United Technologies Research Center

Final Technical Report

High-Efficiency Low Global Warming Potential Compressor

DOE AWARD NUMBER: DE-EE0007039

REPORT PERIOD: 1 Aug. 2015 – 30 Nov. 2017

RECIPIENT: United Technologies Research Center
411 Silver Lane
East Hartford, CT 06108

AUTHORS: F. Cogswell, P. Verma

DATE SUBMITTED: Feb. 23, 2018

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Award Number DE-EE0007039.

Contents

Executive Summary

During this project UTRC designed a novel compressor for use with new low Global-Warming-Potential (GWP) refrigerants. Through two design and testing iterations, UTRC advanced the compressor technology from TRL3 to TRL5. The target application was a 5 Tons of Refrigeration (TR) capacity Roof-Top Unit (RTU), although this technology may be applied to other low-capacity systems such as residential. The prototype unit met all design goals at the ARI-A rating condition and requires high efficiency motor to meet high performance targets at the ARI-B condition. This technology may be used in high efficiency units and with seasonal energy efficiency rating (SEER) exceeding 20. A preliminary cost analysis estimated that there would be less than $25/kbtuh cost impact to the customer.

1. Introduction

The primary goal of this project was to develop a novel compressor for use with low global warming potential (GWP) refrigerants. The target application was a 5TR (Tons of Refrigeration capacity) Roof-Top Unit (RTU). Through two stages of design and calorimeter testing, UTRC advanced this compressor technology from TRL3 to TRL5. Other goals of the project include design (but not building and testing) of a compatible 5TR RTU system which uses the new compressor and the selected refrigerant, prediction of the achievable seasonal energy efficiency ratio, and estimation of the cost impact compared to a baseline R410A unit.

The following sections cover:

1. Review of the accomplishments relative to the major milestones
2. Discussion of the key compressor design parameters
3. Discussion of the compressor testing results
4. Discussion of the RTU design analysis
5. Discussion of the cost and Technology to Market Plan.

2. Major Milestones and SOPO targets

The primary milestones for this project relate to compressor performance and cost impact on the complete RTU should it use this new compressor technology and desired refrigerant. Table 1 from the SOPO lists the following compressor targets:

Table 1: SOPO requirements for Compressor performance

Metric	First Prototype	Second Prototype
Refrigerant flow at ARI-A condition	>90% of that required for 5TR.	>98% of that required for 5TR.
Isentropic efficiency @ ARI-A	> 62%	>= 73%
Isentropic efficiency @ ARI-B	> 62%	>= 73%

2.1 Refrigerant flow rate for the design condition (ARI-A or SEER A2)

Refrigerant flow rate was not an issue for either prototype. As can be seen in below in Figure 3, the required flow for the design condition (A2) and all other conditions was easily achieved.

2.2 Overall compressor efficiency at the ARI-A (SEER A2) and ARI-B conditions

The target full compressor efficiencies are listed as the product of motor and compression efficiency, and are 62% for Prototype-I, and 73% for Prototype-II at both ARI-A and ARI-B conditions. The compression efficiency is determined from refrigerant side measurements. The motor efficiency is determined from power measurements between the inverter and motor divided by the compressor shaft power. The compression isentropic efficiency (not including motor and drive) for both prototypes were 82% and 81% respectively for the ARI-A and B conditions.

The motor efficiency, however, was lower than the final (second prototype) target of 92% at both conditions. The ARI combined compressor efficiencies achieved for Protype-II were:

ARI-A: 73.8% (compared to the 73% SOPO target)
ARI-B: 67.2% (compared to the 73% SOPO target)

Although the overall efficiency target was met at the ARI-A condition, the ARI-B efficiency target was not met due to poor motor efficiency. Analysis of the motor and power supply revealed that this loss was due to excessive harmonics from the power supply to the motor which were more significant relative to the required shaft power at lower speeds. For this project we had used an off-the-shelf inverter. An integrated inverter/motor design is desired and necessary to achieve the target motor/drive efficiencies.

3. Compressor Design

3.1 Required Operating Conditions

ANSI/AHRI Standard 210/240 defines the standard for seasonal ratings of air-conditioning units that produce less than 65,000 btu/hr (5.4TR, 19kW) capacity. For a unit with a variable speed compressor five rating conditions are required:

- "A2": 95F Outdoor; Full speed.
- "B2": 82F Outdoor; Full speed.
- "Ev": 87F Outdoor; Intermediate speed.
- "B1": 82F Outdoor; Minimum speed.
- "F1": 67F Outdoor; Minimum speed.

For all cases the indoor return air temperature is 80F dry-bulb/67F wet-bulb. The "A2" condition is the design condition. The minimum speed can be specified by the manufacturer. The intermediate speed is defined as [min-speed + (full speed – min-speed)/3]. A lower minimum speed is advantageous, provided good cycle efficiency can be maintained, since it reduces the amount of "cycle degradation" in the seasonal efficiency calculation.

3.2 Compressor Design

Two compressor prototypes were designed for performance (capacity, flow rate and efficiency at various operational speeds).

4. Test rig and testing results

4.1 Test Rig and instrumentation

A 5TR compressor calorimeter cart was fabricated. Figure 1 shows a schematic P&ID that was used for Prototype-I, and Figure 2 shows the test cart.

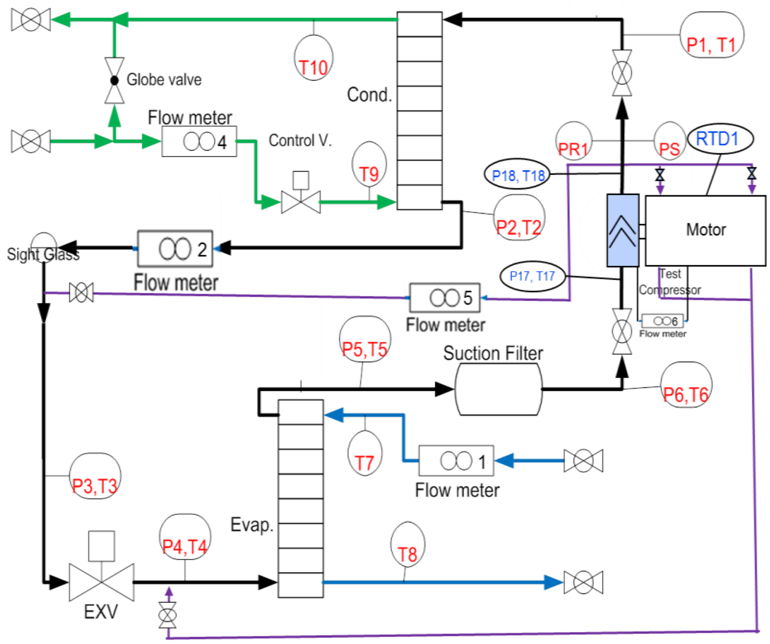

Figure 1: Calorimeter Schematic

The instrumentation includes:

Label	Type/location	Measures	Comments
Flow meter 1	MicroMotion	Water flow to evaporator	Used for energy balance
Flow meter 2	MicroMotion	Primary refrigerant flow exit of condenser	Used to determine net flow produced by the compressor
Flow meter 4	MicroMotion	Propylene glycol water mixture (PGW)flow to condenser	Used for energy balance.
Flow meter 5	MicroMotion	Motor-cooling flow	Used to determine motor cooling flow required.
P1 – P6, T1-T6	Cart	Refrigerant temperatures & pressures around cart	Not used for compressor analysis, just cart diagnostics
P17, T17	Compressor flange	Compressor suction temperature & pressure	Refrigerant inlet state to compressor.
P18, T17	Compressor flange	Compressor discharge temperature & pressure	Refrigerant outlet state from compressor.
RTD1	Compressor	Embedded in motor stator windings	Assess motor cooling effectiveness.
T7,T8	Cart	Water temperature to and from evaporator	Used for energy balance.
T9,T10	Cart	PGW temperature to and from condenser	Used for energy balance.

Figure 2: UTRC Test cart Calorimeter

4.2 Compressor performance

Figure 3 shows the prototype-I compressor test results from the calorimeter testing. As shown in this figure the normalized flow and pressure ratio of the prototype met the expected results.

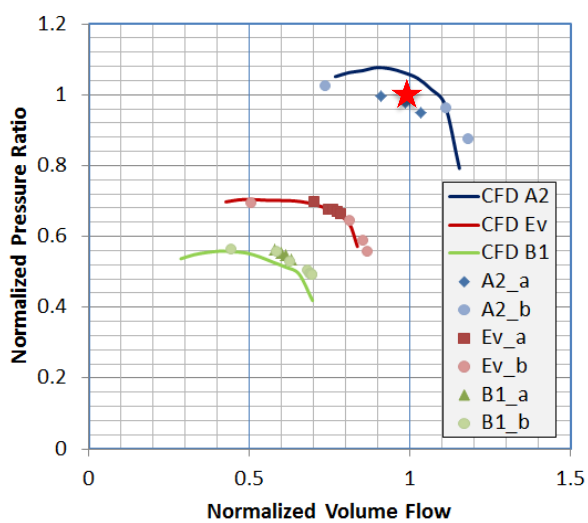

Figure 3: Normalized pressure ratio (measured pressure ratio/max design pressure ratio) and volume flow rate (measured volume flow rate/max design volume flow rate) for three operating speeds; comparison to CFD prediction.

4.3 Drive/motor performance

The compression efficiency is based on the measured refrigerant flow and properties at the compressor suction and discharge. The motor shaft power is equal to the power into the refrigerant. The motor efficiency is defined as the motor shaft power divided by the electrical power into the motor. The motor losses include stator losses, rotor losses and windage losses. Initial attempts on Prototype-I to measure the motor electrical power were not successful given challenges with desired frequency power measurements. The inverter reports power output to the motor, but this power appeared to be too low at many operating conditions. A power analyzer was obtained and installed on the test rig and power data was finally obtained during Prototype-II testing.

5. 5TR RTU Design

Although the primary goal of this project was to develop a novel compressor for a small (5TR) RTU, a secondary goal was to do full system design analysis to determine the impact of the use of low-pressure refrigerants on the other components, and to estimate the overall system cost impact to the customer.

A Carrier 5TR R410A mid-tier unit was used as the baseline for both cost and dimensions including curb-dimension, heat exchanger dimensions, and overall volume. It is highly desirable to keep within this envelop. Overall a SEER of 20 could be achieved with the new compressor and refrigerant.

6. Technology to Market

This project has matured the compressor technology to TRL 5. Going forward further investments will be required to mature and demonstrate system performance to the TRL 5 level that will include the optimization of lower cost and compact heat exchangers (both evaporator and condenser). An accelerated path to commercialization (after system TRL 5 demonstration) can be pursued with DOE (e.g. commercial building) or DOD (e.g. ESTCP) to do limited field trials to validate value proposition of the technology and product in the field. Successful field trials could potentially pave the way for large OEM manufacturers to take this proven technology into mass commercialization.