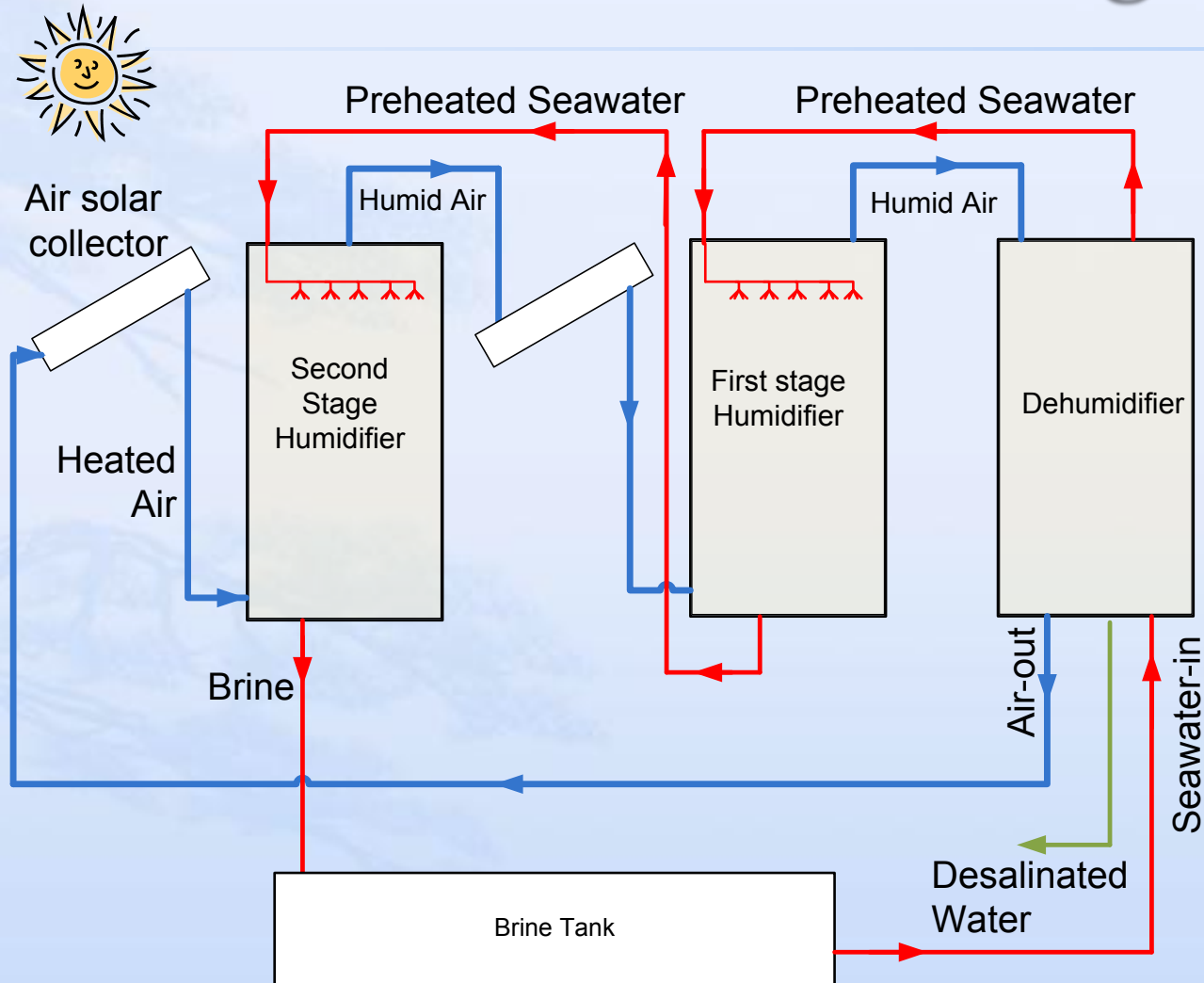


Classification-our Own 2 stage sys.



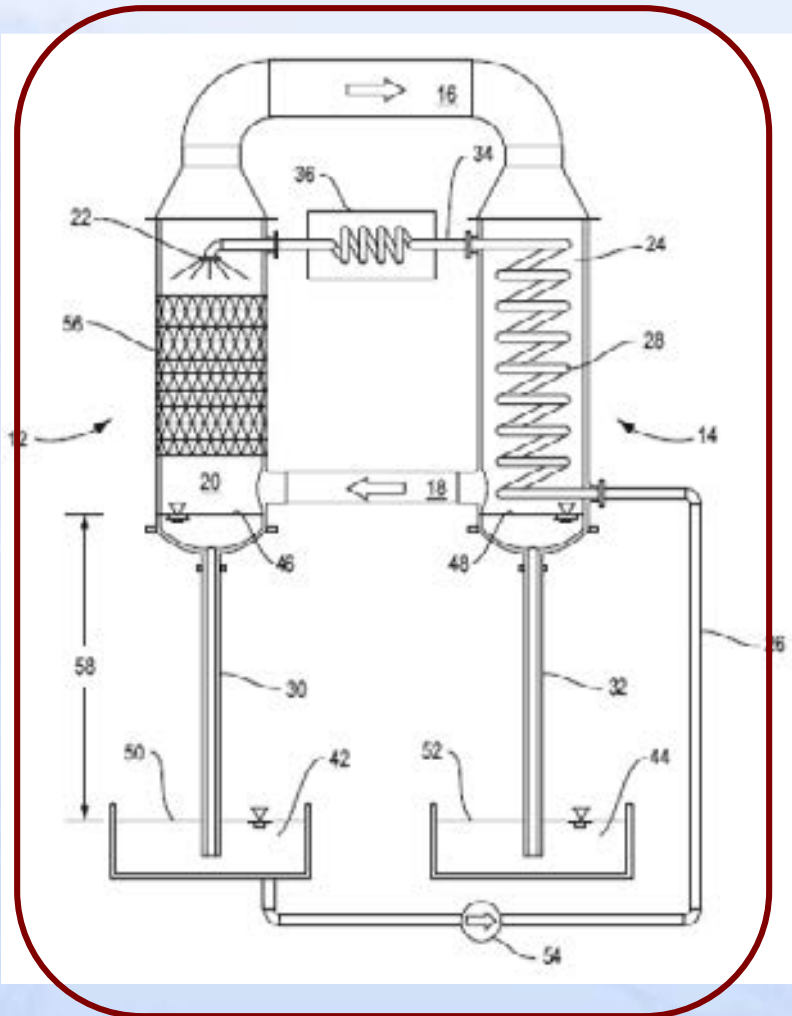
Multi stage Air heated cycle, closed water loop (1)

Classification-our Own 2 stage sys.

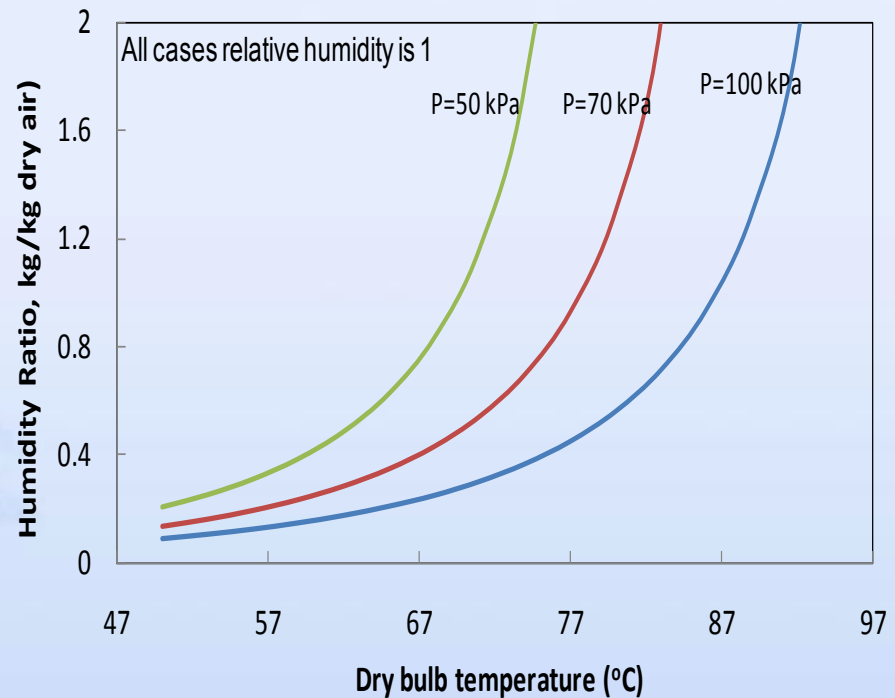


Multi stage Air heated cycle, closed water loop (2)

New HDH cycles



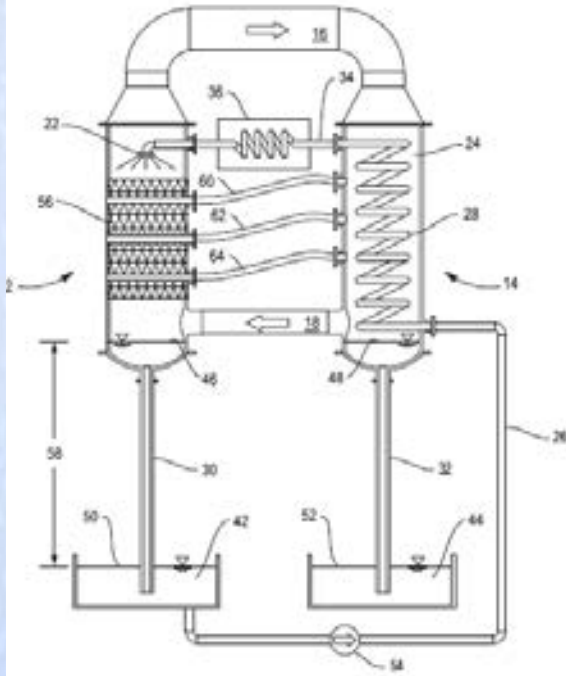
Existing HDH cycles are single pressure systems, with the disadvantage of operating both humidifier and dehumidifier at a very low humidity level or a high humidity level. This limits heat recovery.



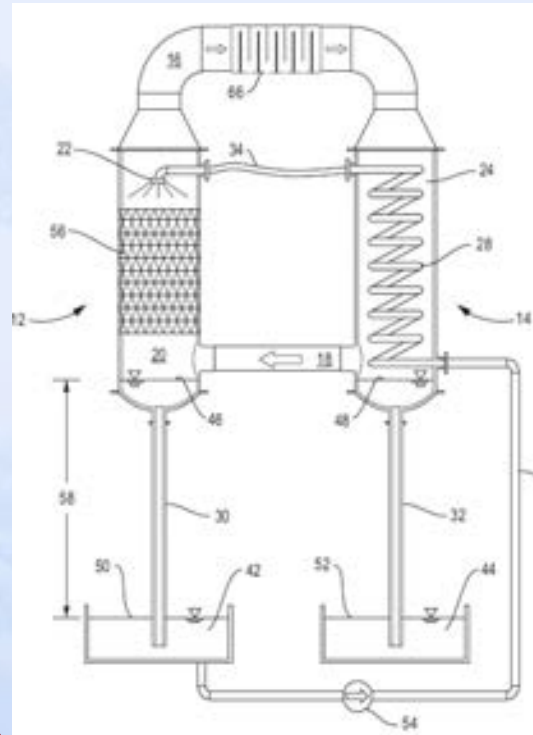
US Patent

Mostafa H Sharqawy, Prakash N. Govindan, John H. Lienhard, and Syed Zybaier
Water separation under reduced pressure. Patent pending, USSN 12/554,726.
Water separation under varied pressure. Patent pending, USSN 12/573,221.

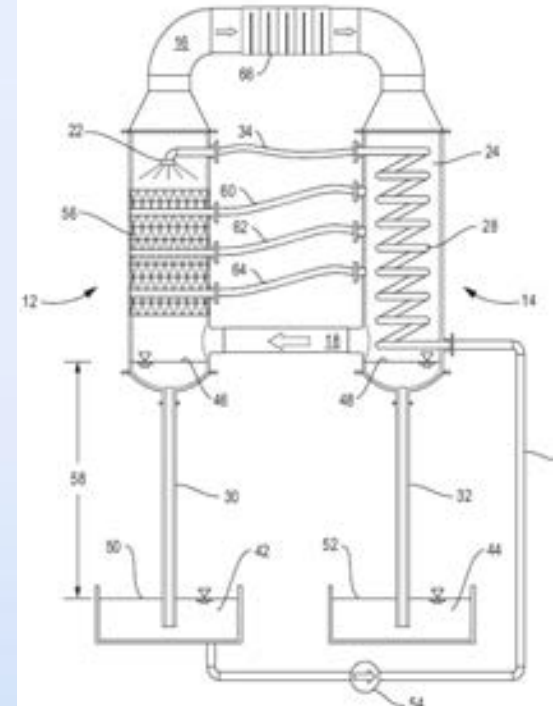
Water Heated with multi-extraction



Air Heated HDH cycle with reduced pressure

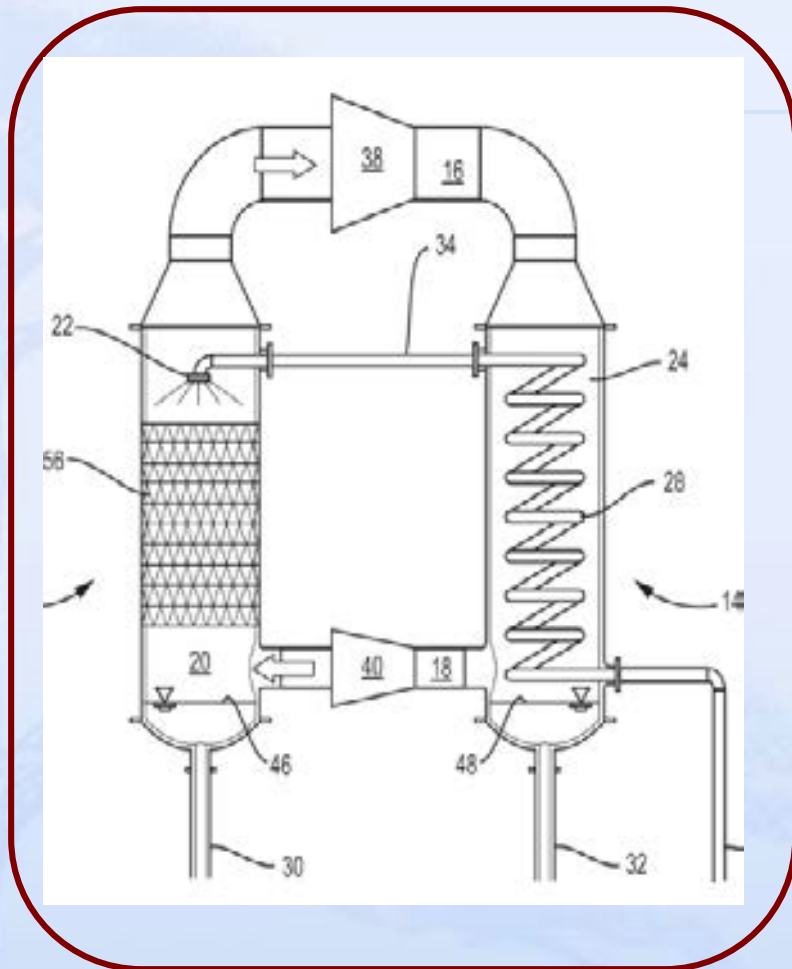


Air Heated with multi-extraction

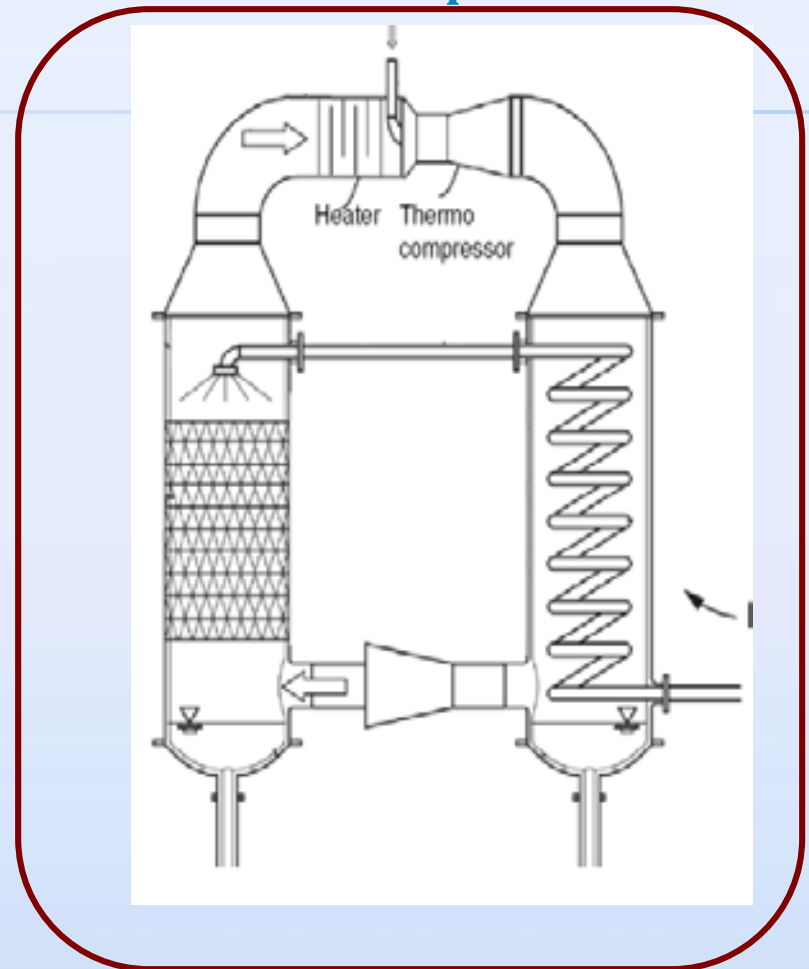


Multi-extraction systems allow heat and mass exchanger balancing and minimize entropy generation Higher GOR

HDH with varied pressure



HDH with varied pressure and thermo-compression



US Patent

Mostafa H Sharqawy, Prakash N. Govindan, John H. Lienhard, and Syed Zybaier
Water separation under varied pressure. Patent pending, USSN 12/573,221.

Comparison of Novel HDH Cycles

Cycle	GOR
Multi-stage air heated cycle	0.85
Efficient air heated cycle	3.5
Best HDH cycle in market	3.6-4.5
Reduced pressure cycle (34 kPa)	4.5
Multi-extraction cycle	>4.5
Thermo-compression cycle	>5
Varied pressure cycle	25
Ideal (reversible) HDH cycle	120

“Thermodynamic Analysis of Humidification Dehumanization Desalination Cycles” by Narayan G, Sharqawy M.H., Lienhard V, J.H., and Zubair S.M., Desalination and Water Treatment 16, 2010

GRADIANT (Spin Off)



Gradiant designed, built, and operates two 12,000 bpd plants in the Permian basin. Both treat produced and flowback waters.



GRADIANT (Spin Off)

- * Technology is based on a carrier gas extraction (CGE) process, which recirculates air through a humidifier and multistage **bubble column dehumidifier** in a closed loop.
- * As saline feedwater enters the unit, it is preheated in the dehumidifier before being heated an additional 10-15°C (18-27°F) using a natural gas-fired boiler.
- * Some of the feedwater is evaporated as it is sprayed over a packed bed and condensed as distillate in the dehumidifier.
- * Meanwhile, the non-evaporated portion of the feed is removed as saturated brine and the now re-humidified air is then returned to the dehumidifier column to continue the process.

GRADIANT (Spin Off)

- * These plant include CGE systems that produce freshwater and SCE systems that produce different grades of reusable fluids to customer specifications.

What Next

- ✿ Solar Energy utilization (back to lab and pilot scale for further development)
- ✿ Working in uncontrolled environment – how to maneuver.
- ✿ Mobile system (Tests ongoing).



Thank you

