LOW-GWP HVAC SYSTEM WITH ULTRA-SMALL CENTRIFUGAL COMPRESSION

2016 Building Technologies Office Peer Review

Dr. Edward Bennett

e-mail: emb@mechsol.com

Vice President of Fluids Engineering
Mechanical Solutions, Inc.
Project Summary

Timeline:
Start date: 10/2015
Planned end date: 6/2017

Key Milestones
1. Milestone 3.3.1; 1/29/16
2. Milestone 2.1.1 ~40% complete; 1/29/16

Budget:
Total Project $ to Date:
• DOE: $134,406 + $56,776 (fy: 2016)
• Cost Share: $52,867

Total Project $:
• DOE: $999,921 ($362,794 Approved Budget)
• Cost Share: $251,525 ($125,886 Approved Budget)

Key Partners:

<table>
<thead>
<tr>
<th>Lennox International, Inc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TURBOCAM International, Inc.</td>
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</table>

Project Outcome:
Advance unrealized design potential of small centrifugal vapor compression in conjunction with advanced heat exchanger design to reduce environmental burdens with the use of low-GWP refrigerants while cost-effectively maintaining performance.
Purpose and Objectives

Problem Statement: Advance unrealized design potential of small centrifugal vapor compression in conjunction with advanced heat exchanger design to reduce environmental burdens with the use of low-GWP refrigerants while cost-effectively maintaining performance.

Target Market and Audience: This project is targeted toward residential and commercial air conditioning. The market is approximately 3 quads of cooling for both residential and commercial. The audience is new units selected for low-GWP refrigerant capability.

Impact of Project:

• **Project Output** – Technical performance goals met, technical and manufacturing pathway established, and prototype for efficient use of low-GWP refrigerants in HVAC applications
• **Near-term outcomes**: Private sector aware of technology through investment/collaboration, begin additional investment to refine technology/reduce cost
• **Intermediate outcomes**: Continued partnership with private sector system and component manufacturers to refine technology and reduce cost, introduce to market
• **Long-term outcomes**: Enable cost effective and energy efficient shift to low-GWP refrigerants in HVAC industry
Approach

Approach: Develop conceptual model in collaboration with system vendor to determine efficiencies, system design and manufactured cost. Refine design and build/test prototype to validate solution.

Key Issues:
1. **Efficiency** – Low-GWP refrigerants are new and untested in this application. Early compressor studies are based on isentropic efficiency, but system efficiency results required.
2. **System integration** – Small centrifugal is a departure from current HVAC applications in this size range. Need good integration into system, including operating methodology, materials compatibility, etc. Heat exchanger is an integral component.
3. **Cost** – Technology will need to be cost effective to be adopted by industry and subsequently consumers.

Distinctive Characteristics: Determine system efficiency and cost estimates early in program
Progress and Accomplishments

Accomplishments:
- Study of various low-GWP refrigerants performed and downselected
- Conceptual aero design completed
- Preliminary heat exchanger design completed, parts being sourced
- Conceptual bearing and motor design completed

Market Impact:
- Presenting findings to date at Purdue Compressor Conference Aug 2016
- Still early in project (Budget Period 1)

Awards/Recognition:
- None to date

Lessons Learned:
- Business Development negotiations with partners can be very time consuming
Project Objectives

• Design and development of an ultra-small, efficient, maintenance-free, oil-free, inexpensive centrifugal compressor, including aero components, rotor-bearing system, inverter and motor for a 5-ton air conditioning system
• Optimization for partial load efficiency, without sacrificing peak load performance
• Design for manufacturability and cost
• Validation and system integration of a high effectiveness heat transfer system, engineered for a very low-GWP refrigerant, e.g., microchannel heat exchanger
• Analysis of:
  — very low-GWP refrigerant compatibility with system materials
  — throughput benefits of centrifugal compression of lower density, very low-GWP’s
• Quantification of beneficial lifecycle impacts of centrifugal technology, including installation, diagnosing, and servicing of systems
• Optimization for unitary “drop in” replacement, including flammability and safety risks, suction line pressure drop, and performance relative to outdoor temperature
• Testing of prototype system
Design and Prototype Development Flowchart

1. System Design
   - Preliminary Compressor Aero Design
   - Detailed Compressor Aero Design
   - Detailed Compressor Manufacturing and Mechanical Design
   - Oil Free Bearing and Motor Design
   - Prototype Development and Testing
   - Integration with Lennox Air Conditioner
System Design

- Conducted by Lennox
  - System design consisting of all components (Compressor, heat exchanger, etc.), using Cycle_D code
- Multiple refrigerants examined
  - Several HFO blends were evaluated
Preliminary Aero Design

- Conducted using PCA Vista Design Code and CFturbo
- Both codes employed modified Redlich Kwong and Peng Robinson Equation of State (EOS) to simulate Refrigerant PVT behavior
Detailed Aero Design

• Upon Completion of the preliminary design, a detailed 3-dimensional geometry of the centrifugal compressor was made using specific turbomachinery design software (ANSYS and CFturbo).
• The flowpath was analyzed using the real gas CFD code, STAR-CCM+
• A secondary flowpath was added to the system using the NX and Pro-Engineer CAD products to add fidelity to the analyses.
• Complete analyses were conducted for subject refrigerants.
• The analyses were completed at the rated condition, as well as a appropriate turndown condition to ensure proper off-design performance.
• The effect of the foil bearings were considered in these analyses. A supply flow was taken from the impeller. This flow will feed the bearings, and provide motor cooling flow.
Compressor Coupled CFD Analysis
Project Integration and Collaboration

**Project Integration:**
MSI and Lennox are coordinating system design parameters to guide development. Lennox participates in requirements definition, design reviews, and parallel development.

**Partners, Subcontractors, and Collaborators:**
Project partner – Lennox International, Inc.

**Communications:**
Presenting findings to date at Purdue Compressor Conference Aug 2016
## Project Plan and Schedule

### Project Dates:
- **Start:** 10/2015
- **End:** 6/2017

### Current and Future Work
- See Schedule

### Major Task Schedule

<table>
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<tr>
<th>Phase</th>
<th>SOPQ</th>
<th>Task #</th>
<th>Task Title or Milestone/ Deliverable Description</th>
<th>Performer (if different from recipient)</th>
<th>Task Completion Date</th>
<th>Progress Notes</th>
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*Project Schedule has been shifted by 2 months due to late kickoff meeting.*

*First Version Of Requirements Document To Be Finalized At Concept Design Review.*

*Subtask 4.2 (Identified TURBOCAM) Conducting In Concert With Production Cost Estimate Effort.*

*Per DOE/MSI Aerodynamic Design Review (1/19/2016).*
Project Budget

Project Budget:
- DOE: $999,921 ($362,794 Approved Budget)
- Cost Share: $251,525 ($125,886 Approved Budget) - Lennox International, Inc

Variances:
- Currently no variances specific to project

Cost to Date:
- Cost Share: $52,867 (CY 2015)

Additional Funding:
- Strategic Partner (Lennox International, Inc.) To Dedicate $251K Cost Share

Budget History

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Next Steps and Future Plans:

- Consider 2-stage compressor
  - Longer lifecycle
  - More refrigerant options
  - Applicable to heat pumps, including cold climate
- Need to investigate higher resolution 3-d printing for various materials