High Efficiency, Residential Gas-Fired Adsorption Heat Pump Water Heater Development

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Oak Ridge National Laboratory

Hot Water Forum
Water Heating, Distribution, and Use Efficiency
American Council for an Energy-Efficient Economy (ACEEE)
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ORNL is managed by UT-Battelle
for the US Department of Energy

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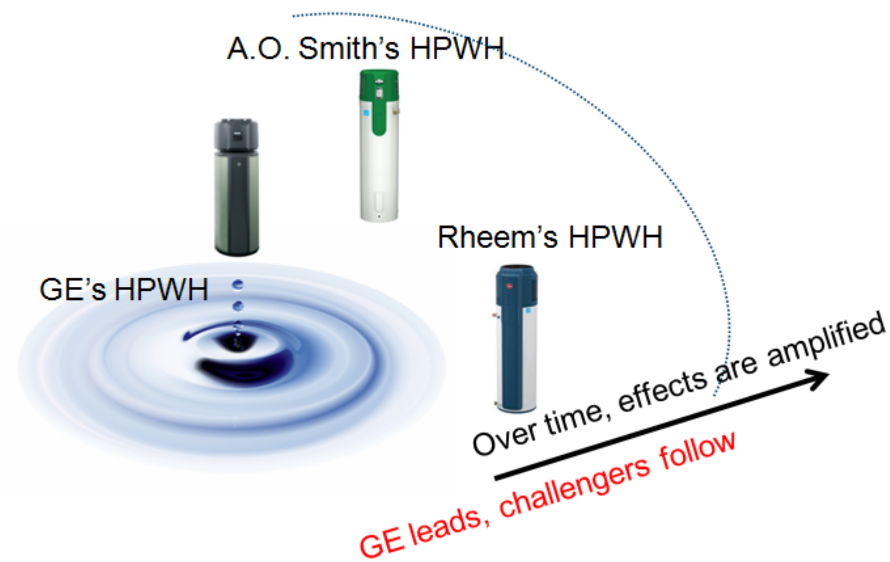
Recent Heat Pump Work at ORNL

- **Design and Development of Integrated Heat Pump (IHP) concepts reduced to practice**
- **Collaborative R&D with multinational companies and manufacturers**
- **Wide range of products brought to the marketplace**
- **Seeking partnership with industry on next generation of water heaters**

Industry CRADA Collaborations are Delivering Additional Equipment Solutions to the Market

Ripple effects of General Electric-ORNL heat pump water heater CRADA

Began production in Louisville KY Feb 2012 (created ~1,000 jobs)



62% energy savings compared to a conventional electric storage water heater, pays for itself in < 3 yr

Heat Pump Water Heater

After CRADA with ORNL, ClimateMaster Launches Trilogy™ 40 Q-Mode™ (1st AHRI Rating > 40 EER)

- Heating, cooling, 100% of water heating (not just a desuperheater)
  - 55-65% energy savings vs. minimum efficiency (SEER 13) equipment
  - 30-35% savings vs. state-of-the-art two-stage GHP with desuperheater

Separate Units [Water Heating; Heating/Cooling]

Single Unit [Water Heating; Heating/Cooling]

The Trilogy 40 Q-Mode Ground Source IHP

- **With rated efficiencies as high as 42.1 EER, the Trilogy™ 40 series is the first geothermal heat pump ever certified by the Air Conditioning, Heating, and Refrigeration Institute (AHRI) to exceed 40 EER at ground-loop (GLHP) conditions.**
- **The Trilogy™ 40 utilizes variable-speed technology to provide an extremely wide range of heating and cooling capacities**
- **In addition, patent-pending Q-Mode™ technology produces year-round domestic hot water on demand, even when space conditioning is not required.**

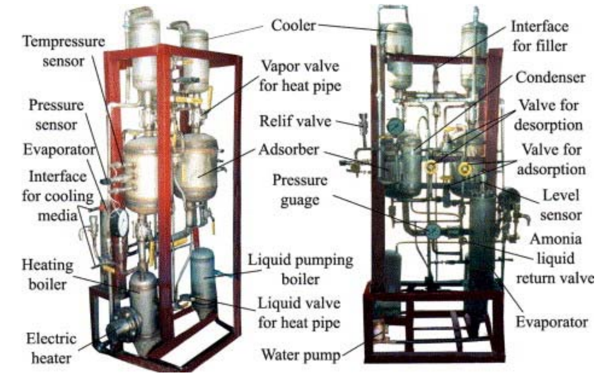
FLC Award 2014

Pushing the Envelope at ORNL on Adsorption Technology

Old applications

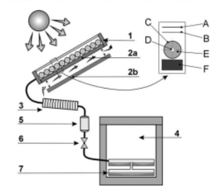
100 kW chiller

ISAAC solar Icemaker
In Kenya



Adsorption ice maker for
Fishing boat

Solar refrigerator



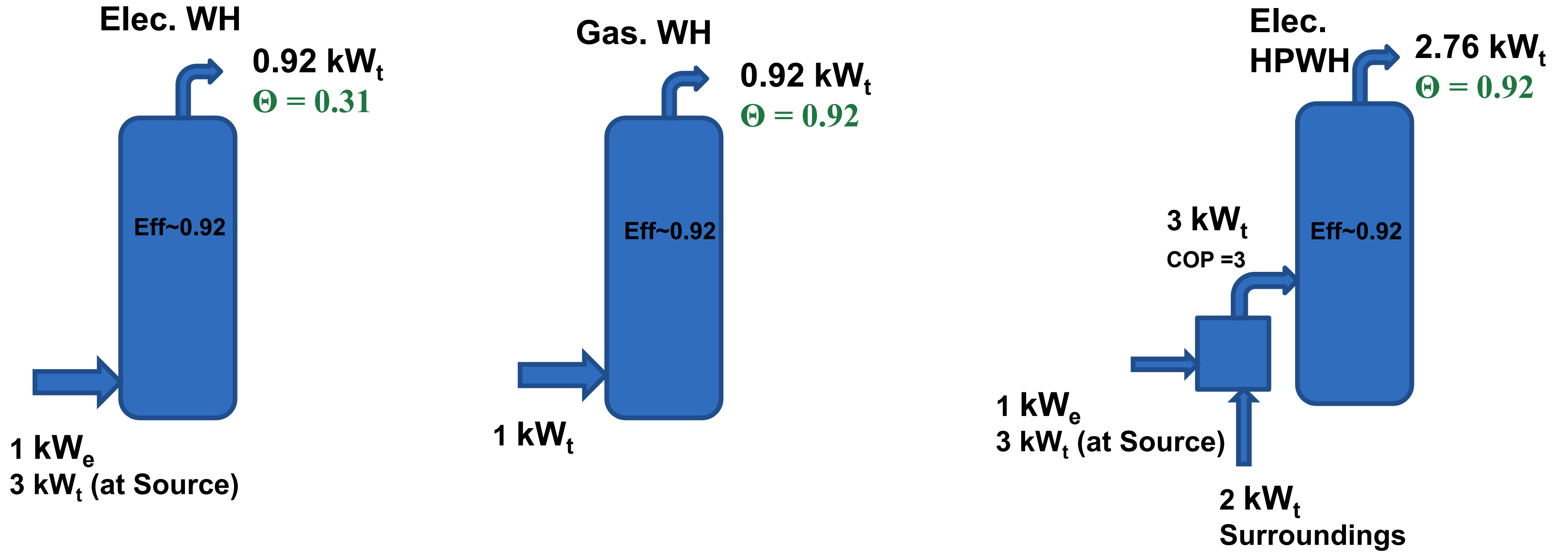
ORNL Pushing the envelope

Gas domestic hot water COP ~ 1.0
Challenge: increase COP to 1.5

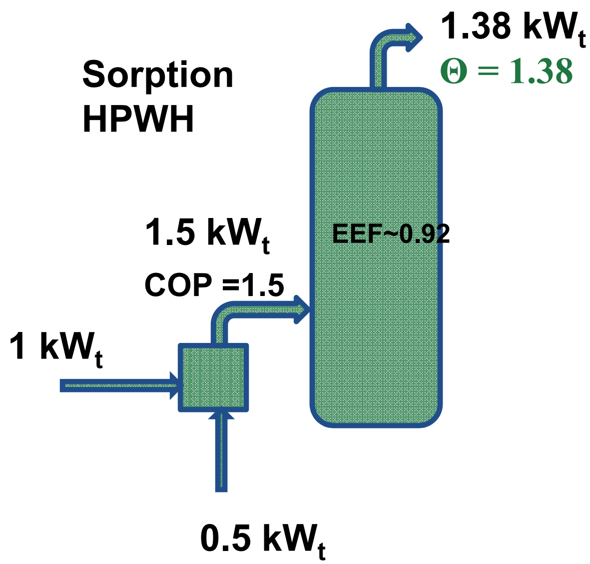
Application of Adsorption technology
for domestic/commercial hot water
production

Adsorbent beds
(generators)

The Case for Sorption HPWHs



$$\theta = \frac{\text{Energy to make HW}}{\text{Thermal Energy at Source}}$$



- **Sorption HPWH uses fossil energy resource more efficiently**
- **Focus on AdHPWH for domestic WH**

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Water Heaters Affected by New Standards, Effective April 2015

WATER HEATERS AFFECTED BY NEW STANDARDS		
Product Class	**Energy factor as of January 20, 2004**	**New Energy Factor Requirements**
Gas-fired Water	0.67 – (0.0019 x Rated Storage Volume in gallons).	For tanks with a Rated Storage Volume at or below 55 gallons: EF = 0.675 – (0.0015 x Rated Storage Volume in gallons). For tanks with a Rated Storage Volume above 55 gallons: EF = 0.8012 – (0.00078 x Rated Storage Volume in gallons).
Oil-fired Water Heater	0.59 – (0.0019 x Rated Storage Volume in gallons).	EF = 0.68 – (0.0019 x Rated Storage Volume in gallons).
Electric Water Heater	0.97 – (0.00132 x Rated Storage Volume in gallons).	For tanks with a Rated Storage Volume at or below 55 gallons: EF = 0.960 – (0.0003 x Rated Storage Volume in gallons). For tanks with a Rated Storage Volume above 55 gallons: EF = 2.057 – (0.00113 x Rated Storage Volume in gallons).
Tabletop Water Heater	0.93 – (0.00132 x Rated Storage Volume in gallons).	EF = 0.93 – (0.00132 x Rated Storage Volume in gallons).
Instantaneous Gas-fired Water Heater	0.62 – (0.0019 x Rated Storage Volume in gallons).	EF = 0.82 – (0.0019 x Rated Storage Volume in gallons).
Instantaneous Electric Water Heater	0.93 – (0.00132 x Rated Storage Volume in gallons).	EF = 0.93 – (0.00132 x Rated Storage Volume in gallons).
NOTE: The Rated Storage Volume equals the water storage capacity of a water heater, in gallons, as specified by the manufacturer.		
Source: Office of Energy Efficiency and Renewable Energy, Department of Energy. 10 CFR Part 430, [Docket Number: EE–2006–BT–STD–0129] RIN 1904–AA90 Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters.		

New, higher energy efficiency standards for residential hot water heaters came in to effect April 2015, cutting the energy use of all sizes and types of water heaters significantly, and dramatically changing the home hot water landscape. The new regulations require electric water heaters to use 47% less energy, and gas water heaters to be 30% more efficient.

There are a variety of products that are already compliant with the 2015 standards

Ref: CONTRACTOR: The online resource for mechanical contracting
http://contractormag.com/residential-plumbing/new-efficiency-standards-residential-water-heaters-are-horizon

Two distinct projects funded by BTO, U.S. Department of Energy

- **Commercial Gas-Fired Absorption Heat Pump Water Heater**
  - **-Working pair is ammonia-water**
  - **-Prototype system is essentially complete**
  - **-demonstrated that target goals with prototype in 2015.**
  - **- Testing of next generation beta unit on-going**

- **Residential Gas-Fired Adsorption Heat Pump Water Heater (AdHPWH)**
  - **-Working pair is ammonia-activated carbon (AC)**
  - **-AdHPWH system, modeled and tested but results fell short of performance target to achieve a minimum energy factor of a standard non-condensing gas fired water heater and have a competitive cost premium for market introduction**

US Market/Environmental Impact

- **In 2010, residential water heating accounted for 2.9 Quads (8.40 TWh) of primary energy use (**2011 Building Energy Data Book, Table 2.1.5**).**

- **When fully deployed, the AdWH may provide up to 0.45 Quad (130 TWh) of primary energy savings, equivalent to 24 million tons of CO_2 emission reductions annually (**2011 Building Energy Data Book, Table 1.4.8**), eliminating the need for HFC refrigerants with significantly higher ODP and GWP.**

- **Market for AdHPWH is about 15% of residential water heating market**

Participation in IEA Annex 43/Research Program

- The U.S through the Oak Ridge National Laboratory became a participant in Annex 43 – Fuel Driven Sorption Heat Pumps in March 2014

- The program of research is the development, demonstration, and promotion of gas-fired heat pumping technology for the commercial and residential markets with COP >1 with working materials having 0 GWP and 0 ODP

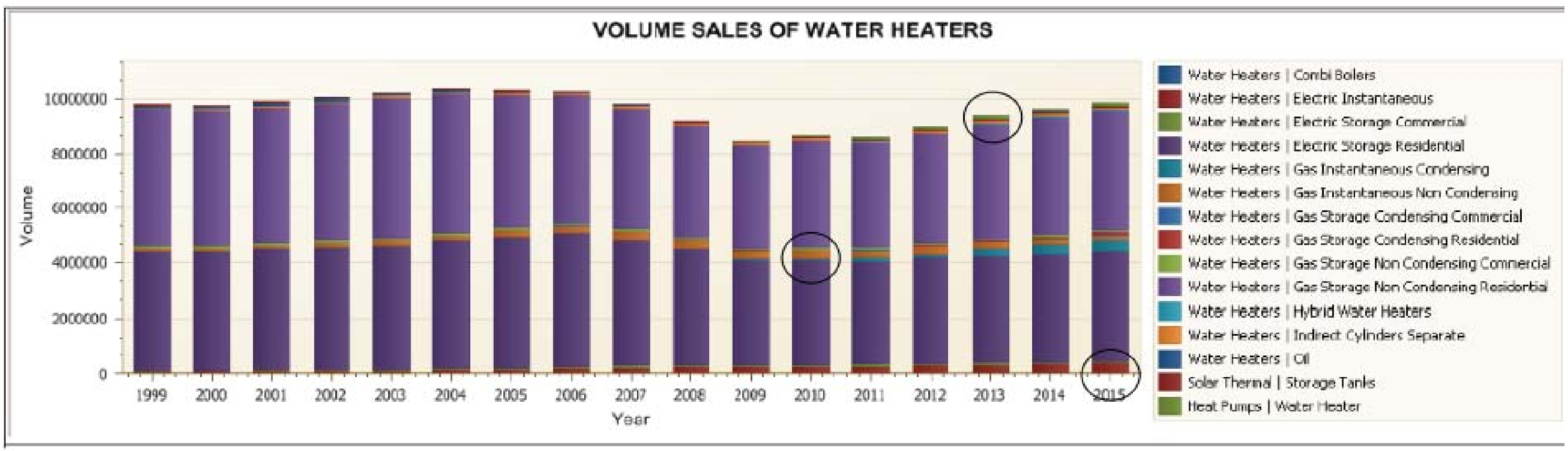
- Research is conducted under the directive of the U.S Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Buildings Technology Program (BTO)

Water Heater Shipment Projections

All Water Heater Industry Shipments: U.S

III.3 Historical Trends and Forecasts : Water Heaters

Fig. III.3 US - SUMMARY OF TRENDS IN THE WATER HEATER MARKET : 1999-2010 AND FORECASTS TO 2015



Electric Storage and
Gas Storage units dominate sales

Mike Parker; ACEEE Hot Water Forum May 2011
Ref: http://www.aceee.org/files/pdf/conferences/hwf/2011/Plenary%20-%20Mike%20Parker.pdf

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Objectives :

- ❑ **Residential Gas-fired Adsorption Heat Pump Water Heater**

  - To develop an adsorption heat pump water heater (AdHPWH) at an installed cost low enough to enable widespread residential market adoption

  -1 to 3 kW capacity

  -Provide hot water at 50°-60°C

  -Ambient temperature range -10°C to 37°C

  - EF>1.0 as determined by the standard rating procedure for storage water heaters.

- ❑ **Industry collaborators to be determined. Currently, In-house R&D at ORNL**

R&D Status

- ❑ **Residential Gas-fired Adsorption Heat Pump Water Heater**

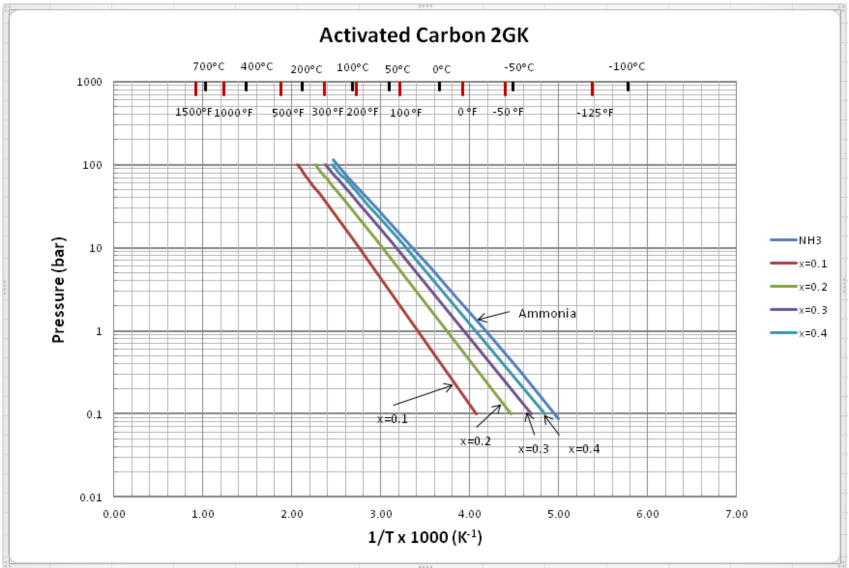
  - ✓ **-Established technical feasibility of AbHPWHs with EF>1.0 using working materials that have 0 GWP and 0 ODP**
  - ✓ **-Identified possible working pairs (activated carbon-ammonia)**
  - ✓ **-Established process constraints and acceptable cost for the manufacturer**
  - ✓ **-Developed a model for parametric analysis**
  - ✓ **-Quantified system size based on cycle times, adsorption capacity, and capacity**
  - ❖ **Prototype testing**

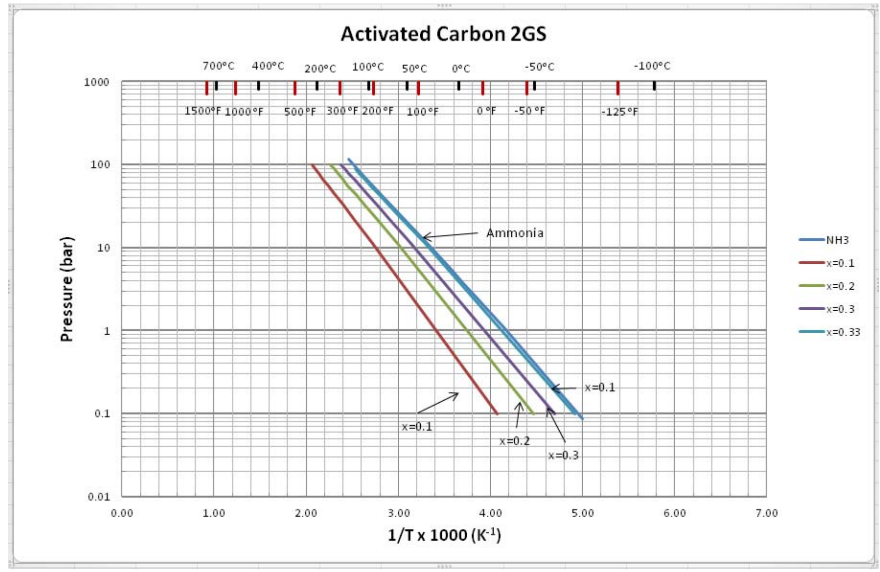
Activated Carbon Samples

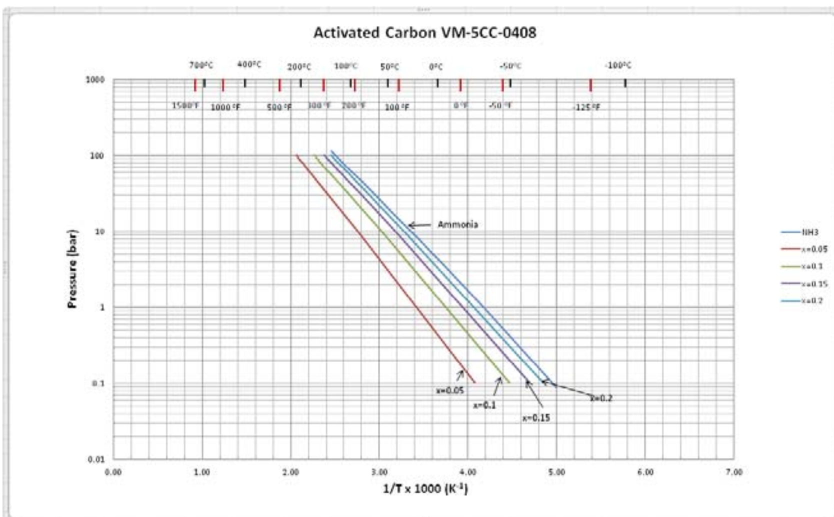
Adsorption data fitted to Dubinin Equation: $x = x_0 \exp\left(k \left[\frac{T}{T_{sat}} - 1 \right]^n \right)$

	x_o	k	n
2GK	0.5204	-5.6321	0.8010
2GS	0.3360	-4.9070	1.156
VM-5CC--0408	0.2672	-5.8932	1.50

Adsorption Isotherms Developed from the Dubinin Parameters







Selected Activated Carbon: G2K
because of higher loading: x_0 = 0.52

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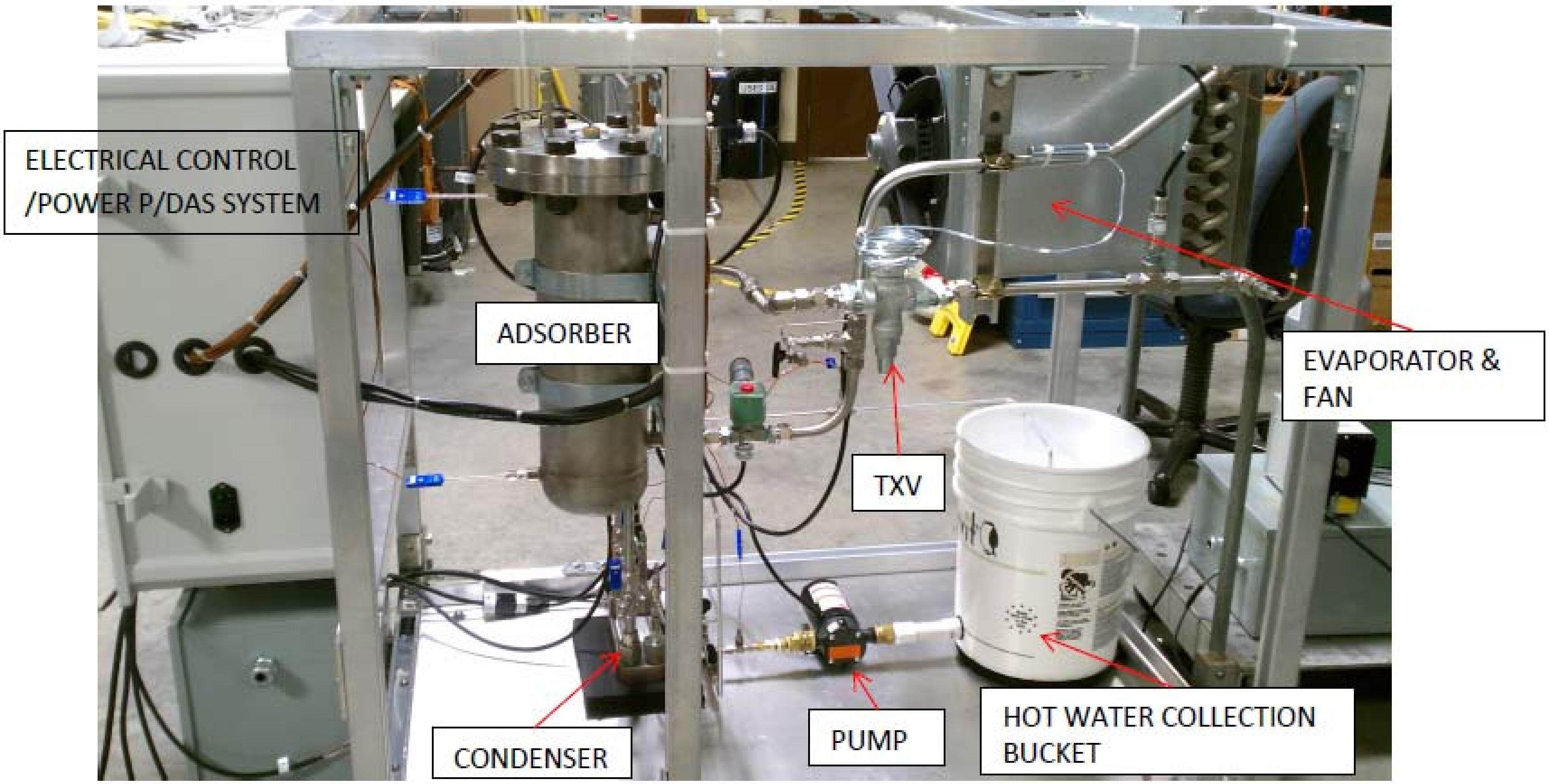
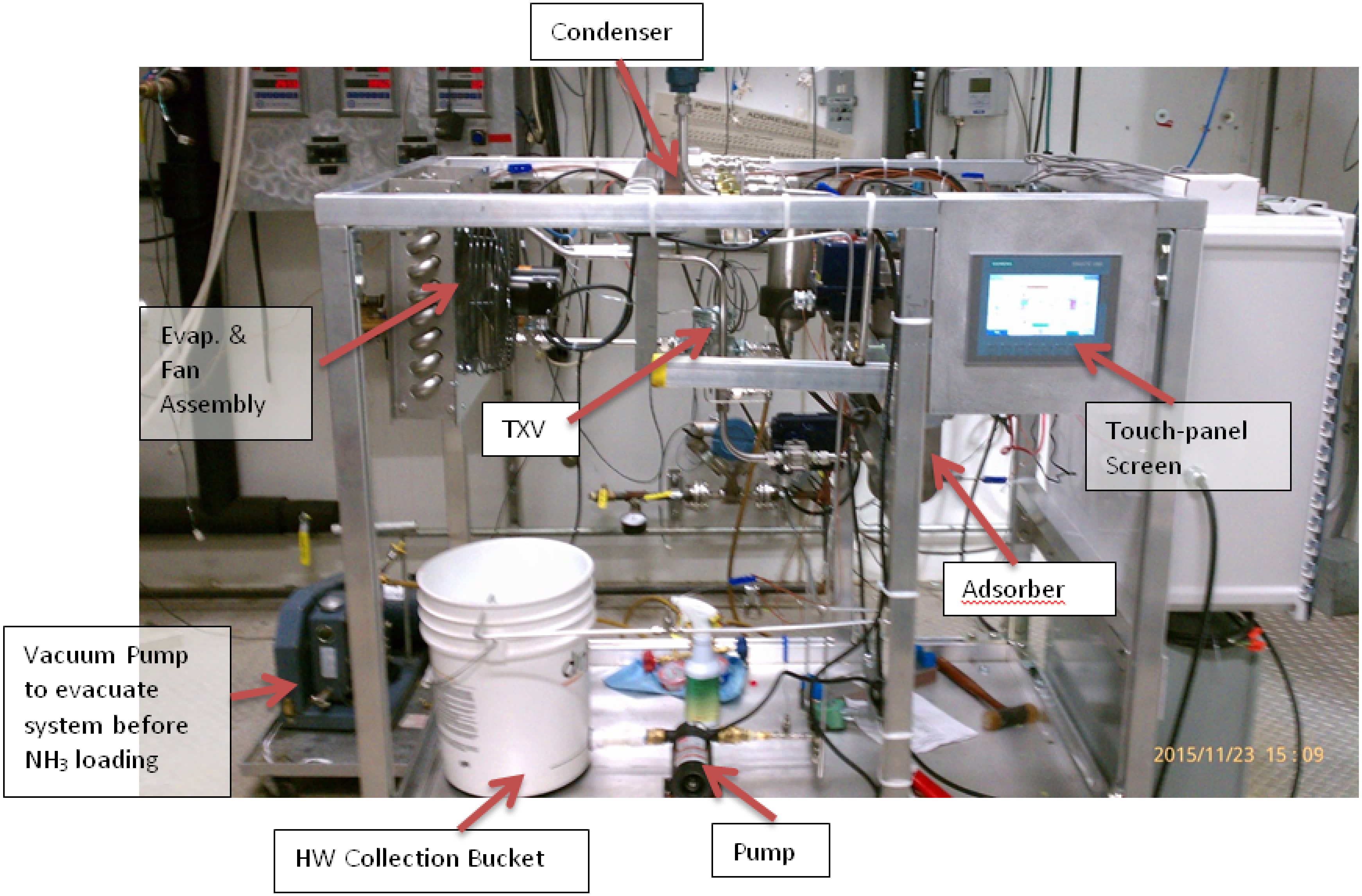
System Components



Prototype Subsystem



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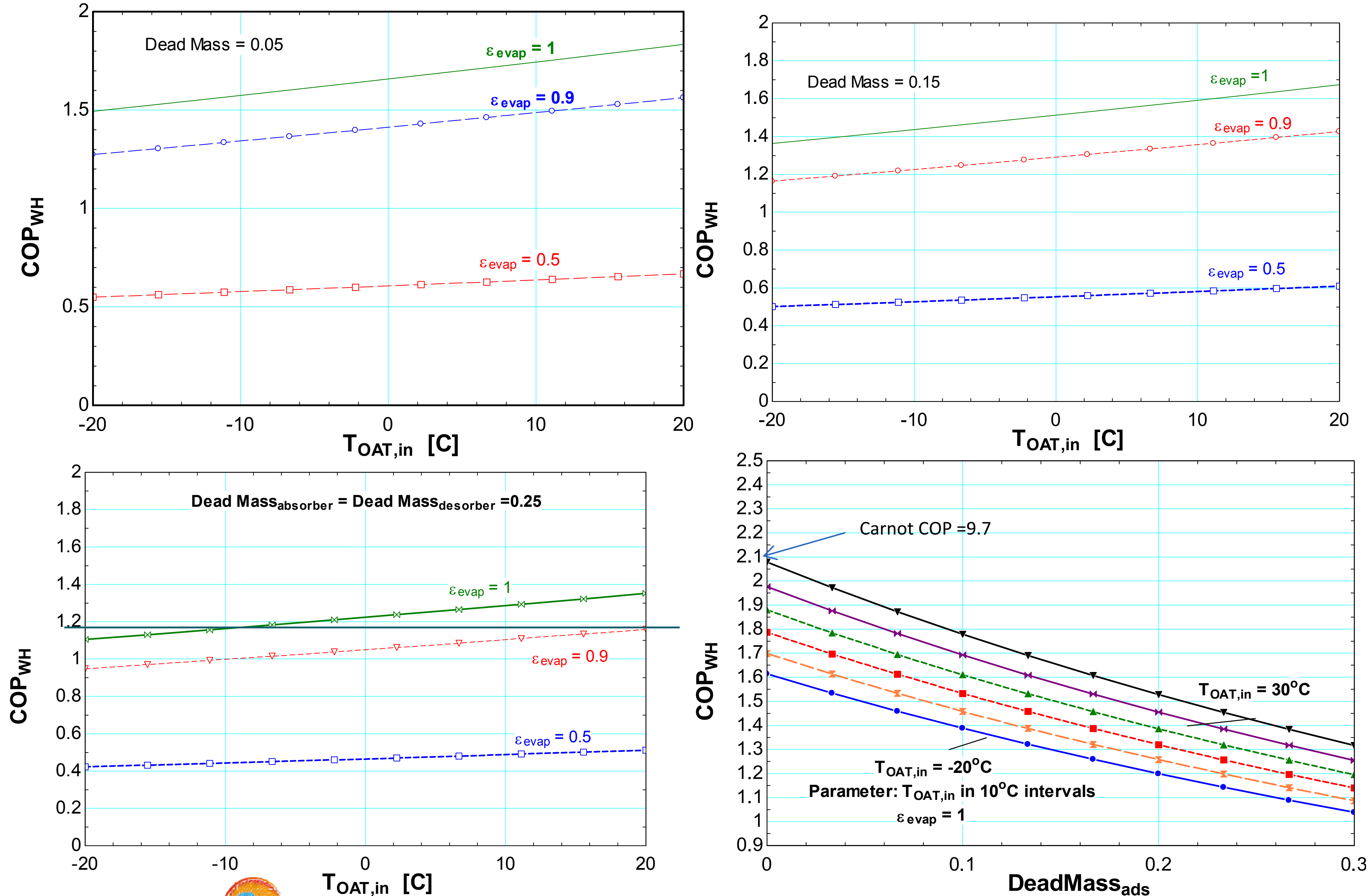
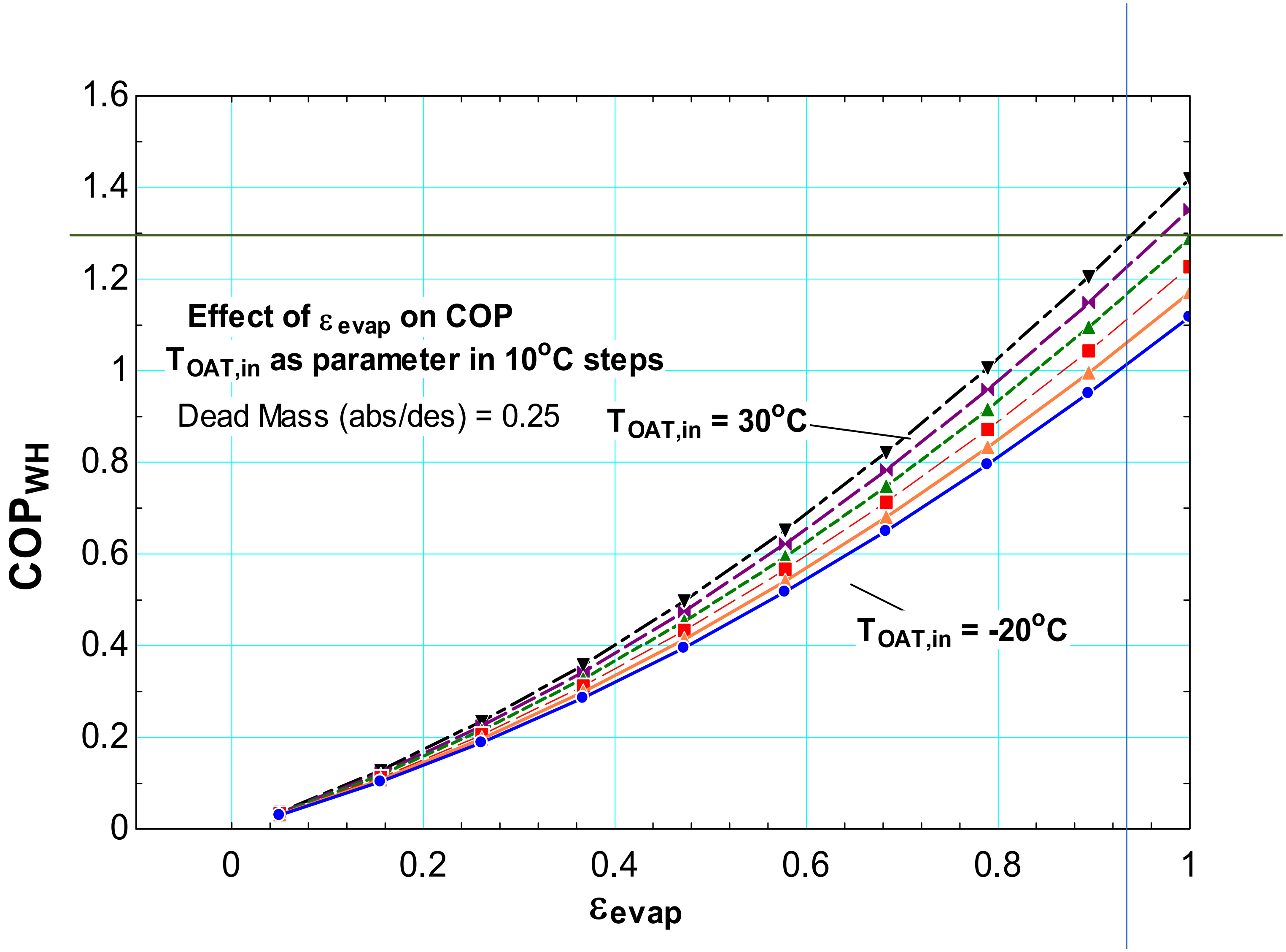
“Dead Mass” Strongly Limits COP



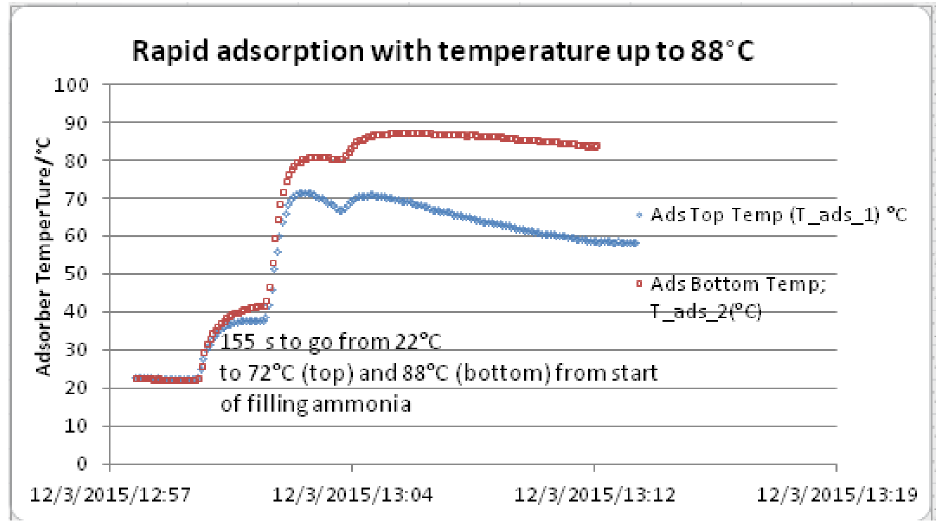
HPP Annex 43

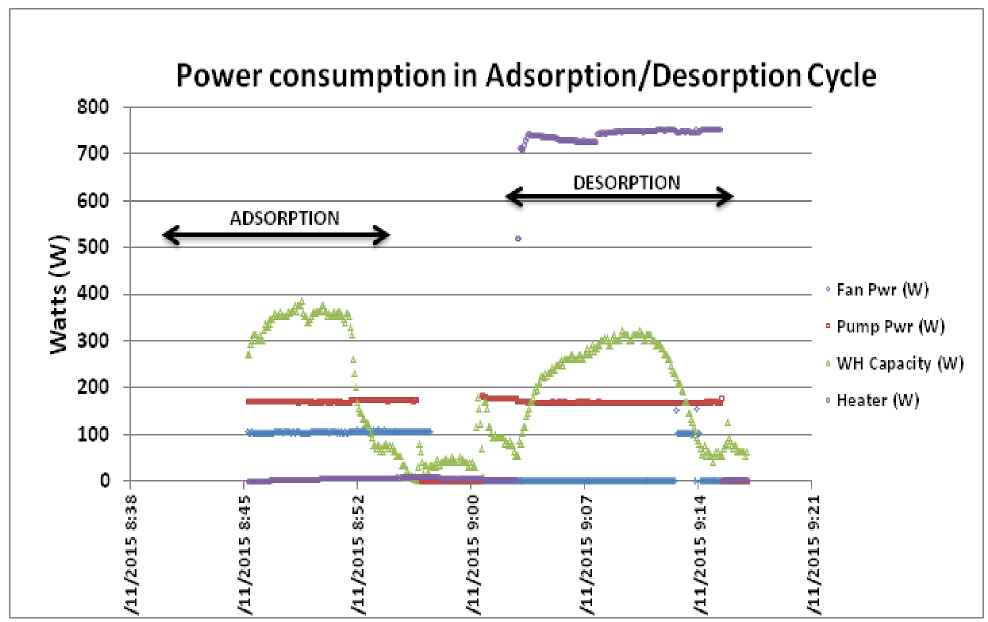
What COP can we expect?

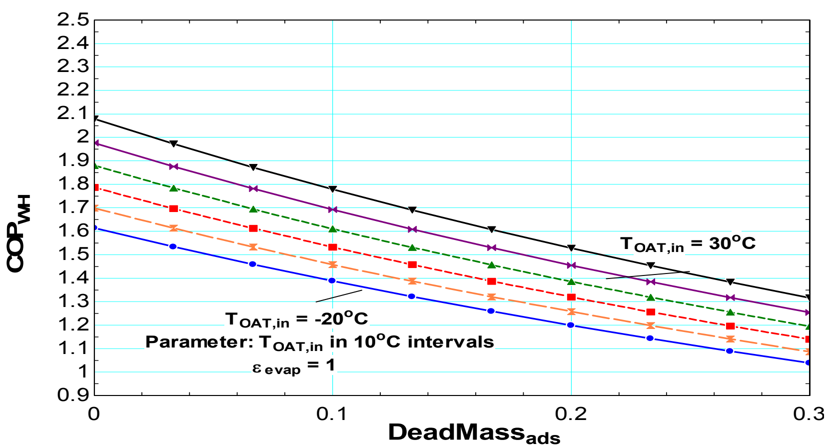


Adsorption is fast but “dead mass” too high

Although adsorption rate is fast, with adsorber bed heating from 22°C to 88°C in 155 s (2.6 mins), the overall cyclic performance fell below target limits. The total energy consumed was more than was produced, mainly due to the dead mass of the system, which was 36 times greater than that assumed by the simulation







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Recommendations

- 85% of the adsorber mass is in the flanges. Need to redesign the adsorber to reduce “dead mass” within acceptable limits
- Use ceramic paper in the adsorber to reduce thermal losses to the adsorber shell. This allows a greater fraction of the heat of adsorption to heat the water through internal insulation.
- Re-configure components to bring them into closer proximity to further reduce mass of metal and to facilitate transport of ammonia over shorter distances, and to lower pressure drops.
- Improvise a TXV. Vendor-supplied TVX’s do not appear to be suitable for bench-top applications
- Look for better adsorbents that have a larger spread of the isosteres, thereby reducing the system pressure considerably.

U.S Consumer Sentiment

- ❑Consumers are interested ---- but remain skeptical about ----- efficient models
- ❑ENERGY STAR ranking is a significant selling point
- ❑Cost-conscious consumers want efficiency rebates and incentives
- ❑About 26% of consumers are skeptical about claims of utility bill savings
- ❑Consumers willing to pay a modest premium for energy efficiency
- ❑Consumer skepticism is reinforced by inexperienced installers
- ❑Consumers are increasingly relying on on-line information to research products
- ❑The single greatest factor in decision-making is the cost of purchase and installation

Source: NEEA Report # 12-234, January 16, 2012

HPP Annex 43

Thank You !

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