COMPACT COMPRESSOR

Fig. 1. Mini-compressor with motor-drive controller.

Small DC device enables innovative cooling designs.

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Refrigeration compressors powered by direct current (DC) electrical energy have traditionally been relegated to mobile refrigeration systems, where batteries or vehicle alternators are the source of power. The number of DC compressors produced today for the worldwide market is tiny when compared to the number of AC compressors, which are mostly reciprocating, rotary, and scroll types largely used in refrigerated appliances and air conditioners. But a recent development, the emergence of solar power, and, to a lesser extent, fuel cells has provided added lift to the entire field of portable power. The result is that mobile refrigeration and portable cooling have been re-energized (both metaphorically and figuratively), creating new opportunities for innovative appliances that do not rely on grid power.

A new DC compressor was recently unveiled by Aspen Compressor, Marlborough, Mass. The compressor development was initiated through a Defense project during the first Persian Gulf War to address the high number of heat-related deaths in the U.S. military. One possible solution was a human-mounted, battery-powered, refrigeration system that could protect soldiers and first responders from heat stress. Such a system required a small, lightweight compressor, but one that could still deliver sufficient cooling.

The design that eventually evolved is shown in ***Fig. 1***, and it is, as of this date, unprecedented in size and weight for a production compressor. The compressor is just over 2.0 in. in diameter, about 3.0 in. in height, and weighs 1.25 pounds. The gas pump is a rolling piston design with a displacement of 1.4 cc, and is powered by a high-torque brushless DC motor. The design was intended to be very small, lightweight, and relatively high in cooling power. The DC motor is controlled with a sensorless drive, and is easily adapted to variable-speed operation up to 7,000 RPM for efficient performance. It also provides rapid cool-down and precise control of temperature. Although no acoustic noise data is available as yet, several users have agreed that the sound level it generates is quite reasonable and acceptable in many products. ***Table 1***

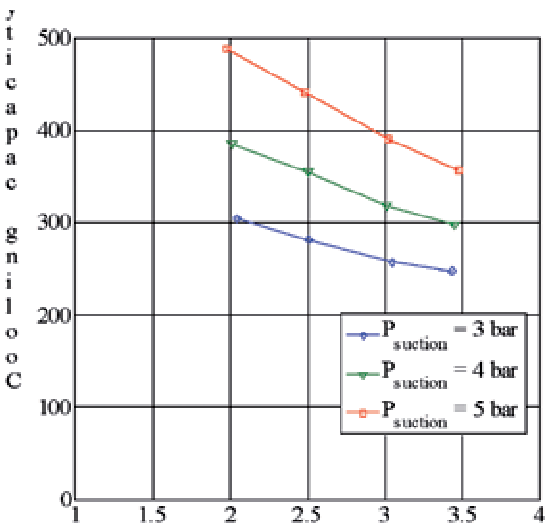

Fig. 2. Mini-compressor cooling capacity compared to pressure ratio at 6,000 RPM.

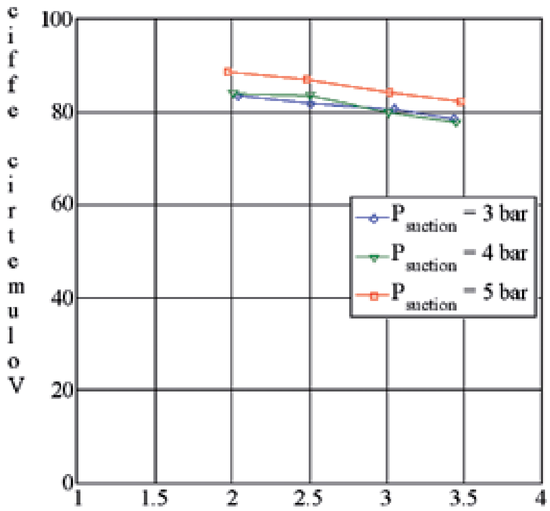

Fig. 3. Mini-compressor volumetric efficiency compared to pressure ratio at 6,000 RPM.

provides a summary of specifications for the compressor.

An independent evaluation of the compressor was performed at Purdue University, which included measurement of cooling capacity, Coefficient of Performance (COP), and volumetric and overall isentropic efficiencies [1]. Volumetric efficiencies were found to range from 73 percent to 90 percent, while the overall isentropic efficiency varied from 44 percent to 70 percent. Cooling capacity was measured from 163 W to 489 W, while the COP varied from 2.1 to 7.4, as shown in ***Fig. 2*** and ***Fig. 3.*** Volumetric and isentropic efficiencies of the mini-compressor as reported in the referenced Purdue technical paper were in fact higher than those found in two other compressors (one reciprocating and one linear), which had similarly been miniaturized for size reduction purposes.

The testing was performed with R-134a as the primary refrigerant, which at this time is a commonly used refrigerant in North American markets. There has, however, been considerable interest in the use of natural refrigerants such as R-290 (propane) and R-600 (isobutane), which have been widely used in Europe. Recently, two industry giants, General Electric and Unilever, announced plans to incorporate hydrocarbon refrigerants into their products showing the possible start of an industry trend. These refrigerants will be tested and evaluated soon in the mini-compressor, and it's believed that they will perform quite well.

The performance and physical characteristics of this device have importance significance for designers of cooling appliances. Given the compressor's modest size and weight, the cooling capacity is very high and can impart more cooling than many reciprocating compressors an order of magnitude larger in size. Depending on ambient and evaporator temperatures, it

POTENTIAL APPLICATIONS

Beer Dispensers
Beverage Dispensers/Refrigerated
Beverage Carts
Buffet Units/Refrigerated
Cabinets/Refrigerated
Commercial Refrigerators/Freezers
Cooled Display Cases
Countertop Appliances/Refrigerated
Drawers/Refrigerated
Ice Cream Cabinets/Dispensers
Ice Storage Bins/Chests
Marine Refrigerators
Medical Product Storage
Milk Coolers/Dispensers
Mini-Bars
Mini Air Conditioners
Portable Spot Coolers
Reach-In Freezers
Solar-Powered A/C & Refrigeration
Vaccine/Medical Transport
Wine Coolers
Yogurt/Smoothie/Slush Machines ■

Refrigerant	R134a
Lubricating Oil	Polyol ester oil
Compressor Type	Rotary (Rolling Piston)
Displacement	1.4cc
Speed	Variable
Speed Range	1,800 – 7,000 RPM
Motor	Brushless DC
Voltage	24V DC
Maximum Current	12 Amps
Evaporator Temperature Range	-18 to +24°C
Condenser Temperature Range	27 to 71°C
Maximum Compression Ratio	About 10:1

Table 1. Mini-compressor specifications.

can generate up to 1,800 BTU/h, enough to perform well in many refrigerated appliances. In a recent test with a 7.0 cu. Ft. commercial refrigerator/freezer, the compressor was able to maintain a minus 20 DegF evaporator temperature and a refrigerator compartment temperature below 40 DegF with an ambient of 110 DegF. These findings suggest that the mini-compressor has sufficient capacity to cool many types of appliances, both mobile and stationary.

Fig. 4 shows the comparative sizes of the mini-compressor with a commonly used reciprocating compressor. Key comparative performance parameters are shown in Table 2. For appliance designers, a striking, but seldom used parameter is that of cooling power density, both volumetric and by weight. The inference to be drawn from this comparison is that a large reduction in both space and weight can be achieved using the mini-compressor. Such factors have historically been used in mobile refrigeration systems only. But now, this device can be considered in some stationary appliances, which is highly unusual for a DC powered compressor.

A small vapor-compression system can have large performance and efficiency advantages over thermoelectric coolers than have been used in some small appliance products. When the mini-compressor is used in a refrigeration system together with a high performance condenser, the complete refrigeration system can be incorporated within a form factor as small as 200 cu. in. This permits a major space reallocation in the cabinet, reducing the volume needed for the refrigeration system and providing considerably more volume for product storage. There's also a weight reduction of approximately 10 lbs. from the use of mini-compressors, another benefit to the product being cooled.

Numerous types of refrigerated appliances can benefit from a compressor size and weight reduction, and some of the more pertinent examples are listed in the box below. In addition to those existing appliances, the mini-compressor is also an enabling technology, that is, it presents an opportunity to conceive and develop new generation cooling products that have not yet been imagined. For example, personal cooling systems using a body-mounted chiller continue to be an intriguing product concept. Such systems have a myriad of applications that could benefit first responders, motorcyclists, multiple sclerosis patients, victims of sports or burn injuries, wheelchair users, and industrial workers operating in a high heat environment.

Fig. 4. Mini-compressor next to reciprocating compressor of equivalent capacity.

The surging solar power market will also provide significant growth opportunities for DC compressors as the emergence of low-cost solar power spurs the development of DC-powered refrigerators, freezers, air conditioners, and other cooling appliances.

In addition to form and function, the appliance designer also needs to recognize that a DC-powered appliance presents its own unique challenges. It's no secret that DC compressors are higher in cost than their AC counterparts. This cost difference is due to the higher cost of DC motors, the need for a separate motor-drive controller, and that there are far fewer DC compressors produced on the world market. In addition, a separate power supply might be needed to convert an AC power source to DC. So, despite the many virtues of a small DC compressor, it may not be suitable in the most price sensitive products.

Nonetheless, the introduction of an innovative mini-compressor that significantly reduces the weight and space allocation in a refrigerated appliance fulfills a growing need for compact thermal management systems. The compressor is reasonably quiet, provides high cooling power, precision control, and unique flexibility. All that remains to be proven is its long term reliability and dependability. ■

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Reference:

1. "Experimental Evaluation of Aspen Miniature Rotary Compressor," Abhijit A. Sathe, Eckhard A. Groll and Suresh V. Garimella, Cooling Technologies Research Center, 19th Annual Compressor Engineering Conference at Purdue University, West Lafayette, Ind., July 2008.

Type	Reciprocating	Rotary
Refrigerant	R-134a	R-134a
Volume, In.3	130	11
Weight, Pounds	9.5	1.3
Speed, RPM	2,000-3,500	1,800-7,000
Capacity, BTU/h (ASHRAE)	764	950*
Cooling Power Density, BTU/In3	5.9	86.3
Cooling Power Density, BTU/lb	80.4	730.7

Table 2. Comparison of specifications between mini-compressor and a reciprocating compressor of equivalent capacity.