Development of Separate Sensible and Latent Cooling System using Electrochemical Compressor

Omar Abdelaziz

Building Technologies Research and Integration Center, ORNL
Acknowledgment

• Co-Authors:
  – Oak Ridge National Laboratory: Qu Ming, Xiaoguang Sun
  – Xergy Inc: Bamdad Bahar, William Parmelee, Scott Fackler, Richard Sherrer, Jacob Zerby
  – University of Delaware: Ashish Chouhan, Ajay Prasad

• The U.S. Department of Energy Office of Building Technologies, BENEFIT FOA.
Outline

• Introduction

• System Components
  – Electrochemical Compressors
  – Metal Hydride Heat Exchangers
  – Sensible Cooling Subsystem
  – Liquid Desiccant Subsystem

• Overall System Results

• Conclusions
Introduction

• Electrochemical Compressors (ECC) are a transformative and disruptive platform
  – Noiseless operation
  – Operate without Global Warming Potential (GWP) working fluids (H₂, H₂O as working fluids)
  – Have the potential for superior performance enhancement

• Our goal is to design a room air conditioning system to achieve the following goals:
  – COP > 4
  – Achieve an incremental installed price premium < $ 70/kBTU [$239/kW] (when manufactured at scale)
  – Set up a high-volume supply chain to be able to provide low cost components to meet commercial unit targets
System Components
Electrochemical Compressors

- ECC can employ many different working fluids and thermodynamic cycles
- In their simplest form, the compressors can compress hydrogen, via proton pumping
  - ECC is supplied with hydrogen to the anode, and compressed hydrogen is generated at the cathode
  - When operated at low ‘voltages’, ECCs provide very high compression efficiencies
Metal Hydride Heat Exchangers

\[ M(s) + \frac{x}{2} H_2(g) \leftrightarrow MH_x(s) + Q \]

- \( M \) is a metal or alloy (e.g., Vanadium (V) or a body center cubic (BCC) solid solution based upon it), or an intermetallic compounds (IMC) (AB5, AB2, etc.); (s) and (g) relate to solid and gas phases, respectively, and Q is the reaction enthalpy.

- The overall process performance is strongly dependent on the intrinsic features of metal hydride reaction including its thermodynamic and kinetic characteristics, as well as composition, structure and morphology of the solid phases \((M, MH_x)\) involved in the process. These features are mainly related to fundamental aspects of hydride materials.
Metal Hydride Heat Exchangers

- Most of the lower-pressure compression alloys (PH < 200 bar at TH < 150 °C) belong to the AB₅-type intermetallic compounds while significantly higher, >1 kbar, H₂ pressures can be generated using AB₂-type compounds.
  - AB₂ compounds have significantly higher enthalpy of adsorption and higher percentage hydrogen storage capacity
  - AB₂ compounds, a much higher thermal exchange capacity is feasible which would lead to smaller heat exchangers.

<table>
<thead>
<tr>
<th>COMPOSITION</th>
<th>A</th>
<th>B</th>
<th>COMPOUNDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₂B</td>
<td>Mg, Zr</td>
<td>Ni, Fe, Co</td>
<td>Mg₂Ni, Mg₂Co, Zr₂Fe</td>
</tr>
<tr>
<td>AB</td>
<td>Ti, Zr</td>
<td>Ni, Fe</td>
<td>TiNi, TiFe, ZrNi</td>
</tr>
<tr>
<td>AB₂</td>
<td>Zr, Ti, Y, La</td>
<td>V, Cr, Mn, Fe, Ni</td>
<td>LaNi₂, YNi₂, YMn₂, ZrCr₂, ZrMn₂, ZrV₂, TiMn₂</td>
</tr>
<tr>
<td>AB₃</td>
<td>La, Y, Mg</td>
<td>Ni, Co</td>
<td>LaCo₃, YNi₃, LaMg₂Ni₉</td>
</tr>
<tr>
<td>AB₅</td>
<td>Ca, La, Rare Earth</td>
<td>Ni, Cu, Co, Pt, Fe</td>
<td>CaNi₅, LaNi₅, CeNi₅, LaCu₅, LaPt₅, LaFe₅</td>
</tr>
</tbody>
</table>
Sensible Cooling Subsystem

- For durable performance, hydride systems must remain dry.
- ECC-driven hydride heat exchangers are dual modular systems.
- When using membranes that require hydration to function, the valves would be appropriately controlled using a parallel system for (1) water removal and (2) water addition to the hydrogen stream, i.e., a desiccant bed for hydrogen pumped toward the hydride bed and a humidifier for the hydrogen gas being pulled from the hydride bed.
Sensible Cooling Subsystem Performance

G: low voltage and current $\rightarrow$ high COP
T: high voltages $\rightarrow$ quick recovery, high capacity, lower COP
Liquid Desiccant Subsystem

80% RA + 20% OA

Exhaust Air

Outdoor Air

Q = 5.4 kW (18,000 Btu/hr)

$\dot{V}_{air} = 0.189$ m$^3$/s (400 cfm)

OA% = 20%

Supply air conditions:

$T_{\text{dry bulb}} = 12.78^\circ$C (55°F)

$T_{\text{wet bulb}} = 12.2^\circ$C (54°F)

SHR = 0.68
Liquid Desiccant Subsystem Performance Results

Liquid-to-air HX

Dehumidifier 0.48kW MA1, 28.3°C, 0.31 kg/s

MA2, 33.3°C, 0.31 kg/s

Air-to-air HX 2.47kW

Air-to-Air HX 3.13kW Generator

Liquid-to-liquid internal HX

Liquid-to-liquid HX

Case 4
SAMR = 1.06
FR_ma = 0.31 kg/s

Air-to-liquid HX

0.72kW

OA, 35°C, 0.2 kg/s

HW, 55°C, 0.2 kg/s

Overall System Results

• The COP of the electrochemical compressor for producing chilled water at 12°C (54°F) was assumed to be 5.
  – Electricity demand for generating 5.06 kW chilled water = 1.02 kW

• In addition, the power to be used for the fans and pumps in LDAC shall be included in the system performance analysis: two fans for the dehumidifier and the regenerator, and two pumps in the dehumidification and regeneration loops.
  – According to ASHRAE/IES Standard 90.1-2013, fan power rate is 365 W/1000 cfm. To provide a 0.2 kg/s (340 cfm) air flow, the fan power is 0.124 kW.
  – According to ASHRAE 90.1, pump power rate is 22 W/gpm. To provide a 0.33 kg/s (5.23 gpm) of water flow in the dehumidification loop and a 0.21 kg/s (3.33 gpm) of water flow in the regeneration loop, the total pump power is 0.188 kW.

• The overall energy consumption for the LDAC/ECC-MHX would be 1.332 kW
Comparison with Baseline System Performance

- For a baseline EER12 room air conditioning unit (COP = 3.5)
  - Cooling demand = 5.856 kW (to provide required subcooling for dehumidification)
  - Total electricity demand = 5.856/3.5 = 1.677

- Energy savings:

\[
\frac{1.677 - 1.332}{1.677} = 21\%
\]
Conclusions

• A basic framework for a highly efficient, noiseless, vibration free heat pump system without GWP working fluids, and utilizing liquid desiccant to avoid latent heat loads has been provided for a room air conditioner.

• The study presented in this paper identified a system configuration for LDAC coupled with electrochemical compression.
  – Five cases of different system configurations were studied and simulated in Sorpsim.
  – The final recommended system configuration was determined based on its 21% energy savings compared to a conventional VC system.
Questions

• Omar Abdelaziz
• abdelazizoa@ornl.gov
• 1-865-574-2089