An overview of advancements in electrochemical compressor driven heat pump systems

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Proton Pump
We can try to mimic nature

5/22/17
Core Technology: Ion Exchange Membranes

Controlling the movement of ions and molecules through nanoscale channels offers revolutionary pathways for development of new home, energy, industrial, medical, and sensing products. This technology is new, transformational, disruptive, and very profitable.

- **The Problem:**
  - Ion Exchange Media are inherently weak.

- **The Solution:**
  - XERGY reinforces them to make composites membranes that are stronger.
    - With DOE funding, we can now make continuous films, that are Ultra-thin, Ultra-strong, Ultra-high performance.
  - XERGY knows how to package them into useful devices, creating great products for critical applications.

- **Ion Exchange Media - Two Key Properties**
  - Can transport Ions under electric field (cations, anions).
    - Recently received three ARPA (Anionic Membrane) awards.
  - Can transport polar molecules (pervaporation). Difference in concentration, temperature, pressure.
    - Some of our new membranes, 5x the best current membranes for moisture transmission.
  - Transformational and disruptive technology
The Breakthrough

• 10 times thinner means 10 times lower cost, and larger gross margin.
• Thinness means shorter distance for ions or molecules to travel. Means lower resistance, higher performance.
• Thinness without compromising on strength. Compositing provides mechanical reinforcement for otherwise weak materials.
• Lower cost plus higher performance ➔ Can penetrate new applications

Because of their thinness and high performance, packaging membranes into functioning devices is non-trivial.

Literally hundreds of product opportunities.
Electrochemical Compressor Cell Schematic

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Electrochemical Compressor Features

• Exergy efficiency up to and even beyond 80% for pressures up to 10,000 psi or 700 bars.

• Governed by the Nernst Equation:
  (Nernst won the 1920 Nobel Prize)
  \[ Q_r = \text{Reaction Quotient, i.e. Pressure Ratio} \]
  \[ E_{cell} = E_{cell}^\Theta - \frac{RT}{zF} \ln Q_r \]

• For 10x Pressure difference, i.e. 0.05 volts, or operating at the Nernst potential, the process is considered isentropic i.e. is both adiabatic and reversible. That is, no heat is added to the flow, and no energy transformations occur due to friction or dissipative effects.

• ELECTROCHEMICAL COMPRESSION IS THE MOST EFFICIENT WAY TO COMPRESS A GAS!!
Operating Voltage correlated directly to Efficiency
Very wide range of Temperatures can be Achieved – depending On Metal Hydride

<< 0 C to >> 100 C

WITH HIGH EFFICIENCY
Wide Thermal Window

Many different metal hydride systems are feasible

Each compound has its own pre-set operating parameters

From – 100°C to 240°C

Known materials!!

Also Many new types of materials emerging like MOF’s.

Technology is in its infancy!

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“Historic” Electrochemical Hydrogen Compressors Not Suitable

New Approach Needed for Home Appliances
7 Generations of ECC’s

- **DOE SBIR PHASE 1**
  - Design Freeze
  - GEN 1
  - Single Cell H2O
  - Commercial Sale (Water Compressor) Dais / ORNL

- **DOE SBIR PHASE 2**
  - Advanced Learnings
  - GEN 2
  - Multi-Cell H2O Graphite

- **DOE SBIR PHASE 2**
  - Advanced plates
  - GEN 3
  - Multi-Cell H2O Metal

- **DOE BENEFIT 2015**
  - Design Freeze
  - GEN 4
  - Graphite Plate – H2 Internal Porting

- **DOE SBIR PHASE 2B**
  - Advanced Plates
  - GEN 5
  - Metal Plate – H2
  - 3 x Smaller

- **DOE BENEFIT 2016**
  - Anhydrous
  - GEN 6
  - Coatings, Simpler System

- **DOE SBIR 2B 2017**
  - Large Plates
  - GEN 7
  - Large Area
  - 3 X Lighter

Available in .4 L/min, 4 L/min, and 40 L/min (roughly 2 Kg/day)
ECC Comparison to Industry Metrics @ Nominal 150 Watts (Cooling) – Current State of the Art

- 5\textsuperscript{th} & 7\textsuperscript{th} Generation, C Variant ECC, within 10% of best reciprocal compressor system!
- Achieved Industry Metric!!

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Industry Metrics
ECC with Metal Hydride Heat Exchangers
Proper Metal Hydride Selection and Formulation is Key

GEA: COP vs Voltage

Metal Hydride Heat Exchangers
ECC: Water as Working Fluid
Water Compression Test Data

(Different Gaskets)

.32 psia Inlet
10 psia Outlet

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Single Cell ECC with Carbon Dioxide as a Working Fluid
Conclusions

• Electrochemical Compressors (ECC’s) can operate with different working fluids, and different thermodynamic cycles. Xergy has demonstrated two cycles with two fluids water and hydrogen and is working on others.

• Theory confirms that this compression technology can provide much higher operating efficiencies.

• Xergy has demonstrated 7 sequential generations of ECC’s, for multiple applications, reducing weight and volume by several orders of magnitude approaching commercial market entry targets. Can be packaged to fit the size requirements of home appliances – such as hybrid hot water heaters and air conditioners.

• Xergy showed that
  • ECC’s can be more efficient (i.e. have inherently high COP’s)
  • Motor-less and therefore most reliable and noiseless,
  • Do not use CFC’s and are therefore non-GHG, environmentally-friendly,
  • Modular and scalable,
  • Operate more efficiently at partial loads, and
  • Can be designed to different form factors.

• This compression technology provides an excellent platform for the development of new heat pumps; and make a huge impact on energy efficiency globally!

• Working with industry leaders to build heat pump systems around these compressors!!