(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 August 2017 (24.08.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/141149 A1

(51) International Patent Classification:
F25B 1/00 (2006.01) ***F25B 13/00*** (2006.01)
F25B 7/00 (2006.01)

(21) International Application Number:
PCT/IB2017/050786

(22) International Filing Date:
13 February 2017 (13.02.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/295,797 16 February 2016 (16.02.2016) US

(71) Applicant: SABIC GLOBAL TECHNOLOGIES B.V. [NL/NL]; Plasticslaan 1, 4612 PX Bergen op Zoom (NL).

(72) Inventor; and
(71) Applicant *(for US only)*: **KARIME, Mustapha** [US/SA]; SABIC T&I, P.O. Box 42503, Riyadh, 11551 (SA).

(72) Inventor: ABDELGHANI, Mohamed Sabri; SABIC T&I, P.O. Box 42503, Riyadh, 11551 (SA).

(74) Agent: KRAWZSENEK, Michael; Norton Rose Fulbright US LLP, 98 San Jacinto Boulevard, Suite 1100, Austin, Texas 78701 (US).

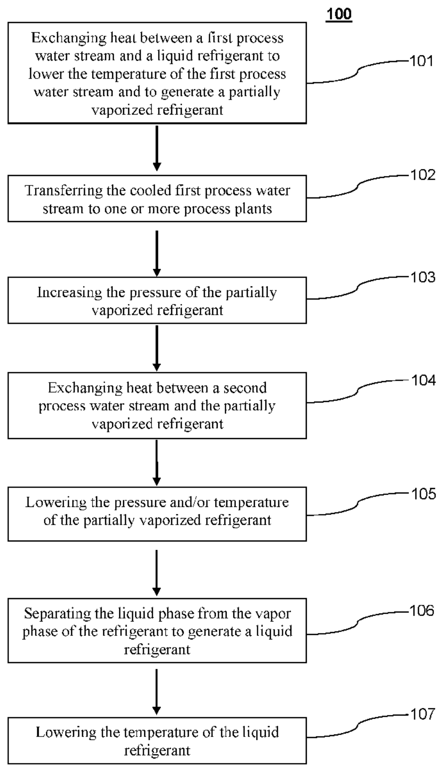
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH,

[Continued on next page]

(54) Title: METHODS AND SYSTEMS OF COOLING PROCESS PLANT WATER

FIG. 1



(57) Abstract: The present disclosure provides methods and system for the cooling of process plant water. A system can include a first heat exchanger for exchanging heat between a first process water stream and a refrigerant; a multiphase pump, coupled to the first heat exchanger, to increase the pressure of the refrigerant; a second heat exchanger, coupled to the multiphase pump and the first heat exchanger, for exchanging heat between a second process water stream and the refrigerant; a first expansion valve, coupled to the second heat exchanger, for lowering the temperature of the refrigerant; a vapor-liquid separator, coupled to the first expansion valve and the multiphase pump, for separating the liquid and vapor phases of the refrigerant; and a second expansion valve, coupled to the vapor-liquid separator and the first heat exchanger, for lowering the temperature of the liquid phase of the refrigerant.

WO 2017/141149 A1

GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *with international search report (Art. 21(3))*

METHODS AND SYSTEMS OF COOLING PROCESS PLANT WATER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority of U.S. Provisional Patent Application No. 62/295,797, filed February 16, 2016, which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] This disclosure relates to methods and systems for cooling process plant water.

[0003] Petrochemical processing plants, such as those involved in the processing of natural gas and olefins and the generation of syngas, can include refrigeration systems that use water-based coolants, also referred to as process plant water, for cooling components of the processing plant. For example, certain water-based cooling systems can be used to remove heat from reactions performed in a processing plant and for the separation of substances within hydrocarbon mixtures for use in a processing plant. Water-based cooling systems can also be used for the condensation of hydrocarbon gas streams.

[0004] Refrigeration methods and systems in the petrochemical industry can use a series of two-stage compressors, flash drums, liquid pumps, cooling towers and heat exchangers, which can lead to high capital and operating costs. Therefore, there remains a need in the art for more efficient and cost-effective methods of cooling process water.

SUMMARY

[0005] The disclosed subject matter provides methods for cooling process plant water including exchanging heat between a first process water stream and a liquid refrigerant within a first heat exchanger to lower the temperature of the process water stream. In certain embodiments, the refrigerant is partially vaporized upon the exchange of heat with the first process water stream to generate a partially vaporized refrigerant having a vapor phase and a liquid phase. The method can include increasing the pressure of the partially vaporized refrigerant and transferring at least a portion of the refrigerant to a second heat exchanger.

[0006] In certain embodiments, the method includes exchanging heat between a second process water stream and the partially vaporized refrigerant within the second heat exchanger to decrease the temperature of the refrigerant. The method can include lowering the pressure and/or temperature of the partially vaporized refrigerant portion and transferring the partially vaporized refrigerant portion to a vapor-liquid separator to separate the liquid phase from the vapor phase thereof, thereby generating a liquid refrigerant. The method can further include lowering the temperature of the liquid refrigerant and transferring at least a portion of the refrigerant to the first heat exchanger to exchange heat with the first process water stream. The method can include transferring the cooled process water to one or more process plants. The pressure of the partially vaporized refrigerant can be increased in a multiphase pump.

[0007] In certain embodiments, the vapor-liquid separator can be a flash drum. In certain embodiments, the liquid refrigerant includes a refrigerant that has a viscosity greater than or equal to about 0.1 cP at a temperature of about 0°C. In certain embodiments, the liquid refrigerant includes a refrigerant that has a boiling point temperature from about -10°C to about -50°C. The liquid refrigerant can be R134A, R404A, R407C, R125 and R410A, and the partially vaporized refrigerant can have a vapor phase of about 30% to about 50%.

[0008] The disclosed subject matter also provides techniques for cooling process plant water that includes exchanging heat between a first process water stream and a liquid refrigerant to lower the temperature of the process water stream, thereby generating a partially vaporized refrigerant. An example method can further include increasing the pressure and/or temperature of the partially vaporized refrigerant to generate a pressurized partially vaporized refrigerant. The method can include exchanging heat between a second process water stream and the pressurized refrigerant to increase the temperature of the second process water stream and/or lower the temperature of the pressurized partially vaporized refrigerant. The method can include lowering the pressure and/or temperature of the pressurized partially vaporized refrigerant and separating out at least a portion of a liquid phase from the partially vaporized refrigerant to generate a liquid refrigerant, and lowering the temperature of the liquid refrigerant to generate a refrigerant suitable for exchanging heat with the first process water stream.

[0009] The disclosed subject matter further provides methods for cooling process plant water that includes exchanging heat between a first process water stream and a liquid refrigerant within a first heat exchanger to lower the temperature of the process water stream, thereby partially vaporizing the refrigerant upon the exchange of heat with the first process water stream. An example method can further include transferring the first process water from the first heat exchanger to one or more process plants, and transferring the partially vaporized refrigerant from the first heat exchanger to a multiphase pump to increase the pressure of the partially vaporized refrigerant. The method can include transferring the partially vaporized refrigerant from the multiphase pump to a second heat exchanger. The method can further include exchanging heat between a second process water stream and the partially vaporized refrigerant within the second heat exchanger to lower the pressure and/or temperature of the refrigerant. The method can include transferring the second process water stream from the second heat exchanger to become the first process water stream entering the first heat exchanger. The method can include transferring the partially vaporized refrigerant from the second heat exchanger to a first expansion valve to lower the pressure and/or temperature of the refrigerant.

[0010] The method can include transferring the partially vaporized refrigerant from the first expansion valve to a vapor-liquid separator to separate the liquid phase from the vapor phase thereof, thereby generating a liquid refrigerant. In certain embodiments, the method can include transferring the liquid refrigerant from the vapor-liquid separator to a second expansion valve to lower the temperature of the liquid refrigerant, and transferring the refrigerant from the second expansion valve to the first heat exchanger to exchange heat with the first process water stream.

[0011] The disclosed subject matter further provides methods for cooling process plant water that includes exchanging heat between a first process water stream and a liquid refrigerant within a first heat exchanger to lower the temperature of the process water stream. The refrigerant can be partially vaporized upon the exchange of heat with the first process water stream. The method can include transferring the partially vaporized refrigerant from the first heat exchanger to a vapor-liquid separator to separate the vapor phase from the liquid phase of the refrigerant. The method can include transferring the vapor phase of the refrigerant to a gas compressor for the compression of the refrigerant. The method can include combining the compressed vapor phase of the refrigerant with the liquid phase of the refrigerant to generate a pressurized partially vaporized refrigerant, and exchanging heat between a second process water stream and the refrigerant within a second heat exchanger to lower the temperature of the refrigerant.

[0012] In certain embodiments, the method can include transferring the refrigerant from the second heat exchanger to a first expansion valve to lower the pressure and/or temperature of the refrigerant. The method can further include transferring the refrigerant from the first expansion valve to a second vapor-liquid separator to separate the vapor phase from the liquid phase of the refrigerant. In certain embodiments, the method can include transferring the liquid phase of the refrigerant from the second vapor-liquid separator to a second expansion valve to lower the temperature of the liquid refrigerant and transferring the refrigerant from the second expansion valve to the first heat exchanger to exchange heat with the first process water stream. The refrigerant can be partially vaporized to have a liquid fraction of about 98%. In certain embodiments, the method can further include transferring the vapor phase of the refrigerant from the second vapor-liquid separator to the gas compressor.

[0013] The disclosed subject matter also provides systems for cooling process plant water that includes a first heat exchanger for exchanging heat between a first process water stream and a refrigerant. In certain embodiments, the system can further include a multiphase pump, coupled to the first heat exchanger, to increase the pressure of the refrigerant. In certain embodiments, the system can include a second heat exchanger, coupled to the multiphase pump and the first heat exchanger, for exchanging heat between a second process water stream and the refrigerant. The system can include a first expansion valve, coupled to the second heat exchanger, for lowering the temperature of the refrigerant. The system can further include a vapor-liquid separator, coupled to the first expansion valve and the multiphase pump, for separating the liquid and vapor phases of the refrigerant, and a second expansion valve, coupled to the vapor-liquid separator and the first heat exchanger, for lowering the temperature of the liquid phase of the refrigerant. The vapor-liquid separator can be flash drum.

[0014] In certain embodiments, a system for cooling process plant water includes a first heat exchanger for exchanging heat between a first process water stream and a refrigerant. The system can include a first vapor-liquid separator, coupled to the first heat exchanger, to separate the vapor phase from the liquid phase of the refrigerant. The system can further include a pump, coupled to the first vapor-liquid separator, for transferring at least a portion of the liquid phase of the refrigerant. The system can include a gas compressor, coupled to the first vapor-liquid separator, for increasing the pressure of the vapor phase of the refrigerant. It can also include a transfer line, coupled to the gas compressor and the pump, for combining the vapor phase of the refrigerant and the compressed liquid phase of the refrigerant, thereby generating a partially vaporized refrigerant. The system can include a second heat exchanger, coupled to the transfer line and the first heat exchanger, for exchanging heat between a second process water stream and the refrigerant. The system can include a first expansion valve, coupled to the second heat exchanger, for lowering the temperature of the refrigerant, and a second vapor-liquid separator, coupled to the first expansion valve and the gas compressor, for separating the liquid and vapor phases of the refrigerant. The system can include a second expansion valve, coupled to the second vapor-liquid separator and the first heat exchanger, for lowering the temperature of the liquid phase of the refrigerant and transferring the refrigerant to the first heat exchanger. In certain embodiments, the refrigerant being transferred from the second expansion valve to the first heat exchanger has vapor fraction of about 2% and/or a liquid fraction of about 98%.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. 1 depicts a method for cooling process plant water according to one exemplary embodiment of the disclosed subject matter.

[0016] FIG. 2 depicts a method for cooling process plant water according to one exemplary embodiment of the disclosed subject matter.

[0017] FIG. 3 depicts a system for cooling process plant water according to one exemplary embodiment of the disclosed subject matter.

[0018] FIG. 4 depicts a system for cooling process plant water according to one exemplary embodiment of the disclosed subject matter.

DETAILED DESCRIPTION

[0019] The disclosed subject matter provides techniques for cooling process plant water. In particular non-limiting embodiments, the presently disclosed subject matter provides closed-loop methods and systems for cooling process plant water. In certain embodiments, the methods and/or systems of the present disclosure do not include a heat sink, *e.g.*, a cooling tower.

[0020] Water-based coolant, *i.e.*, process plant water, can be used to cool industrial plants such as petrochemical plants (also referred to herein as process plants and processing plants). The process plant water can include water from any source, such as but not limited, potable water, demineralized water, ocean water, sea water, ground water, stream water or river water. In certain embodiments, the process plant water can have a pH of about 7 to about 8 and/or an amount less than or equal to about 0.15 mg/kg of dissolved solids. In certain embodiments, such process plant water can be used for the condensation of hydrocarbon gas streams, for the separation of substances within a mixture for use in the process plant and/or for the removal of heat from chemical reactions within the process plant.

[0021] For the purpose of illustration and not limitation, FIGS. 1 and 2 are schematic representations of methods according to non-limiting embodiments of the disclosed subject matter. In certain embodiments, the method 100 or 200 includes exchanging heat between a first process water stream and a liquid refrigerant to lower the temperature of, *i.e.*, cool, the first process water stream 101 or 201. Heat exchange between the first process water stream and refrigerant can occur within a first heat exchanger to form a cooled first process water stream.

[0022] In certain embodiments, prior to exchanging heat with the refrigerant, the first process water stream can have a temperature from about 35°C to about 40°C. In certain embodiments, the temperature of the first process water stream prior to heat exchange with the refrigerant can be about 38°C. In certain embodiments, after exchanging heat with the refrigerant, the temperature of the first process water stream can be from about 24°C to about 26°C. In certain embodiments, the temperature of the first process water stream can be lowered to a temperature of about 25°C after exchanging heat with the refrigerant.

[0023] As used herein, the term "about" or "approximately" means within an acceptable error range for the particular value as determined by one of ordinary skill in the art, which will depend in part on how the value is measured or determined, *i.e.*, the limitations of the measurement system. For example, "about" can mean a range of up to 20%, up to 10%, up to 5% and/or up to 1% of a given value.

[0024] The liquid refrigerant for use in the disclosed subject matter can be any refrigerant that has a viscosity equal to or greater than about 0.1 centipoise (cP). In certain embodiments, the refrigerant has a viscosity from about 0.1 cP to about 1.0 cP or from about 0.1 cP to about 0.5 cP. For example, and not by way of example, the refrigerant can have a viscosity from about 0.1 cP to about 0.45 cP, from about 0.1 cP to about 0.4 cP, from about 0.1 cP to about 0.35 cP, from about 0.1 cP to about 0.3 cP, from about 0.1 cP to about 0.25 cP, from about 0.1 cP to about 0.2 cP, from about 0.1 cP to about 0.15 cP, from about 0.15 cP to about 0.50 cP, from about 0.20 cP to about 0.50 cP, from about 0.25 cP to about 0.50 cP, from about 0.30 cP to about 0.50 cP, from about 0.35 cP to about 0.50 cP, from about 0.40 cP to about 0.50 cP or from about 0.45 cP to about 0.5 cP. In certain embodiments, the viscosity of the refrigerant is measured at 0°C.

[0025] The refrigerant for use in the disclosed subject matter can have a boiling point temperature of about -10°C to about -50°C. For example, the refrigerant can have a boiling point temperature of about -10°C to about -45°C, about -10°C to about -40°C, about -10°C to about -35°C, about -10°C to about -30°C, about -10°C to about -25°C, about -10°C to about -20°C, about -10°C to about -15°C, about -15°C to about -50°C, about -20°C to about -50°C, about -25°C to about -50°C, about -30°C to about -50°C, about -35°C to about -50°C, about -40°C to about -50°C or about -45°C to about -50°C. Such low boiling point temperatures can allow the refrigerant to evaporate easily and exchange heat rapidly with the process water stream. Non-limiting examples of refrigerants suitable for use in the disclosed subject matter include hydrocarbon-based refrigerants, R134A, R404A, R407C, R125 and R410A.

[0026] In certain embodiments, prior to exchanging heat with the first process water stream, the temperature of the refrigerant can be from about 5°C to about 10°C, e.g., about 9°C. In certain embodiments, after exchanging heat with the first process water stream, the temperature of the refrigerant can be from about 7°C to about 20°C.

[0027] In certain embodiments, the refrigerant is at least partially vaporized upon the exchange of heat with the first process water stream. “Partially vaporized,” as used herein, can mean that more than about 10%, more than about 20%, more than about 30%, more than about 35%, more than about 40%, more than about 45%, more than about 50% or more than about 55% of the refrigerant is vaporized (*i.e.*, is in the vapor phase). In certain embodiments, “partially vaporized” can mean that about 30% to about 40% of the refrigerant is vaporized following the exchanging of heat between the refrigerant and the first process water stream. In certain embodiments, about 40% of the refrigerant is vaporized following the exchanging of heat between the refrigerant and the first process water stream.

[0028] The method 100 or 200 can further include transferring the cooled first process water stream, *e.g.*, from the first heat exchanger, to one or more process plants 102 or 202. The process plant can be any plant that uses process water for cooling the one or more reactors and/or gas streams of the process plant. For example, the cooled process water can be transferred to a process plant that produces aromatics, speciality chemicals, olefins, methanol, syngas, etc.

[0029] In certain embodiments, and with reference to FIG. 1, the method 100 can further include increasing the pressure of the partially vaporized refrigerant 103 to, for example, generate a pressurized partially vaporized refrigerant. In certain embodiments, the pressure of the partially vaporized refrigerant can be increased within a multiphase pump, *e.g.*, by transferring the partially vaporized refrigerant from the first heat exchanger to the multiphase pump. For example, and not by way of limitation, at least a portion of the partially vaporized refrigerant is transferred from the first heat exchanger to the multiphase pump. As used herein, “at least a portion” can refer to an amount greater than about 40%, greater than about 50%, greater than about 60%, greater than about 70%, greater than about 80%, greater than about 90%, greater than about 95% or greater than about 99%.

[0030] In certain embodiments, the pressure of the partially vaporized refrigerant can be increased to a pressure of about 5 bar to about 15 bar, e.g., to about 14 bar. The heat generated by the multiphase pump can increase the temperature and/or increase the percentage of the vapor phase of the partially vaporized refrigerant. After pressurization, the refrigerant can have a vapor fraction of about 55% to about 60%. In certain embodiments, the partially vaporized refrigerant can have a vapor fraction of about 55% after the increase in pressure, *e.g.*, within and/or exiting the multiphase pump. The temperature of the partially vaporized refrigerant can increase to a temperature of about 50°C to about 55°C. In certain embodiments, the temperature of the pressurized partially vaporized refrigerant can increase to a temperature of about 52°C.

[0031] Alternatively or additionally, and as depicted in FIG. 2, the method of the disclosed subject matter 200 can include separating the liquid phase from the vapor phase of the partially vaporized refrigerant 203. In certain embodiments, at least a portion of the liquid phase of the refrigerant is separated from the vapor phase of the refrigerant. The separation of the liquid phase from the vapor phase of the refrigerant can occur by transferring the partially vaporized refrigerant from the first expansion valve to a vapor-liquid separator, *e.g.*, a flash drum. In a vapor-liquid separator, a stream of a liquid/vapor mixture, *e.g.*, a multiphasic refrigerant, can be fed through a throttling valve at the entry point (feed inlet) into the vapor-liquid separator, causing rapid reduction in pressure and partial vaporization (flashing) of the liquid in the stream. Gas can be removed from a gas outlet (vapor outlet) at the top of the vapor-liquid separator while liquid can be removed from a liquid outlet at the bottom of the vapor-liquid separator. The separated vapor phase of the refrigerant can undergo compression, *e.g.*, within a gas compressor, and can be combined with the separated liquid phase to generate a partially vaporized refrigerant 204, *e.g.*, a pressurized partially vaporized refrigerant. The compressed vapor can have a temperature of about 57°C and a pressure of about 14 bar following compression. In certain embodiments, the liquid refrigerant exiting the liquid pump can have a temperature of about 9°C and a pressure of about 14 bar. In certain embodiments, the partially vaporized refrigerant obtained after the mixing of the compressed vapor refrigerant and the liquid refrigerant exiting the liquid pump can have a temperature of about 52°C and a pressure of about 14 bar.

[0032] In certain embodiments, the method 100 or 200 can further include exchanging heat between a second process water stream and the pressurized partially vaporized refrigerant 104 or 205. The heat exchange between the second process water stream and refrigerant can occur within a second heat exchanger. The second process water stream can be a process water stream exiting from a process plant, as depicted in FIGS. 3 and 4. The second process water stream can have a temperature of about 30°C to about 33°C, *e.g.*, about 31°C, prior to exchanging heat with the refrigerant. After exchanging heat with the refrigerant, the second process water stream can have a temperature of about 38°C to about 42°C, *e.g.*, about 38°C. The refrigerant can have a temperature of about outlet temperature of about 50°C to about 52°C, *e.g.*, about 51°C, and/or have an outlet vapor phase of about 40% to about 55%, *e.g.*, about 40%, after exchanging heat with the second process water stream. The refrigerant can have a vapor fraction of about 60% upon entrance into the second heat exchanger. The method can include combining the second process water stream, after heat exchange with the refrigerant, with the first process water stream, *e.g.*, prior to entrance into the first heat exchanger. The second process water stream can become the first process water stream, as depicted in FIGS. 3 and 4, to generate a closed process water loop and allow recycling of the second process water stream to the process plant.

[0033] In certain embodiments, the method 100 or 200 can further include lowering the pressure and/or temperature of the pressurized partially vaporized refrigerant 105 or 206. In certain embodiments, at least a portion of the pressurized partially vaporized refrigerant can be transferred from the second heat exchanger to a first expansion valve to lower the pressure and/or temperature of the refrigerant. For example, and not by way of limitation, the pressure of the refrigerant within and/or exiting the first expansion valve can be about 4 bar to about 5 bar, *e.g.*, about 4 bar. Alternatively or additionally, the temperature of the refrigerant within and/or exiting the first expansion valve can be about 10°C to about 13°C, *e.g.*, about 11°C. The vapor fraction of the refrigerant can increase to about 45% to about 75% of the refrigerant, *e.g.*, 45%.

[0034] The method 100 or 200 can further include separating the liquid phase from the vapor phase of the refrigerant 106 or 207. In certain embodiments, at least a portion of the liquid phase of the refrigerant is separated from the vapor phase of the refrigerant to generate a liquid refrigerant. In certain embodiments, the separation of the vapor phase from the liquid phase of the refrigerant can occur by transferring the refrigerant from the first expansion valve to a vapor-liquid separator. With reference to FIG. 1, the method 100 can include transferring the vapor phase of the refrigerant from the vapor-liquid separator to the multiphase pump. Alternatively, and in reference to FIG. 2, the method 200 can include transferring the vapor phase of the refrigerant from the vapor-liquid separator to the gas compressor.

[0035] The method 100 or 200 can include lowering the temperature of the liquid phase of the refrigerant 107 or 208, *e.g.*, to form a cooled liquid refrigerant. Such temperature lowering can include transferring at least a portion of the liquid phase of the refrigerant from the vapor-liquid separator to a second expansion valve. The liquid phase of the refrigerant within or exiting the second expansion valve can include about 1% to about 2%, *e.g.*, 1.5%, of vapor. The temperature of the liquid refrigerant can be lowered to a temperature of about 8°C to about 10°C, e.g., about 9°C. In certain embodiments, the method 100 or 200 can further include transferring the cooled refrigerant to the first heat exchanger for the cooling of the first process stream water, *e.g.*, to generate a closed-loop method for cooling process plant water.

[0036] The disclosed subject matter further provides systems for the cooling of process plant water. For example, FIGS. 3 and 4 are schematic representations of systems according to non-limiting embodiments of the disclosed subject matter. In certain embodiments, the system 300 or 400 can include a first heat exchanger 301 or 401. Heat exchangers can be used to transfer heat from one medium or phase to another. For example, and not by way of limitation, the first heat exchanger 301 or 401 of the disclosed subject matter can be used for exchanging heat between a first process water stream and the liquid refrigerant.

[0037] The heat exchangers can be of various designs known in the art. In certain embodiments, the heat exchangers can be double pipe exchangers, and can include a bundle of tubes housed in a shell, such that fluids to be warmed or cooled within the heat exchanger flow through the shell and/or bundle of tubes. In certain embodiments, the heat exchangers can include corrosion-resistant materials, an alloy, *e.g.*, steel or carbon steel, or brazed aluminum.

[0038] The first heat exchanger 301 or 401 can be coupled to one or more process plant systems 302 or 402. Non-limiting examples of process plant systems are disclosed above. “Coupled” as used herein refers to the connection of a system component to another system component by any means known in the art. The type of coupling used to connect two or more system components can depend on the scale and operability of the system. For example, coupling of two or more components of a system can include one or more joints, valves, transfer lines or sealing elements. Non-limiting examples of joints include threaded joints, soldered joints, welded joints, compression joints and mechanical joints. Non-limiting examples of valves include gate valves, globe valves, ball valves, butterfly valves and check valves.

[0039] In certain embodiments, the system 300 can further include a multiphase pump 303. The multiphase pump for use in the present disclosure can be used to pump a medium that includes multiple phases, *e.g.*, gas and liquid, to a higher pressure. The multiphase pump 303 can be used to increase the pressure of the refrigerant and can be coupled to the first heat exchanger 301. Alternatively and/or additionally, and in reference to FIG. 4, the first heat exchanger 401 can be coupled a vapor-liquid separator 403, *e.g.*, a flash drum, for the separation of the liquid and gas phases of the refrigerant. The vapor-liquid separator 403 can be further coupled to a liquid pump 409, for pumping the separated liquid phase of the refrigerant.

[0040] In certain embodiments, the system 300 or 400 can include a second heat exchanger 304 or 404 for exchanging heat between a second process water stream, *e.g.*, transferred from the process plant system 302 or 402, and the partially vaporized refrigerant. Examples of heat exchangers are disclosed above. The second heat exchanger 304 can be coupled to the multiphase pump 303. Alternatively, and in reference to FIG. 4, the second heat exchanger 404 can be coupled to the liquid pump 409 for the transfer of the liquid phase of the refrigerant from the vapor-liquid separator 403 to the second heat exchanger 404. The liquid pump 409 can be coupled to the second heat exchanger 404 via a transfer line 411. The vapor-liquid separator 403 of system 400 can be coupled to a gas compressor 410 for compressing the separated vapor phase of the refrigerant. The gas compressor 410 can, in turn, be coupled to the second heat exchanger 404 for combining the compressed vapor phase of the refrigerant with the separated liquid phase to generate a partially vaporized refrigerant and to transfer the partially vaporized refrigerant to the second heat exchanger 404. The gas compressor 410 can be coupled to the second heat exchanger 404 via the transfer line 411.

[0041] In certain embodiments, the second heat exchanger 304 or 404 can be further coupled to the first heat exchanger 301 or 401. The second heat exchanger 304 or 404 can be coupled to the first heat exchanger 301 or 401 through a liquid pump 308 or 408, *e.g.*, for the transfer of the second process water stream from the second heat exchanger 304 or 404 to the first heat exchanger 301 or 401. Non-limiting examples of liquid pumps for use in the present disclosure include peristaltic pumps, pneumatic pumps, diaphragm pumps, piston pumps, rotary pumps, centrifugal pumps, positive displacement pumps and reciprocating pumps.

[0042] The system 300 or 400 can further include a first expansion valve 305 or 405 for lowering the temperature of the partially vaporized refrigerant. Expansion valves can change the temperature of a medium, *e.g.*, a refrigerant, by altering the pressure. The pressure within the first expansion valve 305 or 405 can be in a range from about 4 bar to about 5 bar. The first expansion valve 305 or 405 can be coupled to the second heat exchanger 304 or 404.

[0043] The system 300 or 400 can further include a vapor-liquid separator, *e.g.*, a flash drum, 306 or 406 for separating the liquid and vapor phases of the refrigerant. In certain embodiments, the vapor-liquid separator 306 or 406 can be coupled to the first expansion valve 305 or 405. In certain embodiments, and in reference to FIG. 3, the vapor-liquid separator 306 can be coupled to the multiphase pump 303 for transferring at least a portion of the separated vapor phase of the refrigerant to the multiphase pump 303. Alternatively or additionally, and in reference to FIG. 4, the vapor-liquid separator 406 can be coupled to the gas compressor 410, *e.g.*, for the transfer of at least a portion of the separated vapor phase to the gas compressor 410.

[0044] The system 300 or 400 can include a second expansion valve 307 or 407 for lowering the temperature of the liquid phase of the refrigerant. The second expansion valve 307 or 407 can be coupled to the vapor-liquid separator 306 or 406. The second expansion valve 307 or 407 can also be coupled to the first heat exchanger 301 or 401 for the transfer of the refrigerant to the first heat exchanger 301 or 401, to exchange heat with the first process water stream.

[0045] The following example is illustrative of the presently disclosed subject matter and should not be considered as a limitation in any way.

EXAMPLE 1:

[0046] A simulation using the software PRO/II (Invensys Systems, Inc.) was performed to demonstrate a method for cooling process plant water according to one non-limiting embodiment of the disclosed subject matter (FIG. 3). In method simulation software such as, for example, PRO/II, each process component (*e.g.,* flash drum, heat exchanger, etc.) of a user-specified process design/system is mathematically modeled including by each piece of equipment, effluent streams, and attributes of chemical components. Interconnections and the interaction between components are also integral to the model. Table 1 shows the changes in the temperature, pressure and vapor fraction of the process plant water and refrigerant during the simulation.

[0047] The simulated method included the use of a liquid refrigerant having a temperature of 9°C to cool down a process water stream from a temperature of 38°C to a chilled water temperature of 25°C in a first heat exchanger (HX1). In this Example, the refrigerant R134A was used in the simulation. The refrigerant exiting the heat exchanger had a temperature of 6.7°C with a vapor phase fraction of 40%. The refrigerant was then combined with a vapor stream coming from a flash drum further downstream and the refrigerant was fed to a multiphase pump where the pressure of the refrigerant was raised from 3.7 bar to 13.9 bar. The heat generated from the pump increased the refrigerant temperature from an inlet temperature of 7.4°C to an outlet temperature of 52.1°C with a vapor fraction of 54.4% (Table 1).

[0048] The cooled process water was transferred to a plant process where it cooled down different streams in the plant with a total duty of 25.8 MW and exited the plant with an outlet water temperature of 31.1°C. The refrigerant was then fed to a second heat exchanger (HX2) where it is cooled down against the process water exiting the plant. The temperature of the process water increased from 31.1°C to 38°C and the refrigerant cooled to 51.5°C with vapor fraction of 41%. The process water was then pumped back to the first heat exchanger (HX1). The refrigerant was then cooled by lowering its pressure in an expansion valve (EV1) to 4.3 bar, where its temperature decreased to 11.2°C. The vapor was then separated from the liquid by a flash drum and was combined with the multiphase pump inlet feed mixture. The liquid stream was fed to a second expansion valve (EV2) where its pressure was lowered to 4 bar forming a mixture with 1.5% gas fraction with a temperature of 9°C. The mixture was recycled back to the first heat exchanger. The liquid in the mixture to the multiphase pump had a viscosity of 0.25 centipoise (cP), which is within the operating specification of the multiphase pumps.

Table 1

Stream	Flow rate (t/h)	Pressure (bar)	Temperature (°C)	Vapor fraction (%)
Inlet process water to HX1	3434.66	5.00	38.00	0.0
Outlet process water from HX1	3434.66	4.50	25.03	0.0
Inlet refrigerant to HX1	2713.41	4.00	9.04	1.5
Outlet refrigerant from HX1	2713.41	3.70	6.74	40.0
Inlet refrigerant to multiphase pump	4899.97	3.70	6.74	66.8
Outlet refrigerant from multiphase pump	4899.97	13.90	52.14	54.4
Outlet refrigerant from HX2	4899.97	13.70	51.56	41.1
Inlet process water to HX2	3434.66	4.47	31.12	0.0
Outlet refrigerant from EV1	4899.97	4.30	11.21	44.8

[0049] In addition to the various embodiments depicted and claimed, the disclosed subject matter is also directed to other embodiments having other combinations of the features disclosed and claimed herein. As such, the particular features presented herein can be combined with each other in other manners within the scope of the disclosed subject matter such that the disclosed subject matter includes any suitable combination of the features disclosed herein. The foregoing description of specific embodiments of the disclosed subject matter has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosed subject matter to those embodiments disclosed. It will be apparent to those skilled in the art that various modifications and variations can be made in the compositions and methods of the disclosed subject matter without departing from the spirit or scope of the disclosed subject matter. Thus, it is intended that the disclosed subject matter include modifications and variations that are within the scope of the appended claims and their equivalents.

CLAIMS

1. A method for cooling process plant water, the method comprising:

   (a) exchanging heat between a first process water stream and a liquid refrigerant to lower the temperature of the process water stream, thereby generating a partially vaporized refrigerant that comprises a vapor phase and a liquid phase;

   (b) increasing the pressure and/or temperature of the partially vaporized refrigerant to generate a pressurized partially vaporized refrigerant;

   (c) exchanging heat between a second process water stream and the pressurized partially vaporized refrigerant to lower the temperature of the pressurized partially vaporized refrigerant and/or increase the temperature of the second process water stream;

   (d) lowering the pressure and/or temperature of the pressurized partially vaporized refrigerant and separating out at least a portion of the liquid phase from the partially vaporized refrigerant to generate a liquid refrigerant; and

   (e) lowering the temperature of the liquid refrigerant to generate a cooled liquid refrigerant suitable for exchanging heat with the first process water stream.

2. The method of claim 1, wherein the lowering the pressure and/or temperature of the partially vaporized refrigerant portion of step (d) occurs in a first expansion valve.

3. The method of claim 1, wherein the lowering the temperature of the liquid refrigerant of step (e) occurs within a second expansion valve.

4. The method of claim 1, wherein the liquid refrigerant comprises a refrigerant having a viscosity greater than or equal to about 0.1 cP at a temperature of about $0^{o}C$.

5. The method of claim 1, wherein the liquid refrigerant comprises a refrigerant having a boiling point temperature from about $-10^{o}C$ to about $-50^{o}C$.

6. The method of claim 1, wherein the liquid refrigerant comprises a refrigerant selected from the group consisting of R134A, R404A, R407C, R125, and R410A.

7. The method of claim 1, wherein the partially vaporized refrigerant comprises a refrigerant having a vapor phase of about 30% to about 50%.

8. The method of claim 1, wherein the increasing the pressure and/or temperature of the partially vaporized refrigerant occurs within a multiphase pump.

9. The method of claim 1, further comprising transferring the cooled process water to one or more process plants.

10. The method of claim 1, wherein:

step (a) further comprises exchanging heat between the first process water stream and the liquid refrigerant within a first heat exchanger to lower the temperature of the first process water stream, thereby generating the partially vaporized refrigerant, which comprises the vapor phase and the liquid phase, upon the exchange of heat with the first process water stream;

step (b) further comprises increasing the pressure of the partially vaporized refrigerant and transferring at least a portion of the partially vaporized refrigerant to a second heat exchanger;

step (c) further comprises exchanging heat between a second process water stream and the partially vaporized refrigerant portion within the second heat exchanger to decrease the temperature of the refrigerant;

step (d) further comprises lowering the pressure and/or temperature of the partially vaporized refrigerant portion and transferring the partially vaporized refrigerant portion to a vapor-liquid separator to separate the liquid phase from the vapor phase thereof, thereby generating the liquid refrigerant; and

step (e) further comprises lowering the temperature of the liquid refrigerant and transferring at least a portion of the refrigerant to the first heat exchanger to exchange heat with the first process water stream.

11. The method of claim 10, wherein the increasing pressure of the partially vaporized refrigerant of step (b) occurs in a multiphase pump.

12. The method of claim 10, further comprising: (f) transferring at least a portion of the vapor phase of the refrigerant from the separator to the multiphase pump.

13. The method of claim 10, wherein the vapor-liquid separator comprises a flash drum.

14. A method for cooling process plant water, the method comprising:

(a) exchanging heat between a first process water stream and a liquid refrigerant within a first heat exchanger to lower the temperature of the process water stream, thereby partially vaporizing the refrigerant upon the exchange of heat with the first process water stream;

(b) transferring the first process water from the first heat exchanger to one or more process plants;

(c) transferring the partially vaporized refrigerant from the first heat exchanger to a multiphase pump to increase the pressure of the partially vaporized refrigerant;

(d) transferring the partially vaporized refrigerant from the multiphase pump to a second heat exchanger;

(e) exchanging heat between a second process water stream and the partially vaporized refrigerant within the second heat exchanger to decrease the temperature of the refrigerant;

(f) transferring the second process water stream from the second heat exchanger to become the first process water stream entering the first heat exchanger;

(g) transferring the partially vaporized refrigerant from the second heat exchanger to a first expansion valve to lower the pressure and/or temperature of the refrigerant;

(h) transferring the partially vaporized refrigerant from the first expansion valve to a vapor-liquid separator to separate the liquid phase from the vapor phase thereof, thereby generating a liquid refrigerant;

(i) transferring the liquid refrigerant from the vapor-liquid separator to a second expansion valve to lower the temperature of the liquid refrigerant; and

(j) transferring the refrigerant from the second expansion valve to the first heat exchanger to exchange heat with the first process water stream.

15. A system for exchanging heat between a first process water stream and a second process water stream with a refrigerant, the system comprising:

(a) a first heat exchanger for exchanging heat between the first process water stream and the refrigerant and thereby generate a partially vaporized refrigerant having liquid and vapor phases;

(b) a multiphase pump, coupled to the first heat exchanger, to increase the partially vaporized refrigerant pressure;

(c) a second heat exchanger, coupled to the multiphase pump and the first heat exchanger, for exchanging heat between the second process water stream and the partially vaporized refrigerant;

(d) a first expansion valve, coupled to the second heat exchanger, for lowering the lowering the pressure and/or temperature of the partially vaporized refrigerant temperature;

(e) a vapor-liquid separator, coupled to the first expansion valve and the multiphase pump, for separating the liquid and the vapor phases of the partially vaporized refrigerant; and

(f) a second expansion valve, coupled to the vapor-liquid separator and the first heat exchanger, for lowering the liquid phase temperature of the refrigerant.

16. The system of claim 15, wherein the vapor-liquid separator comprises a flash drum.

FIG. 1

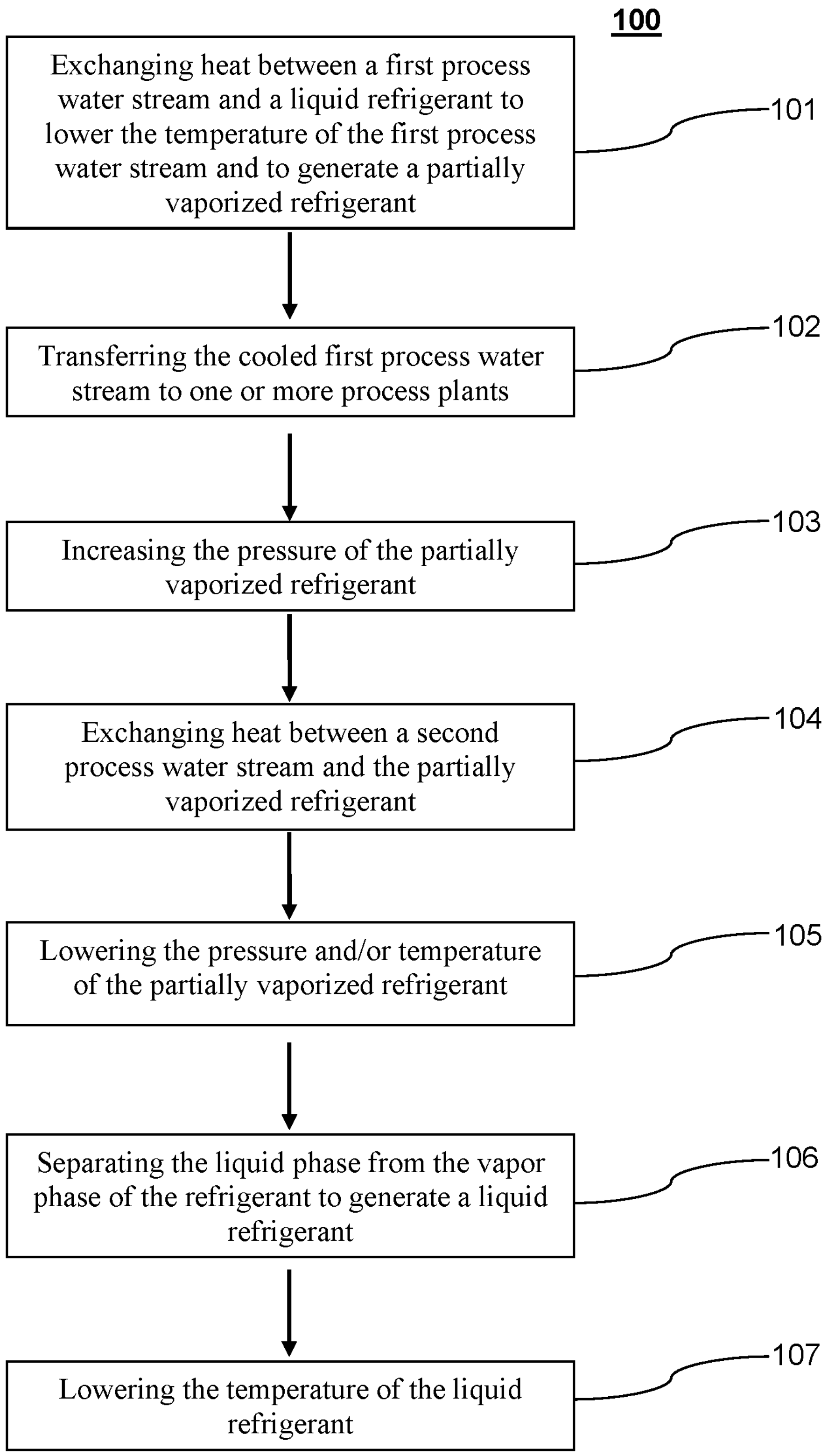

100
Exchanging heat between a first process water stream and a liquid refrigerant to lower the temperature of the first process water stream and to generate a partially vaporized refrigerant
101
Transferring the cooled first process water stream to one or more process plants
102
Increasing the pressure of the partially vaporized refrigerant
103
Exchanging heat between a second process water stream and the partially vaporized refrigerant
104
Lowering the pressure and/or temperature of the partially vaporized refrigerant
105
Separating the liquid phase from the vapor phase of the refrigerant to generate a liquid refrigerant
106
Lowering the temperature of the liquid refrigerant
107

FIG. 2

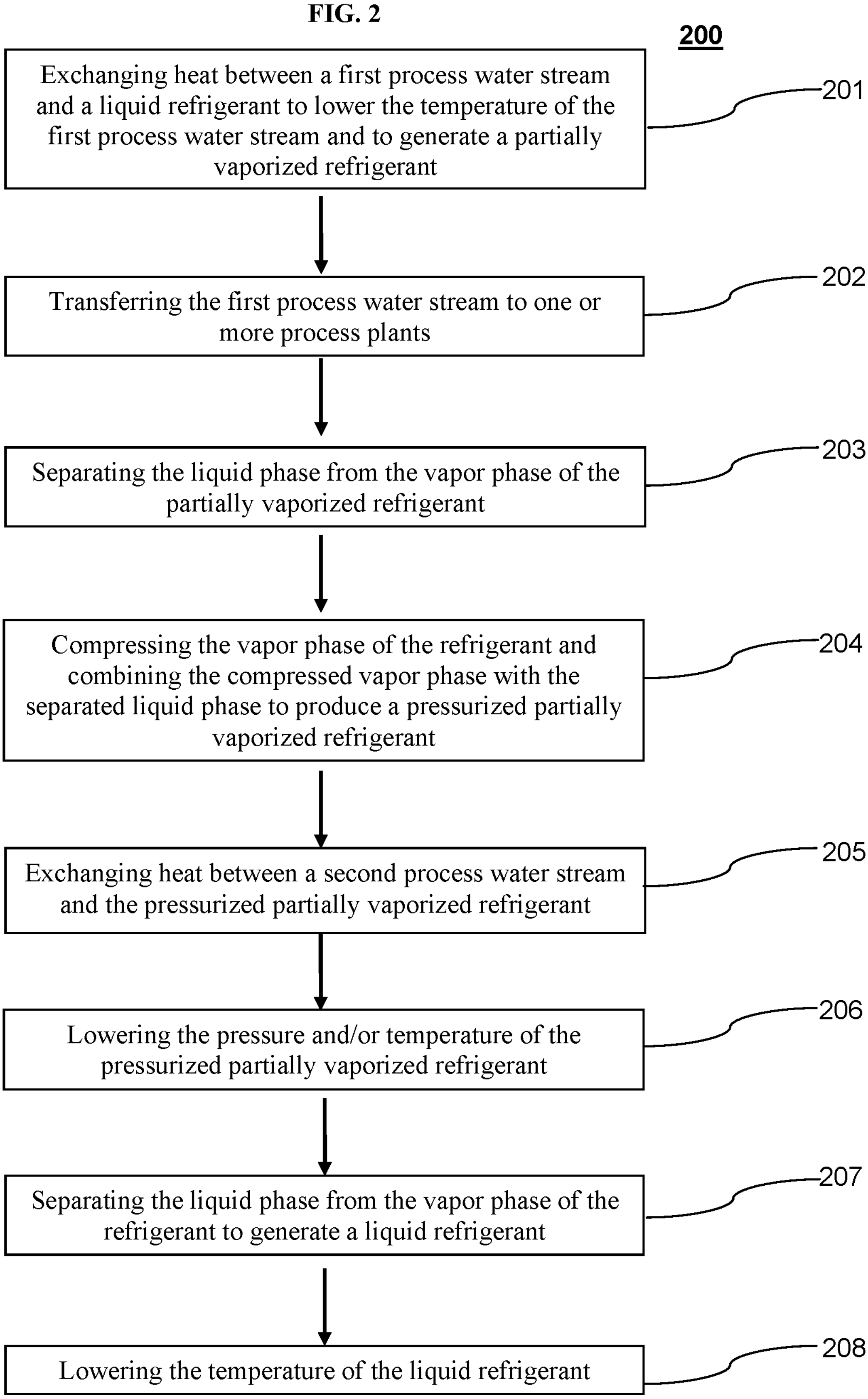

200
Exchanging heat between a first process water stream and a liquid refrigerant to lower the temperature of the first process water stream and to generate a partially vaporized refrigerant
201
Transferring the first process water stream to one or more process plants
202
Separating the liquid phase from the vapor phase of the partially vaporized refrigerant
203
Compressing the vapor phase of the refrigerant and combining the compressed vapor phase with the separated liquid phase to produce a pressurized partially vaporized refrigerant
204
Exchanging heat between a second process water stream and the pressurized partially vaporized refrigerant
205
Lowering the pressure and/or temperature of the pressurized partially vaporized refrigerant
206
Separating the liquid phase from the vapor phase of the refrigerant to generate a liquid refrigerant
207
Lowering the temperature of the liquid refrigerant
208

FIG. 3

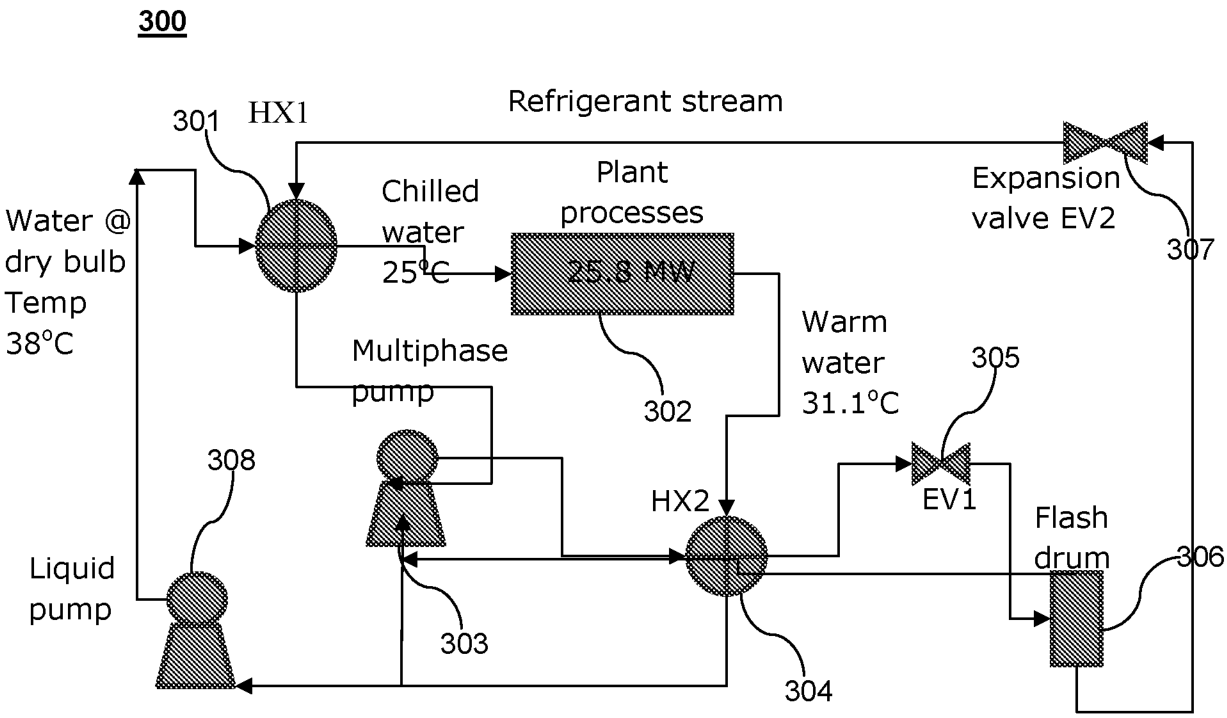
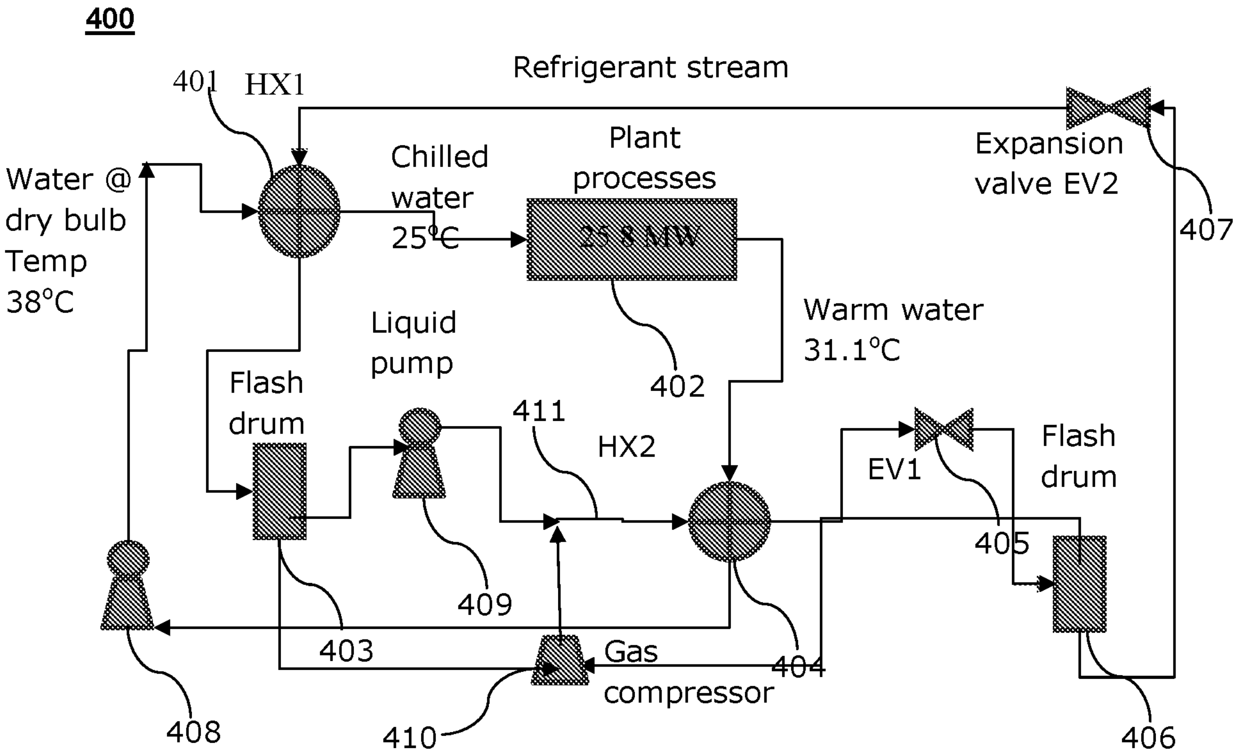

300
Refrigerant stream
301
HX1
Water @ dry bulb Temp 38°C
Chilled water 25°C
Plant processes
25.8 MW
Expansion valve EV2
307
Warm water 31.1°C
Multiphase pump
302
305
308
EV1
HX2
Flash drum
306
Liquid pump
303
304

FIG. 4


400
Refrigerant stream
401
HX1
Water @ dry bulb Temp 38°C
Chilled water 25°C
Plant processes
25.8 MW
Expansion valve EV2
407
Warm water 31.1°C
Liquid pump
402
Flash drum
411
HX2
EV1
Flash drum
405
409
403
Gas compressor
404
408
410
406

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2017/050786

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F25B 1/00; F25B 7/00; F25B 13/00 (2017.01)
CPC - F25B 1/00; F25B 7/00; F25B 13/00 (2017.02)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 62/79; 62/333; 62/498 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2014/0165626 A1 (ARKEMA INC.) 19 June 2014 (19.06.2014) entire document	1-16
A	US 2011/0138839 A1 (LEE et al) 16 June 2011 (16.06.2011) entire document	1-16
A	EP 2 224 188 A2 (LG ELECTRONICS INC.) 01 September 2010 (01.09.2010) entire document	1-16
A	US 2,963,875 A (MILLS) 13 December 1960 (13.12.1960) entire document	1-16
A	US 2010/0313582 A1 (OH et al) 16 December 2010 (16.12.2010) entire document	1-16

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 April 2017	22 MAY 2017

Name and mailing address of the ISA/US	Authorized officer
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774