Miniature BLDC Refrigeration Compressor – Yes, it is a game changer!

Compact refrigeration compressors with the size of small child's fist and the weight of 1.2 lbs are available that efficiently produce 300W~400W of cooling. They are available in 12, 24 and 48V and for various refrigerants. New applications are under development worldwide to start a new trend in mobile cooling and compact appliances.

Refrigeration compressors powered by direct current (DC) electrical energy have traditionally been limited 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.

In 2007, a new BLDC (Brushless DC), hermetic refrigeration compressor was introduced by Aspen Compressor, LLC, based in Somerset, KY (www.aspencompressor.com). The development of the new compressor 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, that is small and light enough for a man-mounted cooling system, yet can deliver sufficient cooling to protect soldiers and first responders from heat stress. The design that eventually evolved is a rolling piston compressor shown in Figure 1. It is unprecedented in terms of its extremely small size and low weight for a production refrigeration compressor.

Figure 1. Miniature Refrigeration Compressor shown with Motor Drive, Controller & a Quarter Coin

The compressor is just over 2.0 inches in diameter, about 3.0 inches in height, and weighs just 1-1/4 pounds. The pump part is of a rolling piston design with a displacement of 1.4cc, or 1.9cc 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 between 2,000 and 6,500 rpm for efficient and load following operation. 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 provides a summary of specifications for the line of compressors.

Table 1 Compressor Specifications

Refrigerant	R134a, 404A, etc.
Lubricating Oil	Polyol ester oil
Compressor Type	Rotary (Rolling Piston)
Displacement	1.4cc or 1.9cc per revolution
Speed	Variable
Speed Range	2000 – 6500 RPM
Motor	Brushless, Sensorless DC
Voltage	12, 24, or 48V DC
Maximum Current	12 Amps
Evaporator Temperature Range	-18 to +24ºC
Condenser Temperature Range	27 to 71ºC
Maximum Compression Ratio	10:1
UL versions, currently available	1.4 or 1.9cc, 24V

An independent evaluation of the 1.4cc 24V 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 isentropic 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.

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.

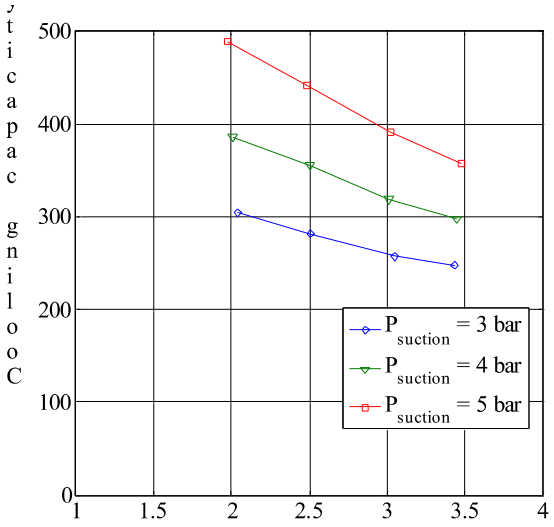


Figure 2 Cooling Capacity Vs. Pressure Ratio at 6,000 RPM

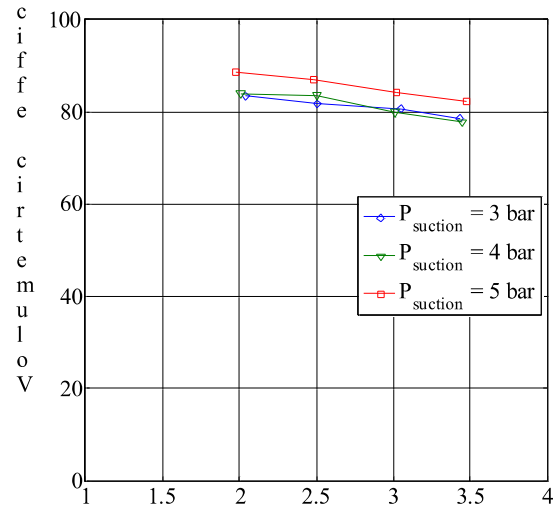


Figure 3 Volumetric Efficiency Vs. Pressure Ratio at 6,000 RPM

Now that the performance and physical characteristics of this device have been described, we can now turn our attention to what this compressor means to the *appliance designer*. For its small size and low weight, the cooling capacity is amazingly high. In fact, it can impart more cooling than many reciprocating compressors ten times 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 at 110ºF ambient. These findings strongly suggest 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 DC compressor. 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 weight. The new compressor has the 14.6 times the cooling power per unit volume, and 9.1 times the cooling power per unit weight. An obvious conclusion to be drawn from this stark comparison is that a large space and weight

savings can be achieved using the miniature compressor. Such factors have historically been prized in mobile refrigeration systems only. Now, even though highly unusual for a DC powered compressor, due to the extraordinary an order of magnitude advantages in terms of weight and volume savings, this compressor is being considered in various stationary applications, such as household countertop appliance: beverage dispensers; ice makers; coffee machines, etc. when the small compressor size is highly desired.

Figure 4. Size Comparison between the New Miniature Compressor (1.4cc displacement) and DC driven Reciprocating Compressor with 20% Less Cooling Capacity

Table 2. Comparison between the New Miniature Compressor and most widely used DC Driven Reciprocating Compressor with 20% less Cooling Capacity

Type	Reciprocating Comp. (shown at left)	Rotary Comp. (shown at right)
Refrigerant	R-134a	R-134a
Volume, cu.in.	130	11
Weight, lbs.	9.5	1.2
Speed, RPM	2,000-3,500	2,000 – 6,500
Capacity, Btu/h (ASHRAE)	764	950*
Cooling Power Density, Btu/cu.in.	5.9 {1}	86.3 {14.6}
Cooling Power Density, Btu/lb	80.4 {1}	730.7 {9.1}

A small vapor compression system can have large performance and efficiency advantages over thermoelectric coolers often used in some small appliance products. When the mini-compressor is used in a refrigeration system together with a high performance condenser and evaporator, the complete refrigeration system can be incorporated within a package as small as 100 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.

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

Countertop Appliances/Refrigerated	Cooled Display Cases
Commercial Refrigerators/Freezers	Refrigerated Buffet Units
Household Appliance	Overclocking of Personal computers
Beverage Dispensers/Refrigerated	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

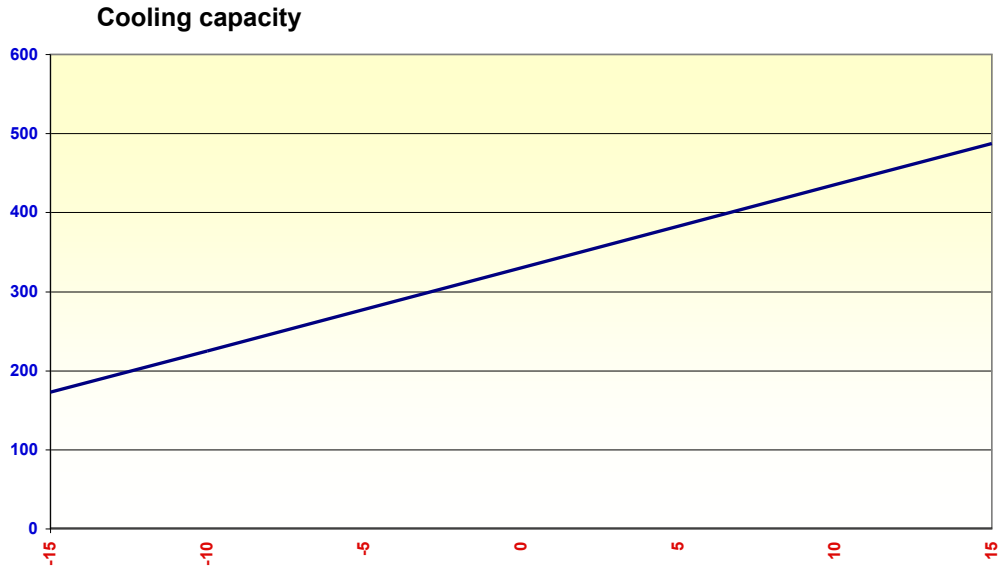
In addition to the listing of appliances above, the miniature compressor is also an *enabling technology* for cooling products that have yet to be conceived and developed. For example, personal cooling systems using a body or vehicle -mounted chiller continue to be an intriguing product concept. Such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

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. Even mall deviations of less than 1ºC 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. As shown in Figure 6, the chiller, introduced in 2009, produces up to 500

Figure 5 Air-Water Chiller utilizing the miniature refrigeration compressor (Courtesy of Termotek AG, Baden Baden, Germany)

watts of cooling at 15ºC water temperature and weighs only 3 kg. The chiller is capable of controlling water temperature delivered to the laser at +/- 0.02ºC.

Figure 6. Cooling Capacity versus Water Temperature



The growing worldwide market in solar power is another key factor in growth opportunities for DC compressors. The emergence of solar power derives from 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.

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, 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. Based on year-long accelerated tests show that

long-term reliability and dependability of the new compressor would be no different from those of larger rolling piston compressors widely used in the air conditioning and refrigeration systems.

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

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