COMPACT COMPRESSORS AND REFRIGERATION SYSTEMS

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Compact compressors and refrigeration systems that can be used to cool computers, servers, and other electronic equipment. Each compact compressor or refrigeration system includes a compact, substantially enclosed hermetic housing having a simple geometry profile, such as a rectilinear profile, which enables the compact compressor or refrigeration system to be easily inserted within a slot, for example, of an electronic component such as a computer server. In one embodiment, a compact compressor is provided, which includes a motor-compressor unit within the housing, including a stator, a rotor disposed interiorly of the stator, and a compressor mechanism disposed interiorly of the rotor to provide a compact profile. In another embodiment, the housing includes the foregoing compact motor-compressor unit, and further includes a condenser formed within one of the walls of the housing and an evaporator formed within another wall of the housing such that the housing defines a completely contained, compact refrigeration system. Alternatively, in another embodiment, the housing may include only one of the condenser and evaporator, with the other of the condenser and evaporator configured as a modular component which is attached to the housing.
COMPACT COMPRESSORS AND REFRIGERATION SYSTEMS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application Ser. No. 60/527,798, entitled "COMPACT REFRIGERATION SYSTEMS AND HEAT EXCHANGERS," filed on Dec. 8, 2003, assigned to the assignee of the present patent application, the disclosure of which is expressly incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to compact, modular cooling systems, and in particular, to compact compressors and refrigeration systems for electronic equipment cooling.

[0004] 2. Description of the Related Art

[0005] Conventional refrigeration systems are typically semi-permanent or permanent systems. For example, in a typical refrigerator, it is not necessary to be able to independently move the refrigeration components with respect to the rest of the refrigerator and the components of such refrigeration systems are permanently installed in the refrigerator. In the quickly changing electronics industry, however, it would be useful to have a compact modular cooling unit mounted in thermal communication with a piece of electronic equipment that the user can independently install and remove.

[0006] Also, as electronic equipment has become increasingly smaller, the heat dissipation requirements of such equipment is exceeding the capacity of cooling systems which employ only forced air to convectively cool the equipment.

[0007] What is needed is an improved compact compressor and/or compact cooling system that can be employed to cool electronic equipment.

SUMMARY OF THE INVENTION

[0008] The present invention provides compact compressors and refrigeration systems that can be used to cool computers, servers, and other electronic equipment. Each compact compressor or refrigeration system includes a compact, substantially enclosed hermetic housing having a simple geometry profile, such as a rectilinear profile, which enables the compact compressor or refrigeration system to be easily inserted within a slot, for example, of an electronic component such as a computer server. In one embodiment, a compact compressor is provided, which includes a motor-compressor unit within the housing, including a stator, a rotor disposed interiorly of the stator, and a compressor mechanism disposed interiorly of the rotor to provide a compact profile. In another embodiment, the housing includes the foregoing compact motor-compressor unit, and further includes a condenser formed within one of the walls of the housing and an evaporator formed within another wall of the housing such that the housing defines a completely contained, compact refrigeration system. Alternatively, in another embodiment, the housing may include only one of the condenser and evaporator, with the other of the condenser and evaporator configured as a modular component which is attached to the housing.

[0009] One embodiment of the invention provides a compact refrigeration system that may be fit within a standard sized slot of a computer server. The system includes enclosure walls that define at least one heat exchanger, such as a condenser or evaporator, and each heat exchanger may define a temperature gradient that has a localized maximum or minimum at the center of the heat exchanger, wherein the heat exchanger defines substantially similar temperatures at locations that are at substantially similar radial distances from the center and local maximum, minimum temperature of the heat exchanger.

[0010] In one form thereof, the present invention provides a compact compressor unit, including a substantially enclosed housing including an inlet and an outlet; and a motor-compressor unit disposed within the housing, including a stator; a rotor disposed substantially interiorly of the stator; and a compressor mechanism driven by the rotor and disposed substantially interiorly of the rotor, the compressor mechanism in fluid communication with the inlet and outlet, whereby the compressor mechanism receives fluid from the inlet at suction pressure, compresses the fluid to discharge pressure, and discharges the fluid at discharge pressure through the outlet.

[0011] In another form thereof, the present invention provides a compact refrigeration system, including a substantially enclosed housing having a simple geometry profile including at least first and second sides; a motor-compressor unit disposed within the housing, including a stator; a rotor disposed substantially interiorly of the stator; and a compressor mechanism having an inlet and an outlet; a condenser formed at least partially within the first side of the housing, the condenser in fluid communication with the compressor mechanism outlet; an evaporator formed at least partially within the second side of the housing, the evaporator in fluid communication with the compressor mechanism inlet; and an expansion device in fluid communication with the condenser and with the evaporator.

[0012] In a further form thereof, the present invention provides a compact refrigeration system, including a substantially enclosed housing having a simple geometry profile, including an inlet and an outlet and at least a first side; a motor-compressor unit disposed within the housing, including a stator; a rotor disposed substantially interiorly of the stator; and a compressor mechanism driven by the rotor; and a first heat exchanger formed substantially within the first side of the housing, the first heat exchanger in fluid communication with the compressor mechanism.

[0013] In a further form thereof, the present invention provides a compact refrigeration system, including a housing, including a first housing component including at least a first pair of opposite sides of the housing; and a second housing component including at least another side of the housing, the first and second housing components insertable one into the other; and a compressor mechanism disposed within the housing.

[0014] In a further form thereof, the present invention provides a compact refrigeration system, including a hous-
ing, including a first housing component including at least a first pair of opposite sides of the housing; and a second housing component including at least another side of the housing, the first and second housing components insertable one into the other; and a heat exchanger at least partially integrated into one of the sides of the housing, the heat exchanger including a passage extending from proximate a central portion of the housing side toward a peripheral portion of the housing side.

[0015] In a further form thereof, the present invention provides a compact refrigeration system, including a housing including an inlet and an outlet; a compressor unit disposed within the housing, the compressor unit including a stator; a rotor disposed substantially interiorly of the stator; and a compressor mechanism driven by the rotor and disposed interiorly of the stator; and a first heat exchanger configured as a modular unit attached to a wall of the housing, the heat exchanger in fluid communication with the inlet and with the outlet.

[0016] In a further form thereof, the present invention provides a compact refrigeration system, including a first housing component having a simple geometry profile including an exterior wall, and a groove formed within the exterior wall; a second housing component into which the first housing component is received, the second housing component having a wall in abutment with the exterior wall of the first housing component and enclosing the groove to define a heat exchanger passage; and a compressor mechanism disposed within the first housing component and in fluid communication with the heat exchanger passage.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0017] The above mentioned and other features and objects of this invention, and the manner of attaining them, will become more apparent and the invention itself will be better understood by reference to the following description of embodiments of the invention taken in conjunction with the accompanying drawings, wherein:

[0018] FIG. 1 is a perspective view of a compact compressor according to a first embodiment of the present invention, showing the components of the compressor housing;

[0019] FIG. 2 is a sectional view taken along line 2-2 of FIG. 1, showing an exemplary manner in which a fluid line or fluid fitting may be attached to the inlet or outlet of the compact compressor;

[0020] FIG. 3 is a perspective cutaway view of the compact compressor;

[0021] FIG. 4 is a further perspective cutaway view of the compact compressor, showing components of the compressor mechanism;

[0022] FIG. 5 is a further perspective cutaway view of a portion of the compact compressor, showing components of the compressor mechanism;

[0023] FIG. 6 is a perspective view of a portion of the compressor mechanism of FIG. 5;

[0024] FIG. 7 is a first exploded view of a compact refrigeration system according to a second embodiment, viewed from a first direction;

[0025] FIG. 8 is a second exploded view of the compact refrigeration system, viewed from a second direction;

[0026] FIG. 9 is a perspective view of the compact refrigeration system, showing the components of the refrigeration system housing;

[0027] FIG. 10 is a perspective view of a first side of the inner housing component of the compact refrigeration system, showing the condenser;

[0028] FIG. 11 is a perspective view of a second side of the inner housing component of the compact refrigeration system, showing the evaporator;

[0029] FIG. 12 is a perspective view similar to FIG. 10, showing exemplary weld lines for securing the outer housing component to the inner housing component of the compact refrigeration system;

[0030] FIG. 13 is a perspective view similar to FIG. 11, showing exemplary weld lines for securing the outer housing component to the inner housing component of the compact refrigeration system;

[0031] FIG. 14 is a perspective view of one compact refrigeration system according to a third embodiment, showing the housing of the compact refrigeration system including a condenser and a modular heat exchanger configured as an evaporator, wherein a portion of the housing of the compact refrigeration system is broken away to show the terminal assembly; and

[0032] FIG. 15 is a perspective view of another compact refrigeration system according to the third embodiment, showing the housing of the compact refrigeration system including an evaporator and a modular heat exchanger configured as a condenser, wherein a portion of the housing of the compact refrigeration system is broken away to show the terminal assembly.

[0033] Although the exemplification set out herein illustrates embodiments of the invention, in several forms, the embodiments disclosed below are not intended to be exhaustive or to be construed as limiting the scope of the invention to the precise forms disclosed.

**DETAILED DESCRIPTION**

[0034] The present invention provides both compact compressors and compact refrigeration systems which, in the exemplary application described below, may be used to provide cooling to electronic equipment. A compact compressor 20 according to a first embodiment of the present invention is shown in FIGS. 1-8. With initial reference to FIGS. 1-4, compressor 20 generally includes a hermetic enclosure or housing 22 and a motor-compressor unit 24 disposed within hermetic housing 22. Referring to FIG. 1, housing 22 generally includes a first or inner housing component 26 and a second or outer housing component 28. To assemble compressor 20, first housing component 26 is insertable within second housing component 28, and the foregoing are secured to one another such as by welding in the manner described below.

[0035] As shown in FIGS. 1 and 3, compressor housing 22 has a simple geometry profile, shown herein as a rectilinear profile. In this manner, compact compressor 20 may be inserted into a slot in an electronics device in a cartridge-
type manner, and be easily removed therefrom for repair or replacement, for example. First housing component 26 is shown in FIGS. 1 and 3, and has a box-type, rectilinear profile generally including three pairs of opposing side walls, including front wall 30, rear wall 32, left side wall 34, right side wall 36, top wall 38, and bottom wall 40 (FIG. 4). Although the words “front”, “back”, “left”, etc., are used herein to designate sides and/or walls of the compact compressors and refrigeration systems of the present invention, same are necessarily arbitrary designations, and the present invention is not limited orientationally to such terms. Front side wall 30 includes inlet 42 and outlet 44, and an electrical terminal assembly 46 is recessed into a cavity defined between left side wall 34 and rear side wall 32, which is surrounded by shoulder 48. First housing component 26 contains motor-compressor unit 24 therein, as described below.

Compact compressor 20 is a removable compressor that can be slid into a electronic component using a suitable slot and latch-type mechanism to allow non-destructive replacement of compressor 20. The electrical terminal assembly 46, as shown in FIGS. 1, 3, and 4, is embedded within the walls of compressor 20 and, when compressor 20 is properly installed, the terminals of electrical terminal assembly 46 mate with corresponding terminals of the electronic component.

[0036] As shown in FIG. 1, second housing component 28 includes top wall 50, bottom wall 52, left side wall 54 and right side wall 56. In assembling compact compressor 20, first or inner housing component 26 is inserted within second or outer housing component 28 as shown in FIG. 1 in a "matchbox"-type manner, wherein cutout portions of top wall 50 and left side wall 54 of second housing component 28 abut shoulder 48 of first housing component 26. Thereafter, first and second housing components 26 and 28 are secured to one another in the manner described below.

In the compact compressors and refrigeration systems disclosed herein, after first and second housing components 26 and 28 are assembled together, each component 26 and 28 has walls or outer surface regions that are exposed to ambient pressure and, during operation, are exposed to internal pressure forces, as described below. The side walls of each component 26 and 28 are configured such that the internal and external pressure forces acting upon one wall are balanced by an opposed pressure force acting upon an opposite wall. In the illustrated embodiments, this is accomplished by having the exposed surfaces or outer walls of housing 22 parallel and of substantially equal surface area. For example, the front and rear side walls 30 and 32 of housing 22 are both defined by first housing component 26, while the top and bottom walls 50 and 52 and the left and right side walls 54 and 56 are both defined by second housing component 28. By configuring the enclosure in this manner, the pressure forces acting on the front and back walls 30 and 32 are balanced by first component 26 without having to transmit these forces through a joint or other interface between first and second housing components 26 and 28. Similarly, the pressure forces acting on the top and bottom walls 50 and 52 and the left and right side walls 54 and 56 are balanced by second housing component 28 without having to transmit these forces through a joint or other interface between first and second components 26 and 28.

[0039] A significant advantage of this design is that it reduces the forces acting at the interface or seal between first and second housing components 26 and 28. Because the pressure forces acting upon each individual housing component 26 and 28 are balanced, the pressure forces do not tend to pull apart the housing components 26 and 28 as is typical in a conventional hermetically sealed compressor housing. This balancing of the forces on the individual components 26 and 28 allows the joint between the housing components 26 and 28 to be welded or otherwise sealed in a manner that ensures the seal between the two components without having to compensate for stress due to pressure forces. The forces acting on the joints between the two components 26 and 28 will be mostly mechanical, such as shock, vibration, handling, and securing forces.

[0040] Although compact compressor 20 and the compact refrigeration systems described below have a rectilinear configuration, alternative embodiments may employ enclosure walls that balance the pressure forces acting on each individual housing component without the use of enclosure walls that are parallel or flat. The exposed walls of the enclosure merely have to be configured such that the overall effective pressure forces acting on individual component walls are substantially balanced to thereby minimize the forces transmitted through the interface between the individual components.

[0041] Referring to FIGS. 3-8 first housing component 26 includes motor-compressor unit 24, which generally includes a motor and a compressor mechanism 60, as described below. Motor-compressor unit 24 shown in FIGS. 7 and 8 is shown as a portion of CRS 120 described below, however, motor-compressor unit 24 of compact compressor 20 an CRS 120 are substantially identical. Referring primarily to FIGS. 7 and 8, bottom wall 40 of first housing component 26 includes a pair of concentric, annular outer and inner stator flanges 62 and 64 extending therefrom. An annular stator 66 is mounted within the space between annular stator flanges 62 and 64, and is secured thereto in a suitable manner, such as via an interference fit. Stator 66 generally includes a stator body with windings. Referring to FIG. 4, electrical leads 68 extend from electrical terminal assembly 46 to the windings of stator 66 for providing electrical power to the windings of stator 66. An annular rotor 70 is disposed within stator 66, and generally includes an annular body having a plurality of magnets 72 attached to the body of rotor 70 around the outer periphery thereof. As shown, magnets 72 are received within complementary shaped, dovetail-shaped recesses around the body of rotor 70 in a press-fit manner, by suitable fasteners, or in another suitable manner.

[0042] First housing component 26 additionally includes a pair of body portions 74 and 76, one body portion 74 including electrical terminal assembly 46, and the other body portion 76 including inlet 42 and outlet 44 of compact compressor 20 (FIG. 1). Annular needle bearing race 78 is fixed within interior stator flange 62, and includes a plurality of needle bearings. An eccentric 80 is fitted within rotor 70 and fixed thereto, and is bearingly supported by bearing race 78. Eccentric 80 includes a central opening 82, a portion of which has an axis which is offset from the rotational axis A-A of rotor 66, as may be seen in FIG. 8. Roller 84 is fitted within the portion of central opening 82 of eccentric 80 which is offset from the rotational axis A-A of rotor 66.
circular discharge valve plate 86 is also received within a portion of central opening 82 of eccentric 80 which is coaxial with rotational axis A1-A1 of rotor 66, and includes a discharge port 88. A flapper-type discharge check valve 90 is secured to discharge valve plate 86, and the movement thereof is limited by valve stop plate 92 also secured to discharge valve plate 86. Discharge housing 94 is disposed over discharge valve plate 86, and includes a arcuate-shaped recess 96 (FIG. 8) therein which defines a discharge muffler chamber. Discharge housing may include a boss (not shown) which fits within an opening in wall 38 of first housing component 26 with an O-ring seal therebetween.

Hub 98 is disposed within the inner annular space of roller 84 and is captured between top wall 38 of first housing component 26 and discharge valve plate 86. Hub 98 includes slot 100 therein in which vane 102 is fitted, with vane 102 biased outwardly by spring 100 by a spring (not shown), such that the tip of vane 102 is in sliding contact with the interior surface of roller 84.

In operation, electrical power supplied to the windings of stator 66 generates a magnetic field therein which rotates rotor 70 within stator 66 about rotational axis A1-A1. Eccentric 80 is rotated concurrently with rotor 70, and causes roller 84 to rotate about the rotational axis A1-A1 of rotor 70. The orbital movement of roller 84 about hub 98 causes vane 102 to reciprocate within slot 98 to define a pair of crescent-shaped, variable-volume working pockets between roller 84, hub 98, and vane 102 for compressing refrigerant within compression mechanism 60.

Referring to FIGS. 1, 5, 7, and 8, compact compressor 20 is connected to other components of a refrigeration system which are disposed externally of compressor 20, such as a condenser, expansion device, and an evaporator (not shown). Refrigerant at suction pressure enters compressor housing 22 through inlet 42, and passes through passages 104 and 106 (FIG. 5) in body portion 76 and bottom wall 40 of housing component 26, respectively, to the inlet of compressor mechanism 60. The refrigerant is compressed by compressor mechanism 60 in the manner described above, and is discharged through discharge port 88 and check valve 90 into discharge muffler chamber 96. Thereafter, the compressed refrigerant passes through discharge passages 108 and 110 (FIG. 5) in top wall 38 and body portion 76, respectively, and outlet 44 of compressor housing 22. The compressed refrigerant then passes through the condenser, expansion device, and evaporator of the refrigeration system before being drawn into inlet 42 of housing 22 to repeat the foregoing cycle.

The interior volume 112 of housing 22 defines an oil sump which is in fluid communication with the refrigerant, and may be at either suction pressure or discharge pressure. Oil within the oil sump may be entrained within the refrigerant for lubricating the moving parts of compressor mechanism 60. For example, referring to FIG. 4, body portion 76 of first housing component 26 may include an oil hole 101, such that refrigerant passing through inlet 42 at suction pressure may entrain oil from the oil sump within interior volume 112 of housing 22 through oil hole 101 into the refrigerant stream to lubricate the moving parts of compressor mechanism 60.

Referring to FIGS. 1 and 2, inlet and outlet 42 and 44 are recessed into front wall 30 of housing 22. In the compact compressor 20 of FIGS. 1-6 and the modular refrigeration system or CRS 120 of FIGS. 7-14, the recessed nature of inlet 42 and outlet 44 avoids having inlet and outlet tubes projecting outwardly from housing 22 and thereby facilitates the installation of the compact compressor 20 or CRS 120. Moreover, as best seen in FIG. 2, the recessed nature of inlet 42 and outlet 44 allow external conduits, or the fittings of an external heat exchanger such as that shown in FIG. 14, to be easily mounted to inlet 42 and outlet 44. In the illustrated embodiment, such conduits or fittings 114 are located in a cylindrical recess 116 that surrounds the outer radial surface of inlet 42 and outlet 44 with O-rings 118 providing a seal therebetween. This allows the external conduit or fitting 114 to be inserted over inlet 42 or outlet 44 with one O-ring 118 being positioned between the internal surface of external conduit or fitting 114 and the external surface of inlet 42 or outlet 44 and a second O-ring 118 positioned between the outer surface of external conduit or fitting 114 and the inner surface of recess 116 without requiring brazing or other similar means of sealing and securing the foregoing components together.

A compact refrigeration system (“CRS”) 120 according to a second embodiment of the present invention is shown in FIGS. 7-13. Except as described below, CRS 120 includes a housing 22 with a compact motor-compressor unit 24 which is substantially identical to that of compact compressor 20 described above, and the same reference numbers will be used below to designate identical or substantially identical features between compact compressor 20 and CRS 120. Housing 22 of CRS 120, similar to that of compact compressor 20, is both compact and modular to facilitate its use in changing environments and smaller spaces associated with electronic equipment. As described above, housing 22 of CRS 120 includes a compact compressor mechanism 60 substantially identical to that described above with respect to compact compressor 20, and additionally includes other refrigeration system components, including a condenser, expansion device, and evaporator, which are located within housing 22 to hermetically seal CRS 120 from the outside environment and reduce the potential for leaks from the system.

Further, as described below, the outer surfaces of CRS 120 include high-density heat flux surfaces to provide heat transfer between CRS 120 and components of the electronic equipment being cooled, and also between CRS 120 and a suitable heat sink or the ambient environment. By locating all of the refrigeration components of CRS 120 within a single enclosure, the potential for leaks is reduced, and CRS 120 may advantageously be formed of stamped parts to thereby reduce the time and cost of manufacture. Similar to compact compressor 20, the outer configuration of CRS 120 may alter to adapt it to its intended application, for example, CRS 120 may be shaped as a parallelepiped, cylinder or other shape, and may define hot and/or cold surfaces on various locations on the exterior of its enclosure.

Referring to FIGS. 7-11, CRS 120 includes a condenser 122 (FIGS. 7 and 10) defined within wall portions 38 and 50 of first and second housing components 26 and 28, respectively, and an evaporator 124 (FIGS. 8, 9, and 11) defined within bottom walls 40 and 52 of first and second housing components 26 and 28, respectively. Bottom walls 40 and 52 of first and second housing components 26 and 28, respectively, including evaporator 124, define a cold face or...
“cold plate” of CRS 120 which may be placed in thermal communication with the surfaces of electrical components, such as computer chips or other electrical circuitry which require cooling, to facilitate transfer of heat from the electrical component to a suitable refrigerant via evaporator 124 of CRS 120. Top walls 28 and 50 of first and second housing components 26 and 28, respectively, including condenser 122, define a hot face or “hot plate” of CRS 120 which may be placed in thermal communication with a suitable heat sink or with the ambient atmosphere to facilitate transfer of heat from the refrigerant to the heat sink or ambient atmosphere via condenser 122.

[0051] Referring to FIG. 10, condenser 122 includes an inlet 126 disposed in a central portion of top wall 38 of first housing component 26, which is in fluid communication with discharge muffler chamber 96 of compressor mechanism 60 (FIG. 7). A spiral condenser passage 128 is shown as a groove which is cast or milled within top wall 38 of first housing component 26, and is enclosed by top wall 50 of second housing component 28. Outlet 130 of condenser passage 128 is in fluid communication with passage 132 in body portion 74 of first housing component 26, which leads to evaporator 124.

[0052] Referring to FIG. 11, evaporator 124 includes a restrictor passage 134, shown as a thin groove which is cast or milled within bottom wall 40 of first housing component 26, and is enclosed by bottom wall 52 of second housing component 28. Restrictor passage 134 is in fluid communication with passage 132 in body portion 74 of first housing component 26. Restrictor passage 134 extends around the outer periphery of first housing component 26, and terminates in expansion device 136, which is configured as the entrance to a relatively wide evaporator passage 138, shown as a relatively wide groove which is cast or milled within bottom wall 40 of first housing component 26, and is enclosed by bottom wall 52 of second housing component 28, as shown in FIG. 9. Evaporator passage 138 extends from the central portion of bottom wall 40 of first housing component 26 in an arcuate, alternating manner as shown in FIG. 11 toward the outer periphery of first housing component 26. The outlet 140 of evaporator passage communicates with a deep, substantially annular recess 142 formed within outer stator flange 64 such that, in operation, refrigerant passing through deep recess 142 around outer stator flange 64 cools stator 66. Recess 142 communicates with the inlet of compressor mechanism 60 via a shallow, wide suction line passage 144. Optionally, the bottom of recess 142 may include openings therein in communication with internal volume 112 of housing 22, such that recess 142 may function as an oil separator.

[0053] In operation, compressed refrigerant discharged from compressor mechanism 60 passes through inlet 126 of condenser passage 128 and thence through condenser passage 128 to allow heat from the refrigerant to diffuse through top wall 50 of second housing component 28 to a suitable heat sink or the ambient atmosphere. As shown in FIG. 10, because inlet 126 of condenser passage 128 is disposed near the central portion of top wall 38 of first housing component 26, and condenser passage 128 extends in a spiral manner outwardly from the central portion of top wall 38 of first housing component 26, passage of high pressure refrigerant from inlet 126 through condenser passage 128 will generate a heat gradient in top wall 50 of second housing component 28. In this manner, top wall 50 of second housing component 28 will be relatively hotter near the center thereof, and progressively less hot toward the outer periphery thereof.

[0054] In other words, CRS 120 may employ heat exchangers, such as condenser 122 and evaporator 124, which are formed in or proximate a wall or face of housing 22 and where the hottest or coolest point (depending upon whether the refrigerant is losing or absorbing thermal energy) of the heat exchanger is in the middle of the wall or face. Because potential heat transfer losses may be due to conduction in the enclosure walls, keeping the temperature gradients in the enclosure walls forming parts of the heat exchangers as low as possible will optimize the performance of the heat exchangers. As described above, for the heat exchanger functioning as condenser 122 or gas cooler, the hottest point of the heat exchanger would be near or at the middle of the wall or face of housing 22, and the refrigerant would travel radially outward, such as in the spiral shaped condenser passage 128, as it cools. Thus, when the refrigerant has reached the outer radial edges of the heat exchanger face and enclosure wall, it will have been cooled and will not increase, or will minimally increase, the temperature gradient within the enclosure walls.

[0055] The high pressure refrigerant then passes through outlet 130 of condenser passage 128 and through passage 132 in body portion 74 of first housing component 26 into narrow restrictor passage 134 in bottom wall 40 of first housing component 26. Upon encountering expansion device 136, the pressure of the refrigerant rapidly decreases, and the low pressure refrigerant then passes through evaporator groove 138 of evaporator 124 allowing the low pressure refrigerant to take up heat from an electronic component to be cooled which is disposed adjacent bottom wall 40 of second housing component 28. As shown in FIG. 11, because expansion device 136 is disposed near the central portion of bottom wall 40 of first housing component 26, and evaporator passage 138 extends in an arcuate, alternating manner outwardly from the central portion of bottom wall 40 of first housing component 26, passage of low pressure refrigerant through evaporator passage 138 will generate a cooling gradient in bottom plate 52 of second housing component 28. In this manner, bottom plate 52 of second housing component 28 will be relatively cooler near its center, and progressively less cool toward its outer periphery.

[0056] Thereafter, the low pressure refrigerant passes into deep recess 142 within stator flange 64 to cool stator 66, and thence through suction line passage 144 into the inlet of compressor mechanism 60 where the refrigerant is compressed to repeat the foregoing cycle. Alternatively, stator 66 itself may include a passage therein, through which some or a portion of the refrigerant is directed to cool stator 66. Also, instead of directing refrigerant from the outlet of evaporator 124 to recess 142 or a passage in the stator 66, high pressure refrigerant from condenser 122 can be expanded, such as by passage through a capillary tube, and then directed directly to stator 66 for cooling purposes without first passing through evaporator 124. This arrangement may be used to provide additional cooling capacity for motor-compressor unit 24. If the pressure of refrigerant which is used to cool stator 66 of motor-compressor unit 24 is higher than the compression suction pressure, an additional expansion
device may be used to further reduce the pressure of the refrigerant to the desired suction pressure after it has cooled motor-compressor unit 24.

[0057] In the manner described above, heat from an electronics component to be cooled is absorbed by evaporator 124, which defines a “cold plate” of CRS 120, and the heat is conveyed to a suitable heat sink or to the ambient environment via condenser 122, which functions as a “hot plate” of CRS 120. The foregoing refrigeration cycle can be a conventional cycle with the refrigerant undergoing a phase change in both condenser 122 and evaporator 124, a transcritical system wherein the refrigerant, such as carbon dioxide, is compressed to a supercritical pressure, or a system wherein the refrigerant remains a gas and does not undergo a phase change.

[0058] Referring to FIGS. 12 and 13, an exemplary manner in which first housing component 26 and second housing component 28 may be secured together is shown. Referring to FIG. 12, welding, such as laser welding, may be performed along the dashed lines 146 around the outer periphery of condenser passage 128 and optionally, between each of the concentric portions of condenser passage 128 to secure top wall 50 of second housing component 28 to top wall 38 of first housing component 26, while concurrently isolating the high pressure condenser passage 128 from communication with other portions of CRS 120. In a similar manner, referring to FIG. 13, welding, such as laser welding, may be performed along the dashed lines 148 around restrictor passage 134, evaporator passage 138, and passage 144 as shown to thereby secure bottom wall 52 of second housing component 28 to bottom wall 40 of first housing component 26 while concurrently isolating restrictor passage 134, evaporator passage 138, and passage 144 from fluid communication with other portions of CRS 120. A similar laser welding technique may be used to secure first and second housing components 26 and 28 of compact compressor 20 of FIGS. 1-6, described above. Further characteristics of CRS 120 are discussed below.

[0059] Although condenser passage 128 of condenser 122 is described above as a groove formed within top wall 38 of first housing component 26, which is enclosed by top wall 50 of second housing component 28, and similarly, restrictor passage 134 and expansion groove 138 are described above as grooves in bottom wall 40 of first housing component 26 which are enclosed by bottom wall 52 of second housing component 28, the foregoing passages may be constructed in alternative configurations. For example, one or more of the foregoing passages may be formed completely within either top wall 38 of first housing component 26, top wall 50 of second housing component 28, or in bottom wall 40 of first housing component 26 or bottom wall 52 of second housing component 28. Still further, the foregoing passages may be formed in top and bottom walls 50 and 52 of second housing component 28, and enclosed by top and bottom walls 38 and 40 of first housing component 26, respectively.

[0060] Similar to compact compressor 20 described above, housing 22 of CRS 120 may have an outer surface or envelope that defines simple geometric shape or profile. The use of a simple geometric shape or profile for the outer envelope facilitates the assembly and interchangeability of the system. The purpose of the simple geometry envelope is to ensure positioning and alignment of the enclosure to other surfaces in the environment. For example, computer servers have slots with predefined dimensions in which electronic components can be inserted. By reducing the height of compact compressor 20 and CRS 120 to less than 1U, i.e., less than about 1.75 inches (4.45 cm), by positioning compression mechanism 60 inside rotor 70 as best seen in FIG. 4, compact compressor 20 and CRS 120, such as those shown in FIGS. 1-9, may have dimensions that allow same to be slid into such a server slot, for example, to provide cooling to the server.

[0061] As described above, CRS 120 is configured to locate the low pressure regions thereof in the corners of housing 22 between first and second housing components 26 and 28. This location for the low-pressure regions will help to keep housing 22 free of leaks by lowering the volume of the high pressure regions and thus the effective surface areas of the high-pressure regions. By locating the low pressure regions in the corners of housing 22, the overall force exerted by the high pressure refrigerant biasing first and second housing components 26 and 28 apart from one another can be reduced. The low pressure in these regions may be maintained by sealing these areas off from the high pressure regions and providing fluid communication between the low pressure regions and a volume of the system that is at suction pressure during operation of the compressor, such as a suction line or evaporator 124.

[0062] When the object to be cooled by CRS 120 is a computer, the limits on power consumption may be relatively restrictive. In such situations, it may be desirable to trade refrigeration system efficiency for reduced power consumption. For example, it may be desirable to cool the refrigerant as it is being compressed so that the compression process approaches an isothermal process to reduce power consumption at the expense of refrigeration system efficiency. The refrigerant may be cooled by convection with refrigerant in internal volume 112 of housing 22, by suction gas diverted to cool compression mechanism 60 before compression of the suction gas, by conduction that vents thermal energy to the ambient environment, evaporator 124 or other heat sink, by thermoelectric devices, or other suitable means.

[0063] The refrigerant used with CRS 120 may also be selected to reduce the power consumption of CRS 120. For example, R245fa may be used as the refrigerant. This freon is conventionally used in heat pump applications or as an insulation blowing agent, not as a refrigerant for a refrigeration system. It has a Global Warming Potential less than R134a. The normal boiling temperature of R245fa is relatively high (15°C) and it also has a relatively low density in comparison to conventional refrigerants commonly used in refrigeration systems. The lower density of R245fa requires that this refrigerant be used with a compressor having a relatively large volumetric displacement and thus negatively impacts its performance as a refrigerant in common refrigeration cycles. For CRS 120 of the present invention, however, a reduction in power consumption by the compressor is highly desirable and although a motor-compressor unit 24 which is designed for use with R245fa will require a large volumetric displacement due to the lower density of the refrigerant, this lower density will also result in a motor that has relatively reduced power requirements. Furthermore, the operating pressures employed when using R245fa are relatively low and the pressure difference across
the system is also relatively low in comparison to refrigerants conventionally employed in common refrigeration cycles and the reduced operating pressures and pressure differences facilitate the manufacture of a lightweight and compact CRS 120.

[0064] Modified versions of CRS 120, namely, CRS 150, are shown in FIGS. 14 and 15 which include only condenser 122 (FIG. 14) or evaporator 124 (FIG. 15). A modular heat exchanger 152, which may be either a condenser or an evaporator, is attached to housing 22 of CRS 150. Except as described below, CRS 150 of FIGS. 14 and 15 each include a motor-compressor unit 24 therein which is substantially identical to that of compact compressor 20 and CRS 120 described above, and further, except as described below, CRS 150 functions in the same manner as CRS 120 described above, and identical reference numerals are used in FIGS. 14 and 15 to designate identical or substantially identical components therebetween.

[0065] As shown in FIGS. 14 and 15, housing 22 of CRS 150 includes inlet 42 and outlet 44 similar to those of compact compressor 20. Modular heat exchanger 152, which may be configured as a condenser or evaporator, is secured to housing 22 via a suitable latching mechanism, for example, and includes an inlet fitting 154 and an outlet fitting 156 in fluid communication with outlet 44 and inlet 42 of housing 22, such as in the manner described above with respect to FIG. 2. Modular heat exchanger 152 generally includes a refrigerant passage therethrough, and a plurality of heat spreading means such as fins 158 to facilitate thermal exchange between the refrigerant within modular heat exchanger 152 and the ambient environment surrounding modular heat exchanger 152.

[0066] In one embodiment, shown in FIG. 14, modular heat exchanger 152 is an evaporator. In this embodiment, CRS 150 includes motor-compressor unit 24 and condenser 122. In operation, compressed refrigerant passes from motor-compressor unit 24 through condenser 122 as described above to transfer heat from the refrigerant to a suitable heat sink or the ambient environment. Thereafter, the refrigerant passes through outlet 44 of housing 22 of CRS 150 and into inlet 154 of modular heat exchanger 152. Modular heat exchanger 152 may include an expansion device therein to allow expansion of refrigerant before the refrigerant passes through the internal passages of modular heat exchanger 152 to take up heat from the area surrounding modular heat exchanger 152. Thereafter, the refrigerant passes through outlet 156 of modular heat exchanger 152, into inlet 42 of housing 22 of CRS 150 and into the inlet of motor-compressor unit 24 to repeat the foregoing refrigeration cycle.

[0067] In one embodiment, shown in FIG. 15, modular heat exchanger 152 is a condenser. In this embodiment, CRS 150 includes motor-compressor unit 24 and evaporator 124 and, in operation, refrigerant compressed by motor-compressor unit 24 passes through outlet 44 of housing 22 of CRS 150 and into inlet 154 of modular heat exchanger 152. In modular heat exchanger 152, the heat from the refrigerant diffuses into the ambient atmosphere. Thereafter, the refrigerant flows through outlet 156 of modular heat exchanger 152 and into inlet 42 of CRS 150, and passes through restrictor passage 134, expansion device 136, evaporator passage 138, and suction line passage 144 and into the inlet of motor-compressor unit 24 as described above, wherein evaporator 124 of CRS 150 functions as a “cold plate” in the manner described above.

[0068] In a still further embodiment, CRS 150 may be configured with both condenser 122 and evaporator 124 as described above with respect to CRS 120, and may additionally include modular heat exchanger 152 to provide a supplemental condenser or evaporator to the system. In a further alternative, modular heat exchanger 152 may be configured as a suction line heat exchanger (“SLHX”) to allow both further cooling of the refrigerant after same passes through condenser 122, and further warming of the refrigerant after same passes through evaporator 124 thereby increase the efficiency of CRS 150.

[0069] While this invention has been described as having an exemplary design, the present invention may be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles.

What is claimed is:

1. A compact compressor unit, comprising:

   a substantially enclosed housing including an inlet and an outlet; and

   a motor-compressor unit disposed within said housing, comprising:

   a stator;

   a rotor disposed substantially interiorly of said stator; and

   a compressor mechanism driven by said rotor and disposed substantially interiorly of said rotor, said compressor mechanism in fluid communication with said inlet and said outlet, whereby said compressor mechanism receives fluid from said inlet at suction pressure, compresses the fluid to discharge pressure, and discharges the fluid at discharge pressure through said outlet.

2. The compact compressor unit of claim 1, wherein said housing has a simple geometry profile.

3. The compact compressor unit of claim 2, wherein said simple geometry profile of said housing comprises a rectilinear profile.

4. The compact compressor unit of claim 1, wherein said housing further comprises at least:

   a first housing component defining at least a first pair of opposite sides of said housing; and

   a second housing component defining at least a third side of said housing, said first and second housing components insertable one into the other.

5. The compact compressor unit of claim 1, wherein said inlet and said outlet are disposed within a common side of said housing, said inlet and said outlet recessed into said common housing side.

6. The compact compressor unit of claim 1, wherein said compressor mechanism is a rotary compressor mechanism.

7. The compact compressor unit of claim 6, including a first axis about which said rotor rotates, said compressor mechanism further comprising:
a hub positioned substantially coaxial with said first axis, said hub including a reciprocal vane;
an annular roller disposed about said hub and said vane to define a variable compression chamber therebetween, said roller driven by said rotor for orbital movement about a second axis eccentric to said first axis.

8. The compact compressor unit of claim 1, wherein said housing further includes an electrical terminal, said electrical terminal at least partially recessed within said housing profile.

9. The compact compressor of claim 1, further comprising a heat exchanger configured as a modular unit attached to said housing in fluid communication with said inlet and said outlet.

10. The compact compressor of claim 9, wherein said heat exchanger is an evaporator, said evaporator including an evaporator inlet in fluid communication with said housing outlet, and an evaporator outlet in fluid communication with said housing inlet.

11. The compact compressor of claim 9, wherein said heat exchanger is a condenser, said condenser including a condenser inlet in fluid communication with said housing outlet, and a condenser outlet in fluid communication with said housing inlet.

12. The compact compressor of claim 9, further comprising a second heat exchanger formed substantially within a wall of said housing.

13. A compact refrigeration system, comprising:
a substantially enclosed housing having a simple geometry profile including at least first and second sides;
a motor-compressor unit disposed within said housing, comprising:
a stator;
a rotor disposed substantially interiorly of said stator; and
a compressor mechanism driven by said rotor, said compressor mechanism having an inlet and an outlet;
a condenser formed at least partially within said first side of said housing, said condenser in fluid communication with said compressor mechanism outlet;
an evaporator formed at least partially within said second side of said housing, said evaporator in fluid communication with said compressor mechanism inlet; and
an expansion device in fluid communication with said condenser and with said evaporator.

14. The compact refrigeration system of claim 13, wherein said compressor mechanism is disposed substantially interiorly of said rotor.

15. The compact refrigeration system of claim 13, wherein said simple geometry profile of said housing comprises a rectilinear profile.

16. The compact refrigeration system of claim 13, wherein said housing further comprises at least:
a first housing component defining at least a first pair of opposite sides of said housing; and
a second housing component defining at least a third side of said housing, said first and second housing components insertable one into the other.

17. The compact refrigeration system of claim 13, wherein said housing further includes an electrical terminal, said electrical terminal at least partially recessed within said housing profile.

18. The compact refrigeration system of claim 13, wherein at least one of said condenser and evaporator includes a passage directed from any port of a respective said side of said housing toward a peripheral portion of said side.

19. The compact refrigeration system of claim 13, further comprising an auxiliary heat exchanger configured as a modular unit attached to said housing in fluid communication with at least one of said evaporator and said condenser.

20. A compact refrigeration system, comprising:
a substantially enclosed housing having a simple geometry profile, including an inlet and an outlet and at least a first side;
a motor-compressor unit disposed within said housing, comprising:
a stator;
a rotor disposed substantially interiorly of said stator; and
a compressor mechanism driven by said rotor; and
a first heat exchanger formed substantially within said first side of said housing, said first heat exchanger in fluid communication with said compressor mechanism.

21. The compact refrigeration system of claim 20, further comprising a second heat exchanger configured as a modular unit attached to said housing in fluid communication with said inlet and said outlet.

22. The compact refrigeration system of claim 21, wherein said first heat exchanger is an evaporator and said second heat exchanger is a condenser, and wherein, in serial order, said compressor mechanism is in fluid communication with said condenser via said outlet, said condenser is in fluid communication with said evaporator via said inlet, and said evaporator is in fluid communication with said compressor mechanism.

23. The compact refrigeration system of claim 21, wherein said first heat exchanger is an condenser and said second heat exchanger is an evaporator, and wherein, in serial order, said compressor mechanism is in fluid communication with said condenser, said condenser is in fluid communication with said evaporator via said inlet, and said evaporator is in fluid communication with said compressor mechanism via said inlet.

24. The compact refrigeration system of claim 19, wherein said compressor mechanism is disposed substantially interiorly of said rotor.

25. The compact refrigeration system of claim 19, wherein said simple geometry profile of said housing comprises a rectilinear profile.

26. The compact refrigeration system of claim 19, wherein said housing further comprises at least:
a first housing component including at least a first pair of opposite sides of said housing; and
a second housing component including at least a third side of said housing, said first and second housing components insertable one into the other.
27. The compact refrigeration system of claim 19, wherein said inlet and said outlet are disposed within a common side of said housing, said inlet and said outlet recessed into said common housing side.

28. The compact refrigeration system of claim 19, wherein said housing further includes an electrical terminal, said electrical terminal at least partially recessed within said housing profile.

29. The compact refrigeration system of claim 19, wherein said first heat exchanger includes a passage extending from proximate a central portion of said first side of said housing toward a peripheral portion of said first side.

30. A compact refrigeration system, comprising:

a housing, comprising:

a first housing component including at least a first pair of opposite sides of said housing; and

a second housing component including at least another side of said housing, said first and second housing components insertable one into the other; and

a compressor mechanism disposed within said housing.

31. The compact refrigeration system of claim 30, further comprising a heat exchanger formed substantially in one of said sides of said housing.

32. The compact refrigeration system of claim 31, wherein said heat exchanger is one of:

an evaporator, said evaporator in fluid communication with an inlet of said compressor mechanism; and

a condenser, said condenser in fluid communication with an outlet of said compressor mechanism.

33. The compact refrigeration system of claim 30, wherein said heat exchanger includes a passage extending from proximate a central portion of said side of said housing toward a peripheral portion of said side.

34. The compact refrigeration system of claim 30, wherein said housing further includes an inlet and an outlet, said housing further comprising a modular heat exchanger attached to said housing in fluid communication with said inlet and said outlet.

35. The compact refrigeration system of claim 30, wherein said first and second pairs of opposite sides of said housing define a rectilinear profile.

36. The compact refrigeration system of claim 30, wherein said compressor mechanism comprises:

a stator;

a rotor disposed substantially interiorly of said stator; and

a compressor mechanism driven by said rotor and disposed interiorly of said stator.

37. A compact refrigeration system, comprising:

a housing, comprising:

a first housing component including at least a first pair of opposite sides of said housing; and

a second housing component including at least another side of said housing, said first and second housing components insertable one into the other; and

a heat exchanger at least partially integrated into one of said sides of said housing, said heat exchanger including a passage extending from proximate a central portion of said housing side toward a peripheral portion of said housing side.

38. The compact refrigeration system of claim 37, further comprising a compressor mechanism disposed within said housing.

39. The compact refrigeration system of claim 37, wherein said heat exchanger is one of:

an evaporator, said evaporator in fluid communication with an inlet of said compressor mechanism; and

a condenser, said condenser in fluid communication with an outlet of said compressor mechanism.

40. The compact refrigeration system of claim 37, wherein said housing includes an inlet and an outlet, said compact refrigeration system further comprising a second, modular heat exchanger attached to said housing in fluid communication with said inlet and said outlet.

41. A compact refrigeration system, comprising:

a housing including an inlet and an outlet;

a compressor unit disposed within said housing, said compressor unit comprising:

a stator;

a rotor disposed substantially interiorly of said stator; and

a compressor mechanism driven by said rotor and disposed interiorly of said stator; and

a first heat exchanger configured as a modular unit attached to a wall of said housing, said heat exchanger in fluid communication with said inlet and with said outlet.

42. The compact refrigeration system of claim 41, wherein said housing further includes a second heat exchanger at least partially integrated into a wall of said housing.

43. The compact refrigeration system of claim 42, wherein said second heat exchanger includes a fluid passage extending from a central portion of said wall outwardly toward a peripheral portion of said wall.

44. A compact refrigeration system, comprising:

a first housing component having a simple geometry profile including an exterior wall, and a groove formed within said exterior wall;

a second housing component into which said first housing component is received, said second housing component having a wall in abutment with said exterior wall of said first housing component and enclosing said groove to define a heat exchanger passage; and

a compressor mechanism disposed within said first housing component and in fluid communication with said heat exchanger passage.

45. The compact refrigeration system of claim 44, wherein said heat exchanger passage extends from a central
portion of said exterior wall outwardly toward a peripheral portion of said exterior wall.

46. The compact refrigeration system of claim 44, wherein said first housing component includes another exterior wall having another groove formed therein, and said second housing component includes another wall in abutment with said another exterior wall of said first housing component and enclosing said another groove to define another heat exchanger passage.

47. The compact refrigeration system of claim 44, wherein said compressor mechanism comprises:

a stator;
a rotor disposed substantially interiorly of said stator; and
a compressor mechanism driven by said rotor and disposed interiorly of said stator.

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