Turbo-Compression Cooling for Ultra Low Temperature Waste Heat Recovery

DE-EE0008325

Colorado State University/Barber Nichols Inc., Modine Manufacturing Co.

06/01/2018 – 06/01/2021

Dr. Todd Bandhauer, Colorado State University

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
June 2-3, 2020

Overview

Timeline

- Project Start Date: 06/01/2018
- Budget Period End Date: 05/31/2020
- Project End Date: 06/01/2021

Budget

	Year 1 Costs	Year 2 Costs	Year 3 Costs	Total Project
DOE Funded	982K	455K	447K	1.88M
Cost Share	275K	148K	47K	470K

AMO MYPP Connection

- Smaller footprint (Target 12.1)
- Cost-effective, low-temperature heat recovery (Target 12.3)

Barriers

- Utilization of low temperature waste heat (90°C to 150°C)
- Reduce system footprint
- Matching cooling demand with variable waste heat supply
- Compact low cost heat exchangers
- High efficiency turbomachinery operated over wide range of conditions

Partners

- CSU in Fort Collins, CO, leads project and is site of experimental validation
- Project partners include:
  - Barber Nichols Inc. – Specialty turbomachinery manufacturer in Arvada, CO
  - Modine Manufacturing Co. – Heat exchanger and commercial chiller manufacturer in Racine, WI

Project Objectives

Challenges in Manufacturing Environments

- AMO Strategic Goal: Improve the productivity and energy efficiency of U.S. through utilization of waste heat
- MYPP Target 12.1: Develop system designs with smaller footprints
- MYPP Target 12.3: Develop innovative, cost-effective systems to recover heat from low-temperature (<230°C) waste heat sources

Validate Turbo-Compression Cooling Concept

- Problem: efficiently convert variable low grade heat (90°C to 150°C) to cooling in manufacturing operations with a small footprint
- Relevance: co-located cooling loads and waste heat are common in many industries (e.g., food, CHP), and significant reduction in manufacturing energy possible
- Challenge: competing absorption units are sensitive to heat load variability and suffer from large footprints and other difficulties
- Solution: develop advanced turbo-compression cooling system that combines high effectiveness compact heat exchangers with highly efficient turbomachinery
- Major risks addressed in this project: (1) high turbine and compressor efficiency (>80%), (2) limited system turndown, (3) high effectiveness HX with low pressure drop, (4) manufacturing system integration

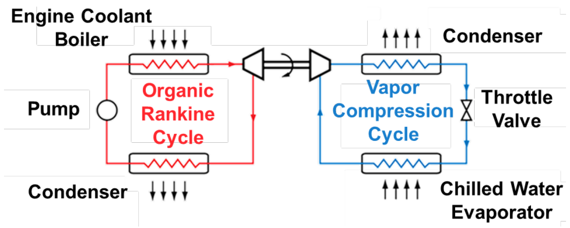
Technical Innovation

Challenges with Current Solutions – Absorption Chillers

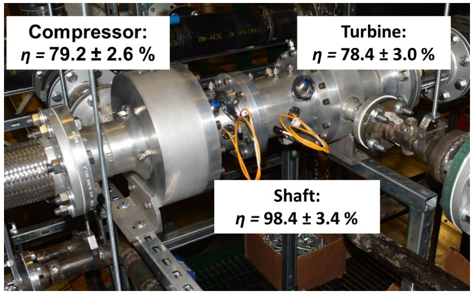
- Low refrigerant pressure require large heat exchangers
- Require steady heat input source, and chemical imbalances cause crystallization
- Corrosive fluids reduce lifespan, require expensive materials

Proposed Solution – Turbo-Compression Cooling

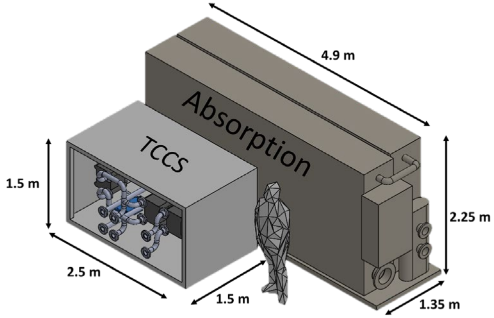
- Non-corrosive, moderate pressure refrigerant: smaller, low cost heat exchangers
- System designed to handle transient and variable heat inputs
- High efficiency turbomachinery and power transmission
- Suited for processes with abundant waste heat and co-located cooling loads
- Potentially much smaller footprint than competitive absorption



Integrated System Diagram



Efficient Turbomachinery and Power Transfer

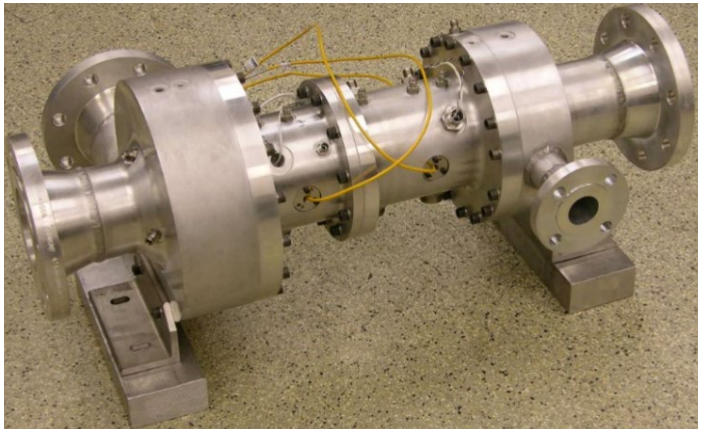


>2.5× Cooling Density Possible without Harmful Refrigerants

Technical Approach

Develop turbo-compression cooling system at industry standard conditions with high turndown and small footprint

- Turbomachinery optimized for operating conditions yields high efficiency and turndown (BNI)
- Compact, aluminum brazed heat exchangers reduce system footprint and cost (Modine)
- Advanced cycle design and integration yields viable waste heat to cooling technology with significant market penetration potential (CSU)



High Efficiency Turbomachinery

Compact Heat Exchangers

Technical Approach

Risk	Challenge	Mitigation	Key Milestones
Meeting Cost Target	HX Costs, Misc. Component Cost	Early discussions with Modine, compare with Turbochill product, possible initiation of mfg. estimate of heat exchangers by Modine	M1.1
Meeting COP Target	High Effectiveness HXs and High Efficiency TC	Early and often Design Reviews, two design concepts	M1.1-M1.4, D1 and D2
Operation at Various Loads	Compressor Stall at Low Turbine Powers	Early and Often Design Reviews, proprietary mitigation strategy	M1.1-M1.4, D1 and D2
HX Manufacturing	Large Devices	Only manufacture key components, utilize existing technologies as much as possible	M1.4
Market Uncertainty	Insufficient Waste Heat and Cooling Load, Recovery and Utilization Mismatch, Test Conditions Do Not Match Market Requirements	Early market analysis will narrow down top industrial prospects, evaluate design changes as needed, test over range of conditions	M7.1, M7.2, M6.2, M6.3

Results and Accomplishments

- **Go/No-Go Decision Point 2 complete, experimental testing ongoing**
- **Year 1**
  - Market Assessment
  - Finalize Design Points, Cost Assessment (M1.1 & M1.2)
  - Finalize Design Concept 1 (M1.3 & M1.4, *D1*)

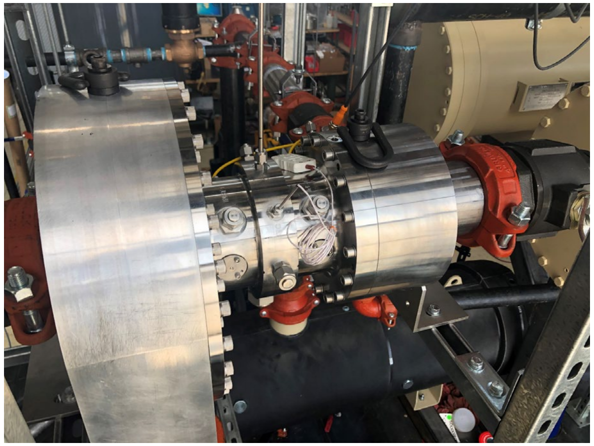
  Market analysis and system design
- **Year 2**
  - Heat Exchanger and Turbomachinery Fabrication (M2.1 & M2.2)
  - System Fabrication (M2.3)
  - Experimental Testing to Validate COP (M3.1)
  - Modeling of Design Concept 2 (*D2*)
  - Secure IP (M7.3)

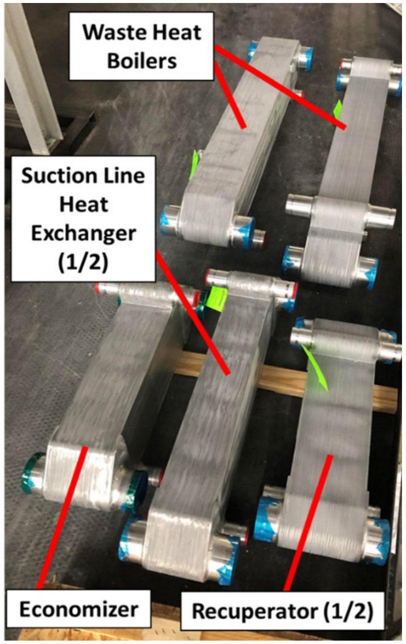
  Build system and meet first performance target
- **Year 3**
  - Finalize Design Concept 2 (M4.1)
  - Fabrication of HX, TC, and System (M5.1 – M5.3)
  - Experimental Testing to Validate COP (M6.1)
  - Experimental Testing to Validate Turndown Ratio and Varying Ambient (M6.2 & M6.3)
  - Secure IP (M7.4)
  - Final Economic and Commercial Validation (M7.5)

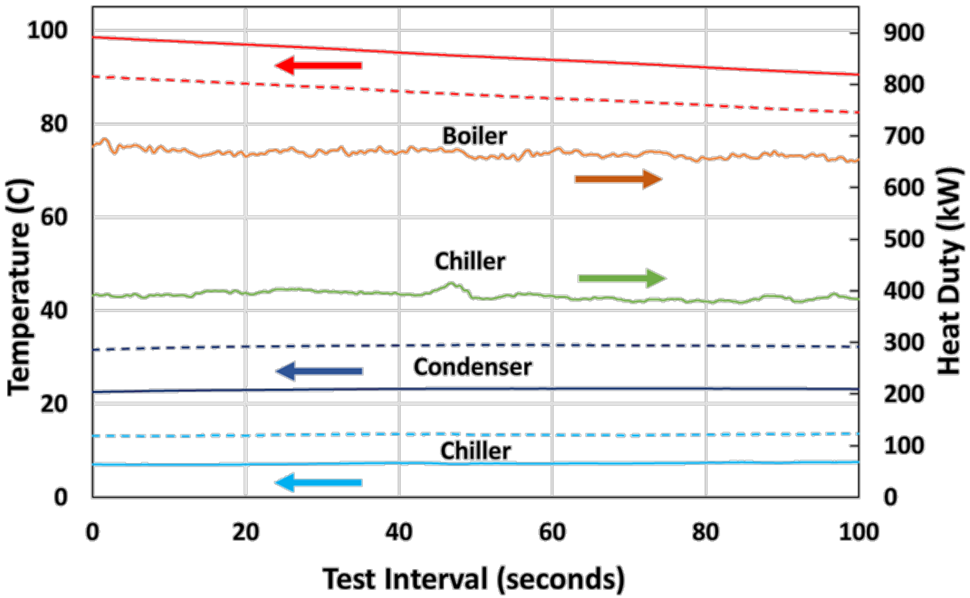
  Modify system and meet final performance targets

Results and Accomplishments

- **Experimental data verified performance of waste heat boiler, power cycle condenser, and operated turbocompressor to design rotational speed**
- **Validated Design Concept 2 model with initial data to achieve Go/No-Go Decision Point 2 (*D2*)**
- **Facility reconstruction ongoing to incorporate waste heat boilers and internally recuperative heat exchangers**
- **Provisional patent application filed**



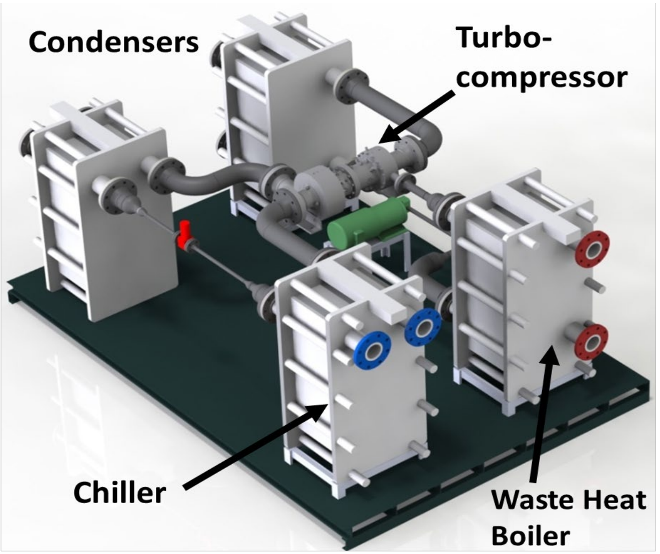




Transition

Project address key technoeconomic risks and understanding likely adoption pathway for low grade waste heat to cooling systems

- Follow-on funding from DOD to investigate viability of waste heat driven TCCS for shipboard cooling
- Commitment from potential commercial partner on ARPA-e SCALEUP STTR
- Exploring additional commercialization options, including with partner Modine



Proposed Turbo-compression Cooling System

300 kW electrical chiller fabricated by partner Modine

Questions?