New Mini-Compressor Could this be a Game-Changer?

Author, S. Ronald Wysk, Vice President Business Development
Aspen Compressor, LLC, Marlborough, MA 01752 USA.

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, 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, LLC, a small high tech company located in Marlborough, Massachusetts. Its 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. A battery-powered refrigeration system required a compressor of meso scale and size, one that could be man-mounted yet deliver sufficient cooling to protect soldiers and first responders from heat stress. The design that eventually evolved is shown in **Figure 1.** It is as of this date unprecedented in size and weight for a production compressor.

The compressor is just over 2.0 inches in diameter, about 3.0 inches in height, and weighs just 1-1/4 pounds. The gas pump is a rolling piston design with a displacement of 1.4cc, 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

Figure 1 Mini-Compressor with Motor Drive Controller

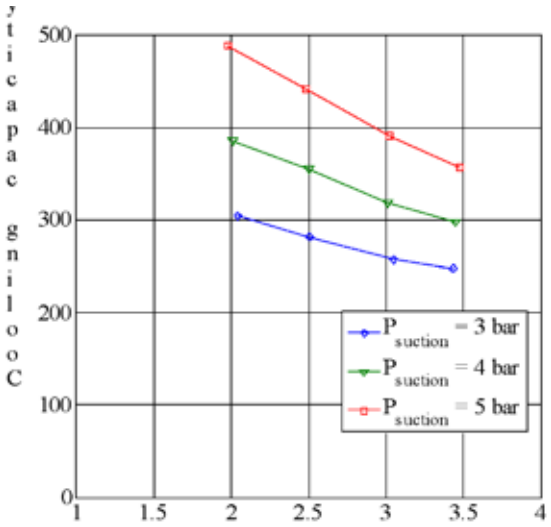


Figure 2 Cooling Capacity Vs. Pressure Ratio at 6,000 RPM

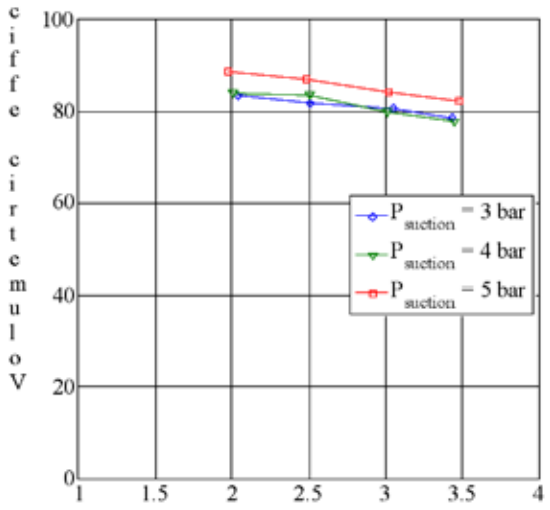


Figure 3 Volumetric Efficiency Vs. Pressure Ratio at 6,000 RPM

have agreed that the sound level it generates is quite reasonable and acceptable in many products. **Table 1** 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% to 90%, while the overall insentropic efficiency varied from 44% to 70%. Cooling capacity was measured from 163 W to 489 W, while the COP varied from 2.1 to 7.4, as shown in Figures 2 & 3 below. 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.

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 +24ºC
Condenser Temperature Range	27 to 71ºC
Maximum Compression Ratio	About 10:1

Table 1 Compressor Specifications

It is noted that the testing described above was performed with R134a as the primary refrigerant, which at this time is a popular choice refrigerant in North American markets. There has however been considerable interest in the use of natural refrigerants such as R290 (propane) and R600 (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.

Now that the performance and

physical characteristics of this device have been described, we can now turn attention to what this compressor means to the *appliance designer*. Given its modest size and weight, the cooling capacity is amazingly high. In fact, it can impart more cooling than many reciprocating compressors an order of magnitude larger in size. Depending on ambient and evaporator temperatures, it can generate up to 1,800 BTU/h, enough to perform well in many refrigerated appliances. In a recent test with a 7.0 cubic foot commercial refrigerator/freezer, the compressor was able to maintain a minus 20ºF evaporator temperature and a refrigerator compartment temperature below 40ºF with an ambient of 110ºF. These findings strongly infer that the mini-compressor has sufficient capacity to cool many types of appliances, whether they're mobile or stationary.

Figure 4 shows the comparative sizes of the mini-compressor with a well-known reciprocating type. Key performance parameters are also 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 space and weight savings can be achieved using the mini-compressor. Such factors have historically been used in mobile refrigeration systems only. But now, this device can even be considered in some stationary appliances, highly unusual for a DC powered compressor.

Figure 4 Mini-Compressor alongside Reciprocating Compressor of Equivalent Capacity

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 in^3. This allows a major space reallocation in the cabinet; namely, much less volume for the refrigeration system and considerably more volume for product storage. There's also a weight reduction of approximately 10 pounds from the use of mini-compressors, another benefit to the product being cooled. But for the most part, the space savings are usually considered more important than weight savings in most refrigerated appliances.

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

Numerous present refrigerated appliance types can benefit from a compressor size and weight reduction. Some of the more relevant are listed below:

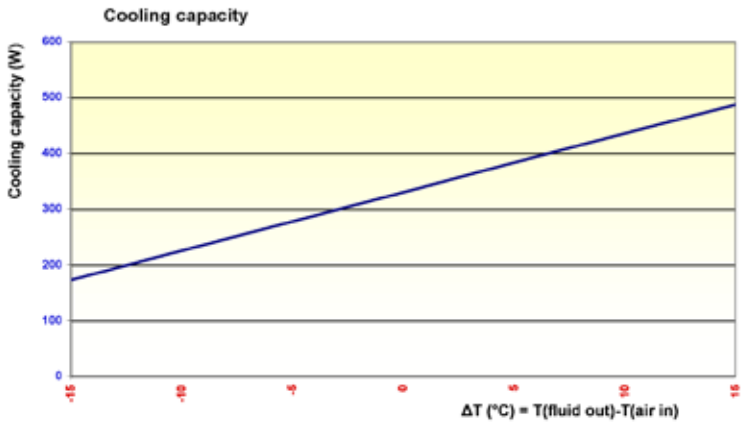
- Countertop Appliances/Refrig.
- Cooled Display Cases
- Commercial Refrigerators/Freezers
- Refrigerated Buffet Units
- Beverage Dispensers/Refrig.
- Milk Coolers/Dispensers
- Cabinets/Refrigerated
- Mini-Bars
- Beverage Carts
- Reach-In Freezers
- Drawers/Refrigerated
- Yogurt/Smoothie/Slush Machines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

In addition to this listing of appliances, the mini-compressor is also an *enabling technology* for cooling products that have yet to be conceived and developed. For example, personal cooling systems using a body-mounted chiller continue to be an intriguing product concept. Such systems have a myriad of applications including first responders, motorcyclists, multiple sclerosis patients, sports or burn injuries, wheelchair users, and numerous industrial worker cooling uses.

Several types of laser products, commercial and medical, require cooling; and, small vapor compression (VC) systems are ideal as cooling systems. Most lasers work best at a fixed operating temperature and need precise temperature control. Small deviations of less than 1°C can affect the beam length, affect repeatability, and even produce false readings. **Figure 5** shows a very small and compact VC based chiller employing the mini-compressor. The chiller introduced in 2009 produces up to 500 watts of cooling and weighs only 3 kg. The chiller is capable of controlling water temperature delivered to the laser at +/- 0.2°C.

Figure 5 Air-Water Chiller (Courtesy of Termotek AG, Baden Baden, Germany)

The breakout market in solar power is another key factor in growth opportunities for DC compressors. The emergence of solar powering derives from a recognition of recent trends in energy usage throughout the world economy. The emergence of lower cost solar powering has created opportunities for the development



of a new class of appliances using DC power such as freezers, refrigerators, air conditioners, and more. Both portable and stationary solar power packages have been developed with increasing storage capacity (amp-hours) and decreasing cost.

In addition to form and function, the appliance designer also needs to recognize that the cost of appliances using DC powering has its own unique set of challenges. It is well known that DC compressors are higher in cost than their AC counterparts. The reasons for this difference are due to the higher cost of DC motors, the need for a separate motor drive controller, and also by the fact that there are far fewer DC compressors produced on the world market. Often, a separate power supply might also be needed to convert an AC power source to DC. Thus, despite the many virtues of a small DC compressor, it may not be suitable in the most price sensitive products.

The mini-compressor is one of the most innovative and striking new products introduced to the HVAC industry in years. It provides major space and weight savings when embedded in a complete refrigerated product. It is reasonably quiet, provides high cooling power, precision control, and unique flexibility. It fulfills a growing need for compact thermal management systems. What remains to be proven is its long term reliability and dependability to the appliance industry. IAM

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, Indiana 47907, July 2008