RECENT DEVELOPMENTS IN MICROTECHNOLOGY-BASED CHEMICAL HEAT PUMPS

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BACKGROUND

PNNL is developing energy systems from microscale components. The first microscale thermal system analyzed at PNNL was a chemical heat pump. The evaporator and condenser were constructed and demonstrated in 1993. New evaporator designs and new fabrication methods were tested in 1994-96.

BACKGROUND

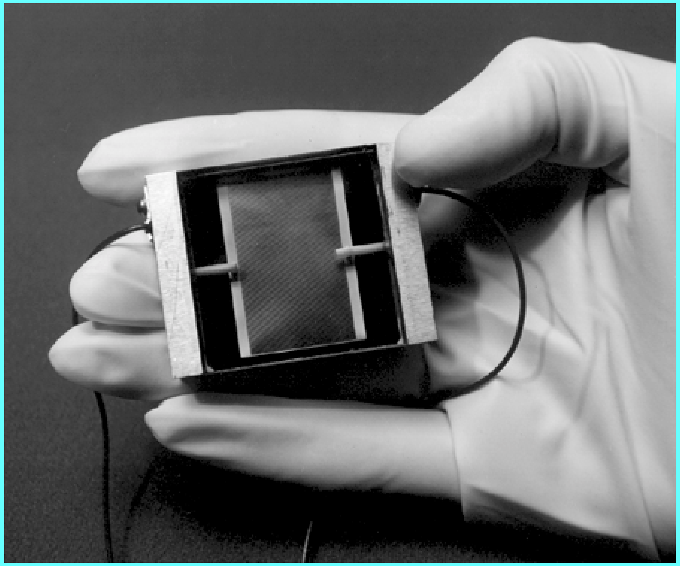
The absorber was constructed and demonstrated in 1995. The desorber (generator) and was constructed and demonstrated in 1996-97. In 1998-99 a microtechnology-based chemical (absorption) heat pump is being constructed by integrating the microtechnology-based components with a commercially-available pump.

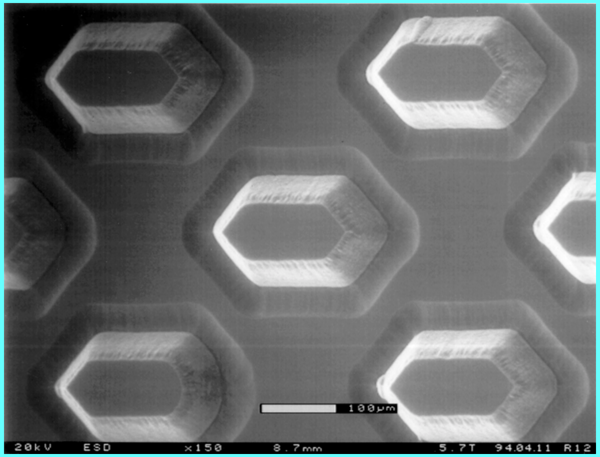
MICROCHANNEL HEAT EXCHANGERS

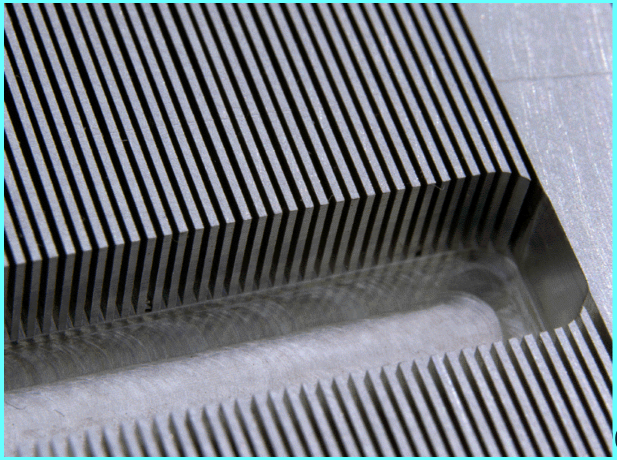
- Heat fluxes: 100^{+} watts/cm^2
- Low pressure drops: 1-2 psi
- High convective heat transfer coefficients:

  Single phase: 1-1.5 W/cm^2-K

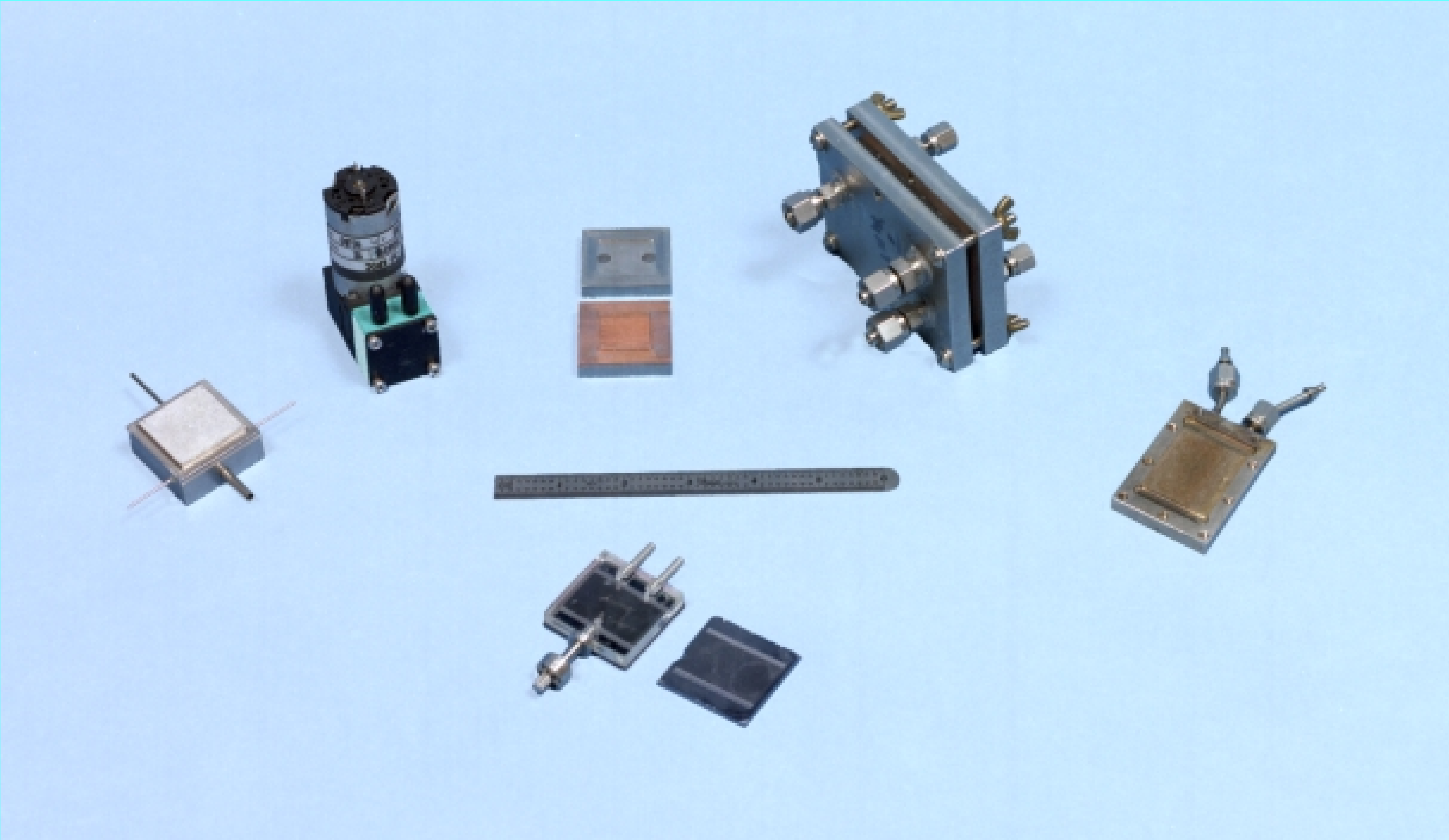
  Phase change: 3-3.5 W/cm^2-K







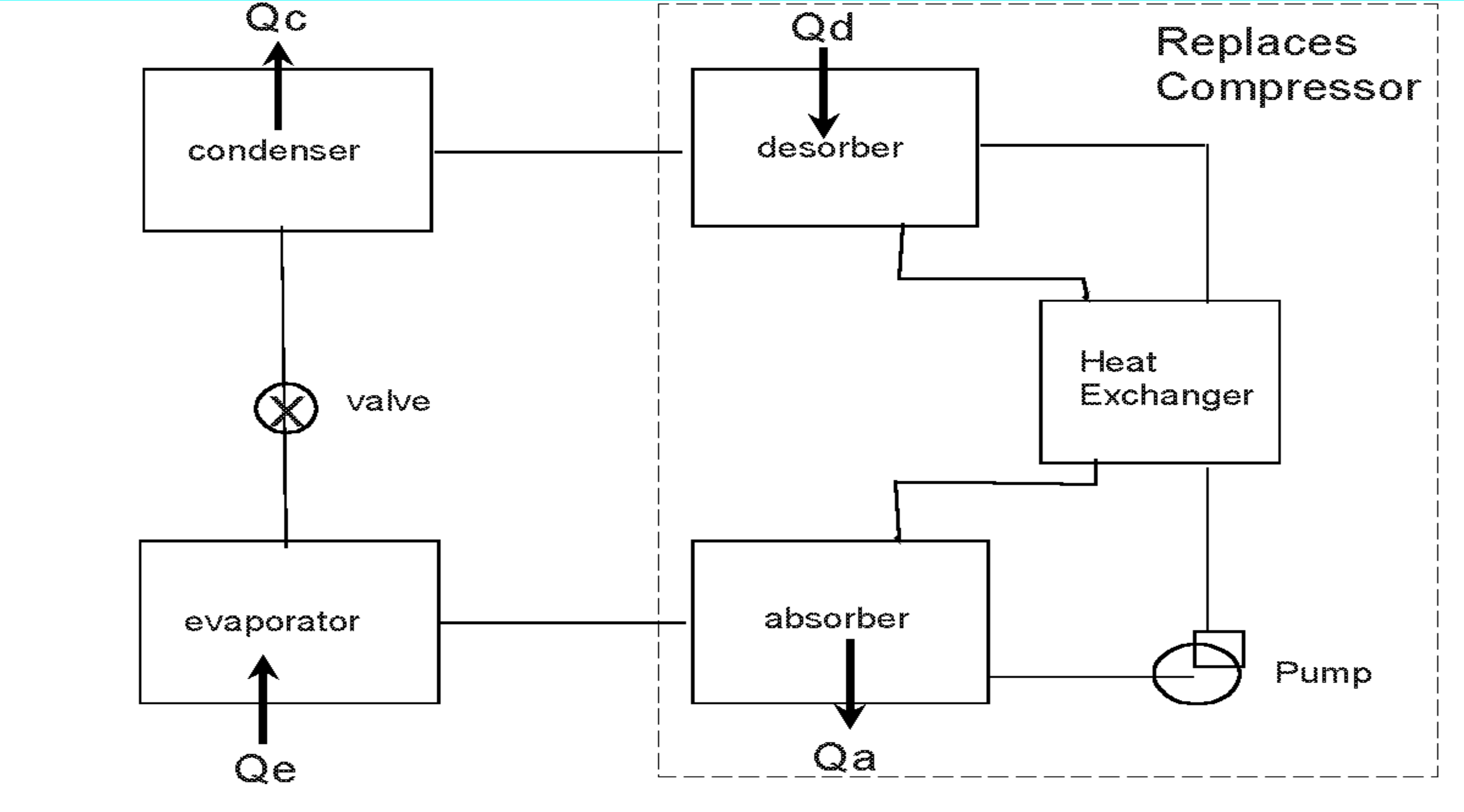
ABSORPTION HEAT PUMP COMPONENTS



CONCEPT DESCRIPTION

Although the chemical compression and vapor compression cycles differ in the way compression is provided, both systems take the same approach to heat absorption and rejection. Compression is accomplished in the chemical heat pump system with a single-effect thermochemical compressor consisting of an absorber, a solution pump, a desorber, and a regenerative heat exchanger.

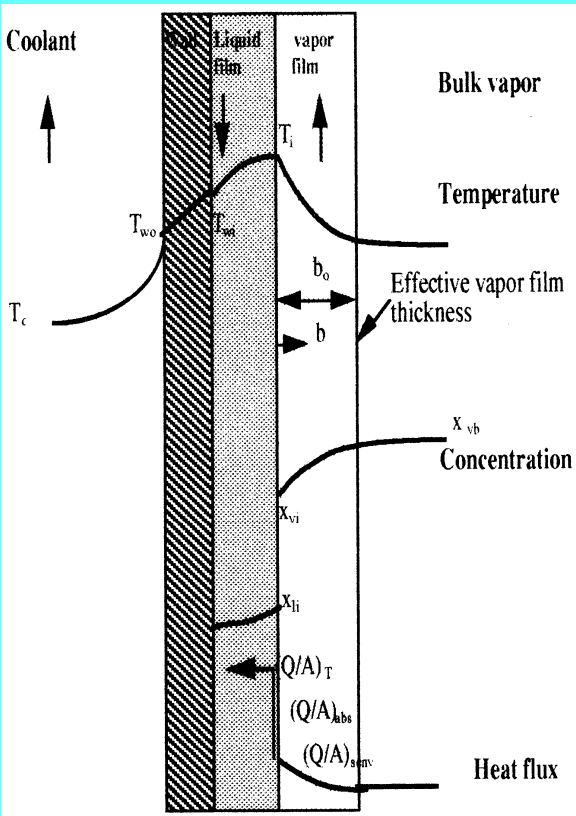
SINGLE-EFFECT ABSORPTION HEAT PUMP



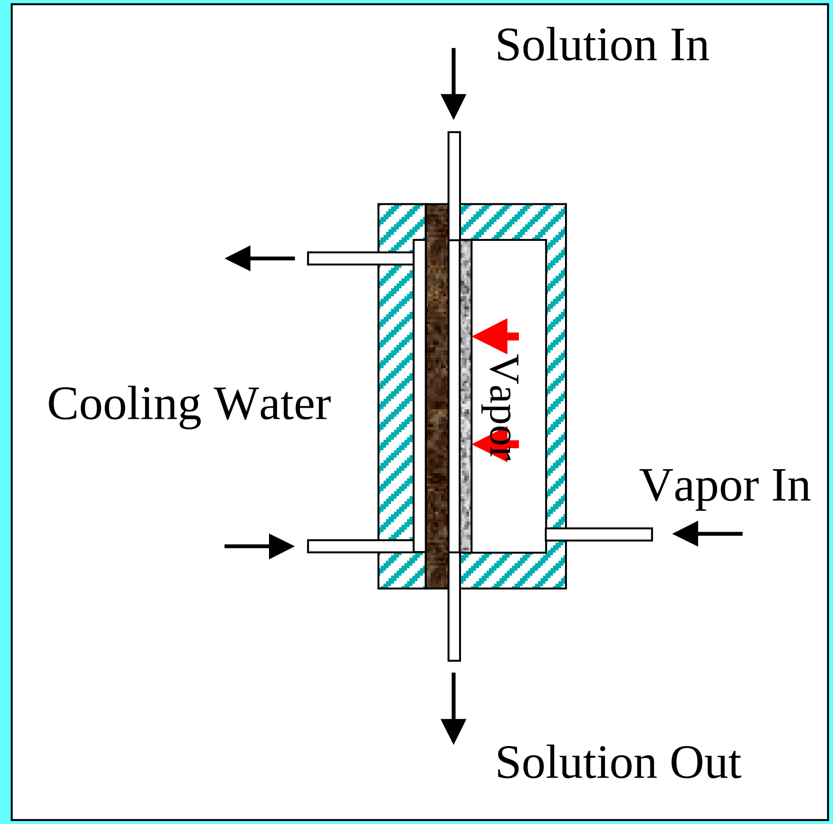
ABSORPTION AND DESORPTION

A conventional absorption heat pump relies on gravity to form falling films, which provide liquid-to-gas contact in the absorber and desorber. Falling films have a film thickness on the order of 1 mm which is a significant barrier to mass diffusion and results in a physically large absorber and desorber.

ABSORBER



Gravity Falling Film

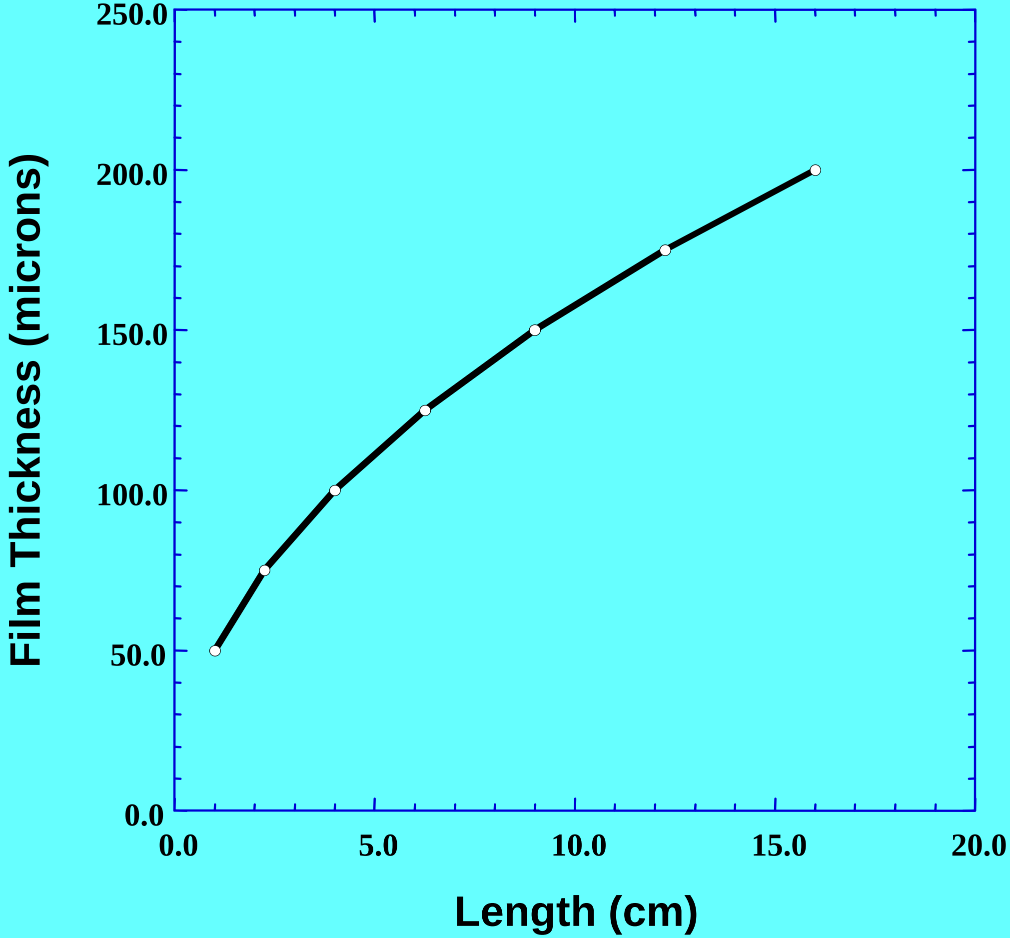


Constrained Thin Film

ABSORPTION AND DESORPTION

Absorber and desorber performance is dependent on the thickness of the mechanically constrained, ultra-thin film. The ultra-thin film is maintained by a micromachined contactor, which allows refrigerant vapor to permeate through it. As the figure below shows, the reduction in the thickness of the thin film from 200 microns to 50 microns would reduce the length by a factor of 16 while keeping the sorption rate constant.

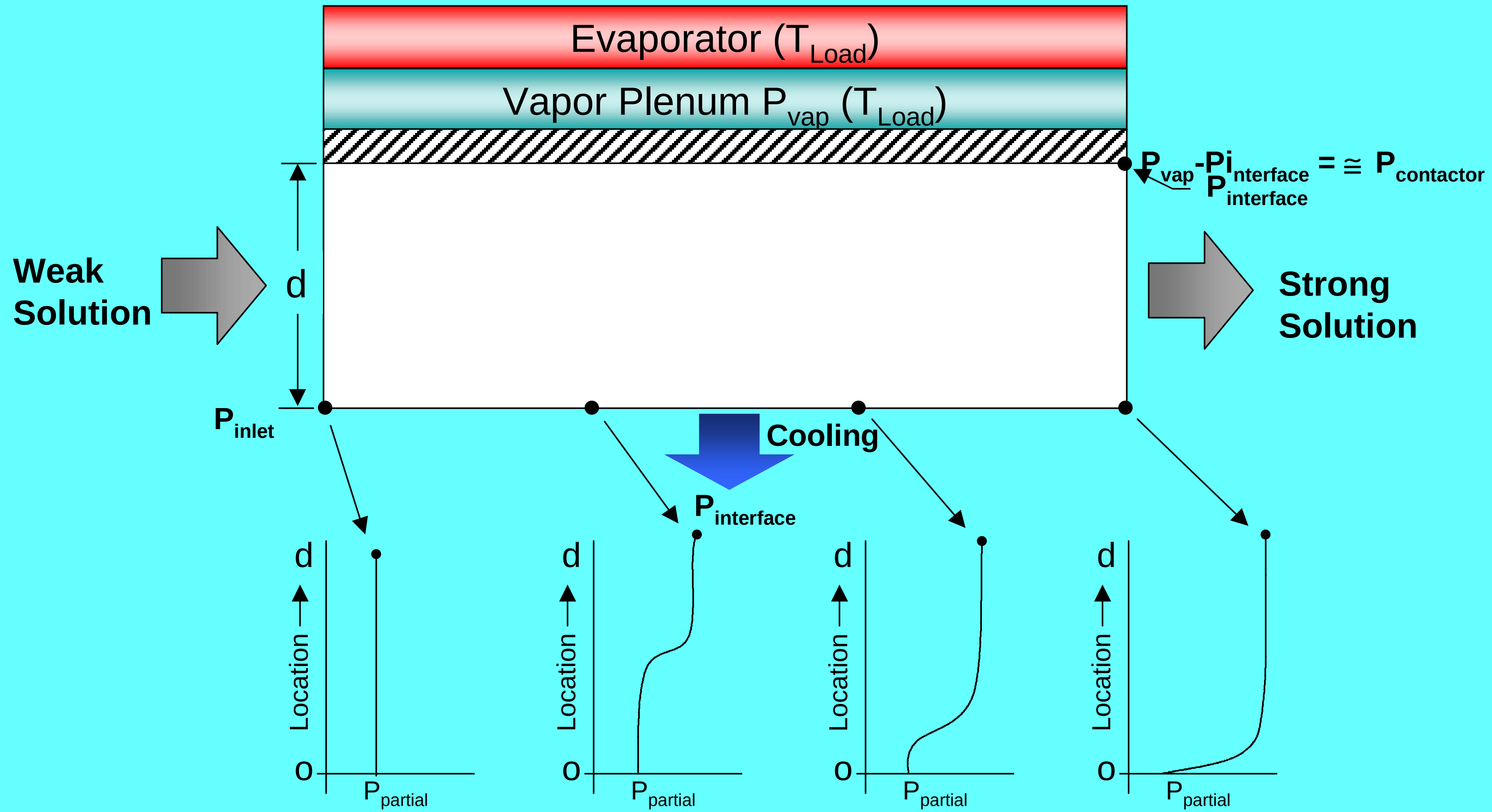
FILM THICKNESS (constant mass flux)



ABSORPTION

The picture below depicts the absorption process. The water vapor pressure, at the interface where the vapor and solution are in contact, is the driving force for the absorption process and must equal the partial pressure of water in the solution at the interface. As the solution passes through the absorber, water is diffused through the thin film. It is important to keep the pressure drop across the micromachined contactor low so that the maximum vapor pressure is available to drive the absorption process.

ABSORBER



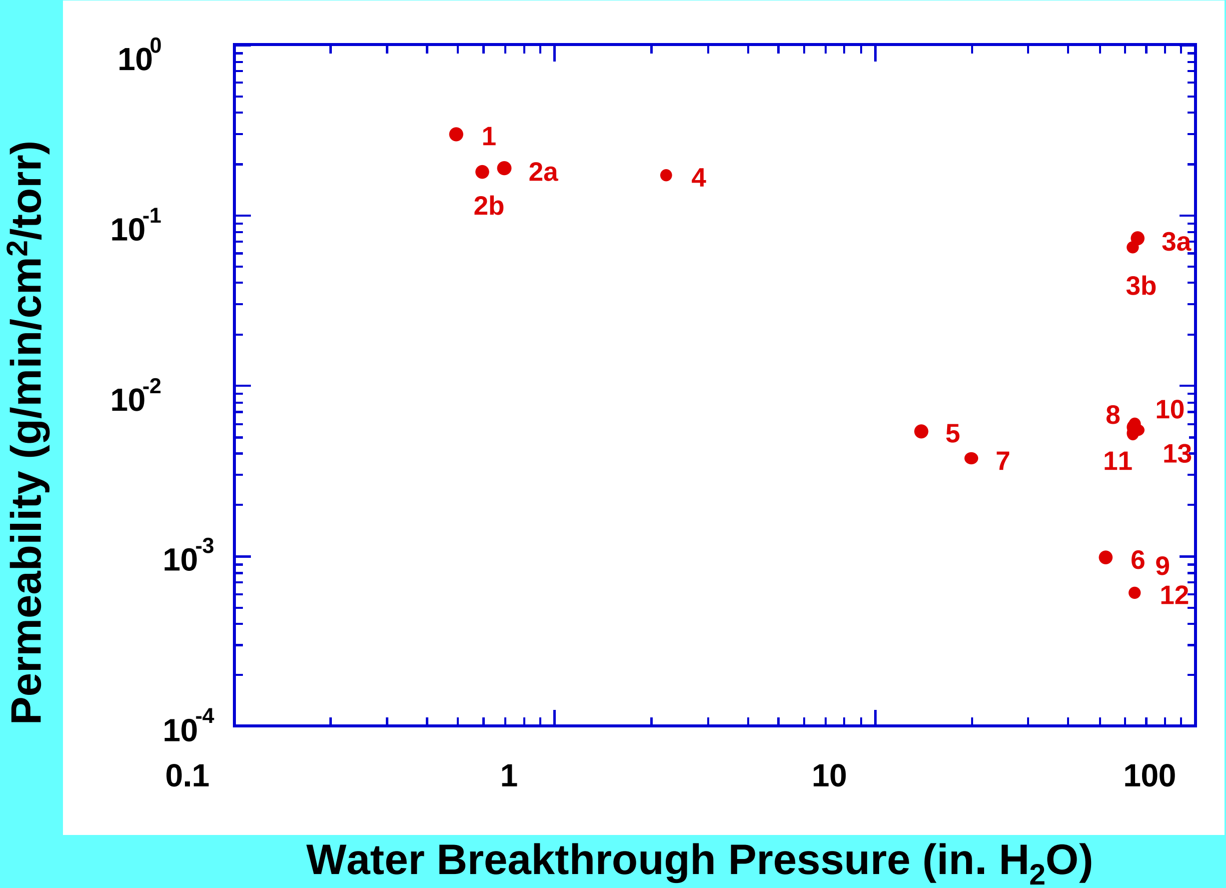
Evaporator (T_Load)
Vapor Plenum P_vap (T_Load)
P_vap - P_interface = ≅ P_contactor
P_interface
Weak Solution
d
Strong Solution
P_inlet
Cooling
P_interface
d
Location
o
P_partial
d
Location
o
P_partial
d
Location
o
P_partial
d
Location
o
P_partial

CONTACTORS

The desorber and absorber depend on the micromachined contactors to prevent liquids from passing though the contactor while minimizing impact of water vapor diffusion. PNNL has evaluated a wide range of contactors. Data on breakthrough pressure (the pressure at which solution will pass through the contactor) and permeability (the mass transfer of vapor through the contactor as a function of pressure difference across the contactor) is summarized below.

CONTACTORS

Permeability versus supported liquid pressure



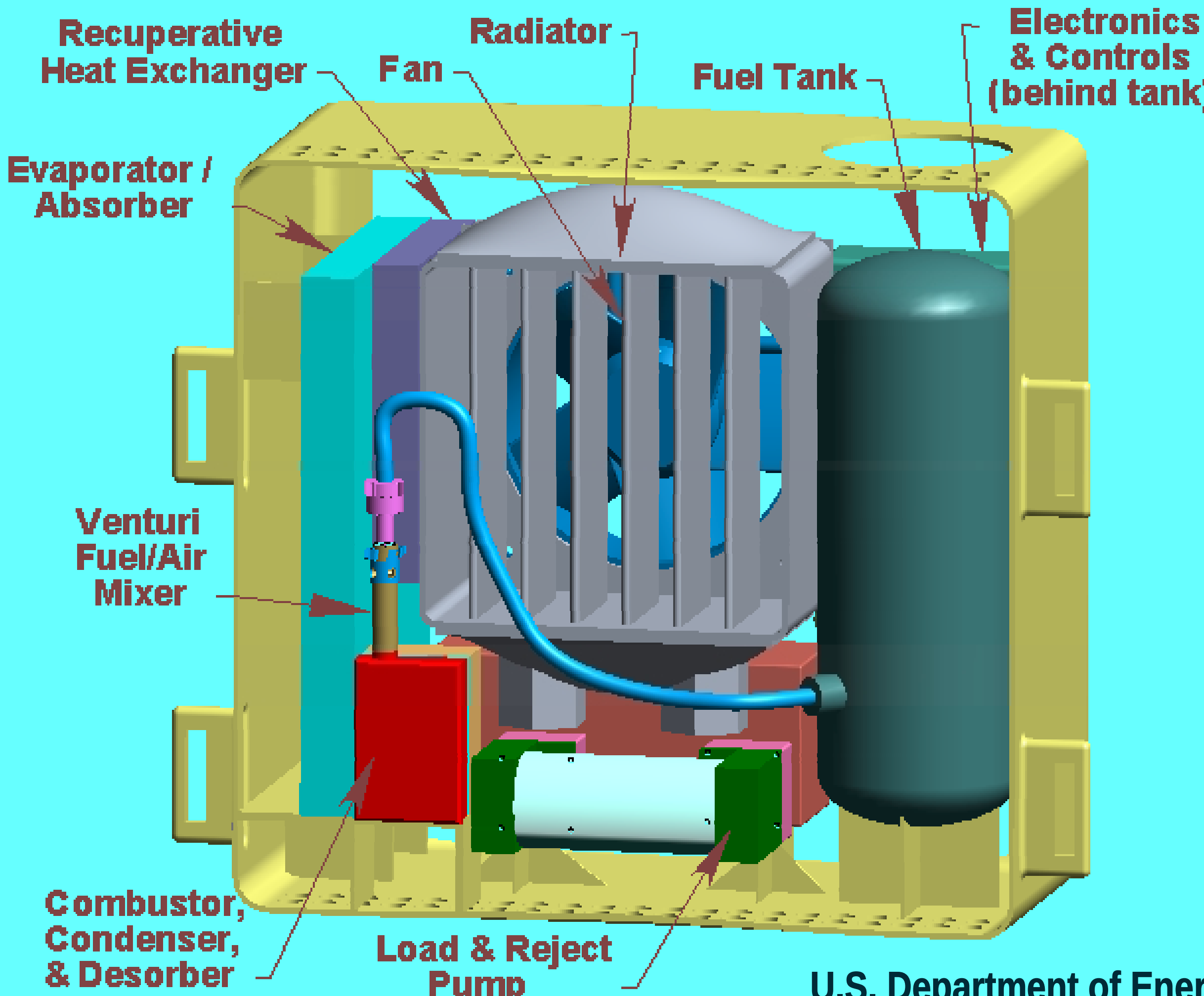
Battelle

MANPORTABLE HEAT PUMP PERFORMANCE

Based on experimental data we have collected, a prototype single-effect LiBr/H_2O, manportable, 350 W cooler has been designed. The table below summarizes the weight and performance characteristics of two manportable coolers. The first system uses a battery to provide electric power for pumps and the fan, while the second system uses a thermoelectric generator (TEG) installed between the combustor and the desorber to provide electric power.

DARPA MANPORTABLE COOLER

- 350 W cooling capacity for 8 hours
- 5.1 kg



CHEMICAL HEAT PUMP CHARACTERISTICS

	Power Source	
Component	NiCd BATTERY	PbTe TEG
	kg	kg
HEAT PUMP	0.92	1.18
RADIATOR	0.85	0.83
FAN	0.65	0.65
BATTERY	1.07	0.03
TEG	0.00	0.18
STRUCTURE	0.47	0.47
PUMPS/FLUIDS	0.43	0.43
FUEL & TANK	0.54	0.68
ELECTRONICS	0.22	0.22
TOTAL	5.14	4.67

CONCLUSIONS

By taking advantage of the high rates of heat and mass transfer attainable in microstructures, PNNL is developing a miniature chemical heat pump with a cooling capacity of 350 W that weighs only 1 kg and is less than 600 cm^3. Compared to a conventional chemical (absorption) heat pump, this is a reduction in volume by a factor of 60.

CONCLUSIONS

A complete manportable cooling system, including the heat pump, an air-cooled heat exchanger, batteries, and fuel, is estimated to weigh between 4 and 5 kg, compared to the 10-kg weight of alternative systems.

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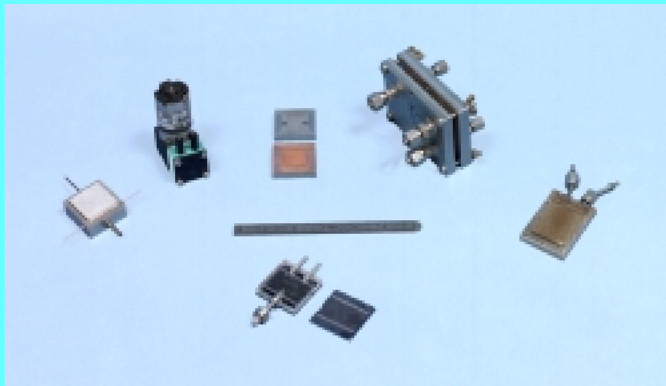

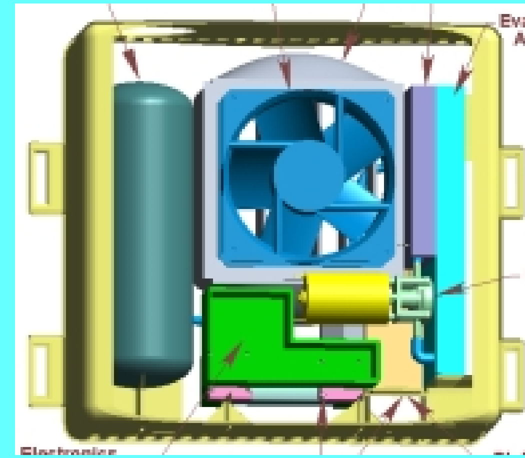

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