MULTI-STAGE HEAT EXCHANGER

Inventors: Jay A. Kohler, York, PA (US); Thomas W. Wise, Dallastown, PA (US)
Assignee: JOHNSON CONTROLS TECHNOLOGY COMPANY, Holland, MI (US)

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ABSTRACT
A refrigeration system that utilizes both an air-cooled heat exchanger and a cooling tower to cool refrigerant prior to the refrigerant being provided to the evaporator. This multi-stage cooling permits the refrigeration system to operate with improved efficiency, while reducing the amount of water lost to evaporative cooling in the cooling tower, since the thermal load handled by the cooling tower is reduced by the air-cooled heat exchanger. This in turn means less water is required to replace water lost to evaporative cooling. In arid regions or regions of low water quality, both efficiency increase and reduction of water lost to evaporative cooling are important improvements.
From Compressor 54

To/From Air Heat Exchanger 30

To/From Cooling Tower 14

To Evaporator 46

FIG-4
MULTI-STAGE HEAT EXCHANGER

FIELD OF THE INVENTION

[0001] The present invention is directed at a hybrid refrigeration system, and specifically, a refrigeration system that cools refrigerant with both an air radiation system and with a cooling tower system to minimize water loss to evaporation, thereby achieving supercooling of the refrigerant while reducing water loss through the cooling tower system.

BACKGROUND OF THE INVENTION

[0002] Refrigeration systems can accomplish heat rejection by heat transfer using either condenser-cooling tower systems or through water-cooled condensers wherein water extracts heat from the refrigerant. The water is subsequently cooled by air through a radiation system.

[0003] Cooling towers are extremely efficient in removing heat from condensers, and are used extensively in areas where water is abundant. Cooling towers and not closed systems, however, and require a substantial amount of make-up water, as cooling towers take advantage of the principles of evaporative cooling in removing heat from the system. Cooling towers also require a make-up source of water that is substantially pure, as lesser quality water or contaminated water can lead to degradation of performance of the heat exchanger components and other components that contact the water. Performance is lost as the components accumulate dirt and contaminants. Restoring the components to optimum performance conditions requires cleaning. Cleaning is expensive and can result in equipment downtime and replacement of corroded equipment. Furthermore, when less than pure water is used, components can be fabricated from expensive corrosion-resistant materials. This can reduce down-time required to replace corroded equipment, although cleaning may still be required periodically. Thus, systems using cooling towers are not practical in arid areas where water is scarce or in areas where water cannot readily be provided in a purified mode. In fact, in many regions of the world, good quality water is or is becoming a scarce and expensive commodity. Cooling towers require a continuous supply of water for make-up, thereby limiting their geographic applications.

[0004] Water-cooled condensers having water cooled by an air radiation system have higher heat rejection temperatures and require larger heat exchanger surface areas, which adds to their cost. The efficiency of such systems is reduced compared to systems utilizing cooling towers.

[0005] What is needed is a system that provides efficient cooling while minimizing the use of precious water.

SUMMARY OF THE INVENTION

[0006] A refrigeration system utilizes both an air-cooled heat exchanger and a cooling tower to cool refrigerant prior to the refrigerant being provided to the evaporator. The refrigeration system utilizes an air-cooled heat exchanger to cool and change the state of refrigerant provided by a compressor to a condenser from a gas to a liquid and cool the refrigerant in the condenser to a first temperature, T1. The air-cooled heat exchanger is a closed water loop system having a first heat exchanger in heat exchange communication with the condenser wherein water extracts heat from the refrigerant, and a second heat exchanger in heat exchange communication with air to cool the heated water. To improve the efficiency of the system, the refrigerant is then cooled to a second temperature, T2. This is accomplished by utilizing a cooling tower. Water in an open loop circulates between a subcooler and the cooling tower. Water from the cooling tower removes heat from the refrigerant in the subcooler (or a different portion of the condenser) to cool the refrigerant to the second temperature T2. The water in the open loop is then circulated to the cooling tower where its temperature is cooled by both convection and evaporative cooling. Water lost by evaporation must be replaced. Because the refrigeration system utilizes an air-cooled heat exchanger to cool the refrigerant to a first temperature T1, the thermal load on the water in the cooling tower loop, which is used to cool the refrigerant to the second temperature T2 prior to being cycled to an evaporator, is reduced. This reduced thermal load means that the cooling tower can be smaller and the amount of water lost to evaporation by evaporative cooling in the cooling tower is reduced.

[0007] An advantage of this system is that the expense required to build a cooling tower is reduced, since the cooling tower may be of a reduced size.

[0008] Another advantage of this system is that the amount of water required to replace the water lost by the cooling tower due to evaporative cooling is reduced. In arid or dry climates where water is a precious commodity and in short supply, this is a significant improvement, since no longer is the property owner faced with a choice between reduced efficiency from solely using an air-cooled heat exchanger or using a system that relies on a cooling tower requiring large amounts of water for water replacement due to evaporative cooling.

[0009] This system also has an advantage in areas in which water quality is poor. Since less water is required for water replacement due to evaporative cooling, there will be less corrosion or dirt build up as water circulates over the equipment. If the water is treated before being added to the open water loop associated with the cooling tower, there will be less water required which will lower the water treatment costs.

[0010] Other features and advantages of the present invention will be apparent from the following more detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a cut-away view of a building having a refrigeration system having an air-cooled heat exchanger outside the building and a cooling tower on the roof of the building.

[0012] FIG. 2 is a cut-away view of a building having a refrigeration system having an air-cooled heat exchanger outside the building and a cooling tower remote from the building but adjacent to a body of water.

[0013] FIG. 3 is a view of a prepackaged hybrid condenser/ subcooler unit, having internal connections between the condenser and subcooler and which requires external connections to the compressor, the evaporator, the air heat exchanger and the cooling tower.

[0014] FIG. 4 is a view a condenser and subcooler which require a separate connection of the condenser to the subcooler.

[0015] FIG. 5 is a view of a prepackaged refrigeration system having a compressor, an evaporator, and a condenser/
Detailed Description of the Invention

[0016] FIG. 1 depicts a refrigeration system installed in a building 12. The refrigeration system includes a cooling tower 14 positioned on the roof of building 12. In other exemplary embodiments, cooling tower 14 may be located elsewhere, such as on the ground near building 12, adjacent a body of water or any other suitable location. Cooling tower 14 may be located away from the building and adjacent to a river, pond, lake or other body of water, such as cooling tower 140 depicted in FIG. 2. Cooling tower 14, FIG. 1, and cooling tower 140, FIG. 2, are not closed loop systems. Water lost to the atmosphere through evaporation by evaporation cooling must be replenished. A body of water can provide the make-up water required for efficient cooling tower operation, although water may come from an available public system piped into the building, such as is shown in FIG. 1.

[0017] In an exemplary embodiment, cooling tower supply water 38 is supplied to cooling tower 14 from condenser/subcooler 36, and cooling tower return water is returned to condenser/subcooler 36 by cooling tower return line 40. In FIG. 1, a cooling tower return water replenishment line 61 is connected to cooling tower return line 40 to replenish water lost by evaporation in cooling tower 14. In FIG. 2, water lost by evaporation in cooling tower 140 may be replenished from a naturally occurring water source, which may be a lake, river or pond, through water replenishment line 610. Condenser/subcooler 36 is also connected to air-cooled heat exchanger 30 located outside of building 12 adjacent the ground floor in FIGS. 1 and 2, and to an evaporator 46. Air-cooled heat exchanger 30 may be located in any suitable area, and is connected to the condenser/subcooler 36 by closed loop return line 32 and closed loop supply line 34. Water or other suitable fluid(s) circulates in a closed system through lines 32, 34 between heat exchanger 30 and condenser/subcooler 36. Refrigerant circulates as a gas from compressor 54, driven by motor 56 through refrigerant line 58 to condenser/subcooler 36 where it undergoes a change of state and is condensed to a liquid. Although compressor 54 is depicted as a single compressor, the refrigerant system may include a plurality of compressors 54 operating in series, in which refrigerant gas flows from a first compressor to a second compressor and so forth prior to circulation to condenser/subcooler 36, or in parallel, in which the refrigerant gas is split between multiple compressors 54 prior to being circulated to condenser/subcooler 36. Heat is removed from the refrigerant gas in condenser 36, cooling the refrigerant to a first temperature 0, by heat exchange with water from the closed loop system connected to heat exchanger 30. The water in the closed-loop system then circulates to heat exchanger 30, where heat is removed convectively from the water by air.

[0018] Refrigerant at temperature 0 is further cooled in condenser/subcooler 36 after cooling to temperature 2 by water from cooling tower 14, provided by cooling water return line, which may be supplemented by water from cooling tower return water replenishment line 61. Condenser/subcooler 36 is a hybrid unit that includes two separate heat exchange units, a condenser 60 and a subcooler 62. This hybrid condenser/subcooler may be packaged together for installation as a single unit or as part of a package, as depicted in FIGS. 3 and 5, or the condenser 60 and subcooler 62 may be provided as separate apparatus for installation as depicted in FIG. 4.

[0019] Heat removed from the refrigerant by the “cooling tower” further reduces the refrigerant temperature from a temperature 0 to a temperature 1 in subcooler 62 while the water temperature is increased. This water is returned to cooling tower 14 through cooling tower supply line 38, where the heated water is cooled. In the cooling tower 14, water flows over fill, for example a plastic or a wood material used to maximize the surface area that the water contacts, to improve its heat exchange ability. Cooling tower 14 may additionally include fans to further improve heat removal from the water by providing additional air flow over the water. Some of the water evaporates, and the change in state of the water from a liquid to a gas absorbs energy from the water, further cooling the remaining liquid. The cooled liquid is then returned via cooling water return line 40 to the subcooler.

[0020] Subcooled refrigerant is then circulated from condenser/subcooler 36 to an evaporator 46 through refrigerant line 42, and optionally through an expansion valve. The subcooled refrigerant in evaporator 46 absorbs heat from water circulated in evaporator 46 to provide chilled water to be circulated through chiller water supply line 48 to air handler system 22. The cooled refrigerant also undergoes a phase change as it absorbs heat in evaporator 46. As shown in FIG. 1, the cooled water is circulated through chiller water supply line 48 to air handler 22. Building 12 may include a plurality of air handlers 22 connected to chiller water supply line 48. However, the chilled water can be routed for other purposes in addition for use with air handler(s) 22. As shown in FIG. 1, each floor of building 12 includes an air handler 22, but building 12 may have as few as one air handler 22 or may have a plurality of air handlers 22 for each floor, as shown. Air handlers 22 cool air from return ducts 18 through a heat exchange relationship with the chilled water. For example, fans may blow air across a heat exchanger utilizing the chilled water, thereby cooling the air. The cooled air then is circulated to the building areas through supply ducts 20. Water, heated by the heat exchange relationship with the return air, is returned to evaporator 46 by chiller water return line 50 for recirculation through the system. The refrigerant, converted to a refrigerant gas in evaporator 46, is returned to compressor 54, to be again compressed as a gas to a high pressure and an elevated temperature before being recirculated to condenser 60.

[0021] FIG. 3 depicts condenser/subcooler 36 of FIGS. 1 and 2 as a single unit. Condenser/subcooler 36 includes a first heat exchanger, condenser 60, in series with a second heat exchanger, subcooler 62. These units may be oriented horizontally or vertically with respect to one another. Condenser 60 is plumbed so that refrigerant gas at an elevated temperature and pressure from compressor 54 enters condenser/subcooler 36, runs through condenser 60, where it is condensed to a liquid at a first temperature 0, passes through subcooler 62, and then exits condenser/subcooler 36 at a second temperature 1 to evaporator 46 via refrigerant line 42. Refrigerant gas entering condenser 60 from compressor 54 in refrigerant loop at an elevated temperature and pressure enters into a heat exchange relationship with water in water loop in a closed loop system entering condenser 60 through line 34 from air heat exchanger 30. The water line 34 absorbs heat from the refrigerant in the heat exchanger and changes the state of the refrigerant from a gas to a liquid, lowering the
refrigerant temperature to temperature $T_1$. Water from condenser 60 returns via line 32 in the water loop at an elevated temperature to air heat exchanger 30 where heat is removed as air is passed over the water loop, cooling the water.

[0022] Refrigerant at a temperature $T_1$ from condenser 60 enters subcooler 62 in the refrigerant loop where water in a water loop from cooling tower 14 or 140 enters through line 40 and is placed in heat exchange relationship with the refrigerant in subcooler 62, further lowering the refrigerant temperature to temperature $T_2$. The water from line 40, having absorbed heat from the refrigerant, is returned to the cooling tower through cooling water return line 38. Chilled refrigerant at temperature $T_2$ is delivered to evaporator 46 via refrigerant line 42. When condenser/subcooler 36 is supplied as a single unit as shown in Fig. 3, it can be installed on-site by connecting refrigerant lines 58 and 42 to the compressor and the evaporator respectively, and by connecting lines 32, 34 extending from condenser/subcooler 36 to air heat exchanger 30, and by connecting lines 38, 40 extending from condenser/subcooler 36 to cooling tower.

[0023] FIG. 4 depicts condenser/subcooler 36 in a system where condenser 60 and subcooler 62 are separate items and connected on-site. While condenser/subcooler 36 of FIG. 4 operates exactly as condenser/subcooler 36 described in FIG. 3, above, assembly of condenser/subcooler 36 of FIG. 3 is slightly different. A refrigerant connection is made between condenser 60 and subcooler 62, since these components may be shipped and provided to the site unconnected to one another. Refrigerant line 58 from compressor 54 is connected to condenser 60 and refrigerant line 42 from subcooler 62 is connected to evaporator 46. Lines 32, 34 from closed loop heat exchanger are connected to condenser 60 and lines 38, 40 from cooling tower 14 are connected to subcooler 62. In this embodiment, plumbing connections between condenser 60 and subcooler 62 are joined on-site. The flow of refrigerant and cooling water is identical to the flow set forth in the description of FIG. 3 above.

[0024] FIG. 5 depicts the refrigeration system 10 including condenser/subcooler 36 as a single, packaged unit. The system functions as described in FIG. 1. Some of the plumbing connections are not made on-site, as the single, packaged unit can be preassembled. The system can be installed by connecting piping extending from the refrigeration system to piping systems in building 12. Once refrigeration system 10 is positioned on-site, connections are made through lines 38, 40 to cooling tower 14 and through lines 32, 34 to air-cooled heat exchanger 30. Cooling tower return water replenishment line 61, FIG. 1, or line 610, FIG. 2, may be connected to line 40 outside of refrigeration system 10. The chilled water system that supplies chilled water from the evaporator to the air handler(s) 22 is also connected to the refrigeration system through lines 48, 50.

[0025] Condenser/subcooler 36 provides improved efficiency over a water-cooled condenser system using water cooled by an air radiation system. This system provides efficiency slightly reduced from that of a system solely utilizing a cooling tower, but uses less water than such a system. A smaller cooling tower can be utilized with condenser/subcooler 36 because of a smaller thermal load in the cooling tower water loop as a result of the refrigerant temperature first being lowered to temperature $T_1$ by the closed-loop, water-cooled air-cooled heat exchanger. The smaller cooling tower requires less heat transfer surface and loses less water to evaporation, requiring less water replenishment. The condenser/subcooler 36 provides heat transfer properties that are comparable to that of a water tower system, and provides a cost advantage in that a smaller cooling tower can be utilized, and expensive replenishment water supplies are reduced. Importantly, condenser/subcooler 36 provides a lower exiting refrigerant temperature $T_2$ than an air radiation system. The temperature of refrigerant exiting condenser/subcooler 36 approaches that of a cooling tower-only system. A smaller cooling tower also provides an advantage of not only reduced cost, but also of reduced space when space is a consideration, such as in a crowded or congested area.

[0026] While only certain features and embodiments of the invention have been shown and described, many modifications and changes may occur to those skilled in the art (e.g., variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters (e.g., temperatures, pressures, etc.), mounting arrangements, use of materials, colors, orientations, etc.) without materially departing from the novel teachings and advantages of the subject matter recited in the claims. The order or sequence of any process or method steps may be varied or re-sequenced according to alternative embodiments. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention. Furthermore, in an effort to provide a concise description of the exemplary embodiments, all features of an actual implementation may not have been described (i.e., those unrelated to the presently contemplated best mode of carrying out the invention, or those unrelated to enabling the claimed invention). It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation specific decisions may be made. Such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure, without undue experimentation.

What is claimed is:

1. A multi-stage cooling system for use in a refrigeration system having a condenser, a subcooler, an evaporator, and a pressurized gas circulating refrigerant in a closed system, comprising:

- an air-cooled heat exchanger in heat exchange communication with the condenser, the air-cooled heat exchanger cooling the refrigerant to a temperature before exiting the condenser and circulating the refrigerant to the subcooler;
- a cooling tower having an open water loop in heat exchange communication with the subcooler, the water-cooled cooling tower cooling the refrigerant from the first temperature to a second temperature before circulating the refrigerant to the evaporator; and
- wherein a thermal load on the cooling tower from cooling the refrigerant from the first temperature to the second temperature is reduced, resulting in a reduced consumption of water by the cooling tower.

2. The system of claim 1 wherein the air-cooled heat exchanger includes a closed water loop having a first heat exchanger in communication with the condenser and a second heat exchanger in communication with the air.

3. The system of claim 2 wherein the cooling tower is sized to accommodate the thermal load required to cool the refrigerant from the condenser exit temperature to the second temperature.
4. The system of claim 1 wherein the refrigeration system further includes a plurality of compressors operating in series.

5. The system of claim 1 wherein the refrigeration system further includes a plurality of compressors operating in parallel.

6. A refrigeration system that includes a compressor, a condenser, an evaporator, an expansion valve, refrigerant in a refrigerant loop cycled from the compressor, to the condenser and to the evaporator; the improvement comprising: an air-cooled heat exchanger that includes a fan, an outdoor heat exchanger, and a first closed water loop that cycles water from the condenser to the outdoor heat exchanger, wherein the water removes heat from a refrigerant gas in the condenser, condensing the refrigerant gas to a liquid at a first temperature, and wherein the outdoor heat exchanger removes heat from the water by circulating air over the outdoor heat exchanger with a fan; a subcooler unit comprising a subcooler heat exchanger, a cooling tower, a cooling tower supply water line, and a cooling tower return water line, wherein the subcooler unit receives the refrigerant liquid from the condenser and cools the refrigerant liquid to a second temperature lower than the first temperature using cooling water, the cooling water supply line providing heated water from the subcooler to the cooling tower, the cooling tower cooling the water, the cooling water return line providing cooled water from the cooling tower to the subcooler, and the cooling tower return water replenishment line providing additional water to the cooling water return line to replenish water evaporated in the cooling tower;

7. The refrigeration system of claim 6 wherein refrigerant is provided to the evaporator at the second temperature; and wherein a thermal load on the subcooler unit resulting from cooling the refrigerant from the first temperature to the second temperature is reduced due to cooling by the air-cooled heat exchanger.

8. The refrigeration system of claim 7 wherein evaporative cooling in the open loop system results in evaporation of water, which evaporation is reduced due to the reduced thermal load.

9. The refrigeration system of claim 8 wherein the open loop system further includes a cooling tower return water replenishment line, wherein the cooling tower return water replenishment line that replaces water lost to evaporation, which replacement is reduced due to reduced evaporation from the reduced thermal load.

10. The refrigeration system of claim 8 further including a body of water in fluid communication with the cooling tower return water replenishment line.

11. The refrigeration system of claim 10 wherein the body of water in fluid communication with the cooling tower is a river, a stream or a lake.

12. The refrigeration system of claim 10 wherein water from the body of water is first treated and purified prior to entering the cooling water return line.

13. The system of claim 1 wherein the refrigeration system further includes a plurality of compressors operating in series.

14. The system of claim 1 wherein the refrigeration system further includes a plurality of compressors operating in parallel.

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