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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
1 November 2012 (01.11.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/149149 A1

(51) International Patent Classification:
F28D 7/16 (2006.01) *F28F 17/00* (2006.01)
F28F 1/02 (2006.01)

(21) International Application Number: PCT/US2012/035197

(22) International Filing Date: 26 April 2012 (26.04.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/480,823 29 April 2011 (29.04.2011) US

(71) Applicant *(for all designated States except US)*: **CARRIER CORPORATION** [US/US]; 1 Carrier Place, Farmington, Connecticut 06034 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **ESFORMES, Jack, Leon** [US/US]; 5896 Invincible Drive, Jamesville, New York 13078 (US). **SISHTLA, Vishnu, M.** [US/US]; 4444 Winding Creek Road, Manlius, New York 13104 (US).

(74) Agent: **LEVY, Howard, I.**; Cantor Colburn LLP, 20 Church Street, 22nd Floor, Hartford, Connecticut 06103 (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, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, 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, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, 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, 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))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

[Continued on next page]

(54) Title: SHELL AND TUBE HEAT EXCHANGER

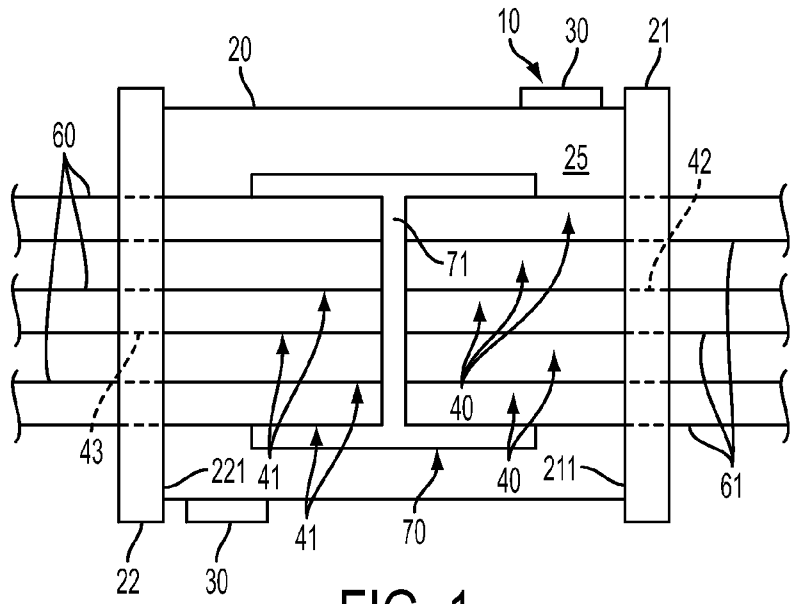

FIG. 1

(57) Abstract: A heat exchanger is provided and includes a shell extending between opposing tube sheets to define an interior, nozzles coupled to the shell by which a first fluid is communicated with the interior and a tubular body extending between the opposing tube sheets to transmit a second fluid through the interior whereby heat transfer occurs between the first and second fluids along a heat transfer portion of the tubular body defined from respective planes of opposing faces of the opposing tube sheets, the heat transfer portion having at least first and second topologies at first and second sections thereof, respectively, which are respectively disposed proximate to the respective planes of the opposing faces of the opposing tube sheets.

WO 2012/149149 A1

Published:

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

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

SHELL AND TUBE HEAT EXCHANGER

BACKGROUND OF THE INVENTION

[0001] The subject matter disclosed herein relates to a heat exchanger and, more particularly, to a shell and tube heat exchanger.

[0002] Heating and cooling systems, such as HVAC and refrigeration systems, typically employ various types of heat exchangers to regulate heating and cooling. These heat exchangers often include shell and tube or tube in tube heat exchangers or condensers. In each case, heat transfer usually occurs between fluids that are directed to flow in close proximity to one another.

[0003] For example, in a shell and tube heat exchanger, a shell forms an exterior surface of a vessel into which refrigerant vapor is introduced. Water is then directed through water tubes extending through the vessel such that heat transfer occurs between the refrigerant and the water.

[0004] Shell and tube heat exchangers typically represent about 50% of the cost of water cooled chillers and they often at least partially determine an amount of refrigerant a system will need as well as the unit footprint, both of which will tend to increase over time in response to increasing energy efficiency requirements that typically increase the size and cost of shell and tube heat exchangers. In view of this trend, shell and tube heat exchanger design improvements to date have capitalized on improved tube surfaces offered by suppliers. Unfortunately, the new tube surfaces cannot be fully optimized as the tubing is designed for a very broad operating range.

BRIEF DESCRIPTION OF THE INVENTION

[0005] According to one aspect of the invention, a heat exchanger is provided and includes a shell extending between opposing tube sheets to define an interior, nozzles coupled to the shell by which a first fluid is communicated with the interior and a tubular body extending between the opposing tube sheets to transmit a second fluid through the interior whereby heat transfer occurs between the first and second fluids along a heat transfer portion of the tubular body defined from respective planes of opposing faces of the opposing tube sheets, the heat transfer portion having at least first and second topologies at first and second sections thereof, respectively, which are respectively disposed proximate to the respective planes of the opposing faces of the opposing tube sheets.

[0006] According to another aspect of the invention, a heat exchanger is provided and includes a shell extending between opposing tube sheets to define an interior, nozzles coupled to the shell by which a first fluid is communicated with the interior and at least first and second fluidly communicative tubular bodies extending between the opposing tube sheets to transmit a second fluid through the interior whereby heat transfer occurs between the first and second fluids along respective heat transfer portions of the at least first and second tubular bodies defined from respective planes of opposing faces of the opposing tube sheets, the respective heat transfer portions of the at least first and second tubular bodies having at least first and second topologies.

[0007] According to yet another aspect of the invention, a heat exchanger is provided and includes a shell defining a first interior, a sub-cooler defining a second interior in the first interior, nozzles coupled to the shell by which a first fluid is communicated with the first and second interiors, first and second tubular bodies to transmit a second fluid through the first interior whereby heat transfer occurs between the first and second fluids along respective heat transfer portions thereof, and a third tubular body to transmit the second fluid through the second interior whereby heat transfer occurs between the first and second fluids along a heat transfer portion thereof, the heat transfer portion of the second tubular body having a different topology as compared to those of the first and third tubular bodies.

[0008] According to yet another aspect of the invention, a heat exchanger is provided and includes a shell defining an interior, nozzles coupled to the shell by which a first fluid is communicated with the interior and first and second tubular bodies to transmit a second fluid through upper and lower elevational sections of the interior, respectively, whereby heat transfer occurs between the first and second fluids along respective heat transfer portions thereof, the heat transfer portion of the second tubular body having a different topology as compared to that of the first tubular body.

[0009] These and other advantages and features will become more apparent from the following description taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWING

[0010] The subject matter which is regarded as the invention is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

[0011] FIG. 1 is a plan view of a shell and tube heat exchanger;

[0012] FIGS. 2, 3 and 4 are schematic views of the shell and tube heat exchanger of FIG. 1;

[0013] FIG. 5 is a plan view of a shell and tube heat exchanger with multiple passes;

[0014] FIG. 6 is a plan view of a shell and tube heat exchanger according to further embodiments; and

[0015] FIG. 7 is a plan view of a shell and tube heat exchanger according to still further embodiments.

[0016] The detailed description explains embodiments of the invention, together with advantages and features, by way of example with reference to the drawings.

DETAILED DESCRIPTION OF THE INVENTION

[0017] In shell and tube heat exchangers, for example, there is often a high heat flux between the temperature of the refrigerant and the temperature of the coolant at the coolant entrance to the shell. As a result, a substantial degree of heat transfer between the refrigerant and the coolant occurs at or near the coolant entrance. However, as the coolant progresses through the shell, the heat flux decreases as the temperatures of the refrigerant and the coolant approach one another. In accordance with aspects of the invention, a tubing surface in the exemplary shell and tube heat exchanger uses a multiplicity of tubing surfaces that are strategically placed. These tubing surfaces take into account the decreasing heat flux across the shell and compensate for it by way of tubing surfaces having, for example, increasing heat transfer surface area.

[0018] In an exemplary embodiment, in a flooded evaporator, three tubing surfaces could be used in place of just one common surface as is the practice today. In the first half of the entering pass, the heat exchanger would use a tube surface that is optimized for the high heat flux in that section of the heat exchanger. In the second half of the entering pass, the tube surface would be optimized for the medium heat flux in this section of the heat exchanger. Finally, in the second pass, the tube surface would likewise be optimized for the lower heat flux in this section of the heat exchanger.

[0019] These and/or other embodiments of this concept may be used independently or in combination and include different tube diameters in the same heat exchanger to better optimize the amount of external surface area and cross-sectional flow area for water flow in that section of the heat exchanger, different tube surfaces in the upper and lower half of a shell and tube arrangement where the upper half uses a tube optimized for the small amount of liquid refrigerant condensate in this region and the lower half uses a different surface that is less affected by the heavy liquid refrigerant condensate in this region, subcooler tubes in the condenser that use a different surface than the main section of the condenser and that is optimized specifically for the subcooler, a falling film bundle where different tube surfaces are used in different areas in the bundle as the film thickness changes in the direction of condensate flow and a falling film bundle where the upper region of the bundle uses tubes optimized for film evaporation and the lower region uses tubes optimized for pool boiling where the tubes are submerged in the refrigerant.

[0020] With reference to FIGS. 1 and 2, a heat exchanger is provided as, for example, a shell and tube heat exchanger 10 although it is to be understood that the overall form of the heat exchanger may be varied and need not be limited to a shell and tube configuration. The heat exchanger includes a tubular shell 20 extending between substantially planar, opposing tube sheets 21, 22 to define a shell interior 25 and nozzles 30, which are coupled to the shell 20. The nozzles 30 permit and regulate communication of a first fluid, such as refrigerant vapor, with the shell interior 25.

[0021] The heat exchanger further includes a tubular body 40 or multiple tubular bodies 40 extending between the opposing tube sheets 21, 22 to transmit a second fluid, such as water, through the shell interior 25 whereby heat transfer occurs between the first and second fluids along a heat transfer portion 41 of the tubular body 40. In a first set of embodiments, the tubular body 40 transmits the second fluid through the shell interior 25 in a single direction as a single pass heat exchanger. The heat transfer portion 41 of the tubular body 40 is the portion of the tubular body at which it is expected that a substantial portion of the heat transfer will occur and is defined along the tubular body 40 exterior surface from respective planes of opposing faces 211, 221 of the opposing tube sheets 21, 22.

[0022] In particular, it is to be understood that the tubular body 40 will be formed at opposite ends thereof with substantially smooth mating surfaces 42, 43. These mating surfaces 42, 43 can be engaged with corresponding mating surfaces of the opposing tube sheets 21, 22 by, for example, welding, brazing or metallurgical bonding, to form a tight seal between the tubular body 40 and the tube sheets 21, 22. In this way, the shell interior 25 is sealed from an exterior thereof but for access thereto for the first fluid via the nozzles 30. The mating surfaces 42, 43 generally extend from distal ends of the tubular body 40 and end axially proximate to the planes of the opposing faces 211, 221.

[0023] The heat transfer portion 41 of the tubular body 40 has at least first and second topologies 50, 51 at first and second sections 501, 511 thereof, respectively, as shown for example in FIG. 2. The first and second sections 501, 511 are respectively disposed proximate to the respective planes of the opposing faces 211, 221 of the opposing tube sheets 21, 22 and extend in axially opposite directions. That is, the first section 501 and the first topology 50 of the heat transfer portion 41 extends from the plane of the face 211 in a first axial direction and the second section 511 and the second topology 51 extends from the plane of the face 221 in a second axial direction, which is opposite to the first axial direction.

[0024] In accordance with embodiments, the first section 501 and the first topology 50 may be formed from the face 211 to a mid-section of the heat transfer portion 41 while the second section 511 and the second topology 51 may be formed from the mid-section of the heat transfer portion 41 to the face 221. In accordance with further embodiments, the mid-section may be defined at the mid-point of the tubular body 40, which can be anywhere along the tubular body 40, such that the first and second topologies 50, 51 respectively extend along respective portions or, in some cases, halves of the heat transfer portion 41. In accordance with still further embodiments, the heat transfer portion 41 may include other sections interposed between the first and second sections 501, 511. In these cases, the heat transfer portion 41 includes three or more sections and three or more topologies.

[0025] In any case, if it is assumed that the first topology 50 is associated with the coolant entrance to the shell interior 25 where heat flux is largest and the second topology 51 is associated with the coolant exit where heat flux is the lowest, then the second topology 51 will have, for example, more heat transfer surface area than the first topology 50. Where each topology is characterized by the addition of fins on the exterior surface of the tubular body 40, this means that the fins of the second topology 51 will be larger and/or more concentrated than those of the first topology 50. As such, a degree of heat transfer from the coolant entrance to the coolant exit will be substantially maintained despite a decreasing heat flux. Moreover, since the first topology 50 does not include the larger and/or more concentrated fins of the second topology 51, a cost of the tubular body 40 as a whole may be reduced. For a shell and tube heat exchanger having many tubular bodies 40 (see below), the cost reduction can result in multiplied savings.

[0026] For single pass heat exchangers, generally, the tubular body 40 may be plural in number with each tubular body 40 being arranged together in a bundle within the shell 20 to transmit the second fluid through the shell interior 25. In accordance with various embodiments, the first and second topologies 50, 51 for each plural tubular body 40 may be substantially similar or unique (i.e., different) from one another. That is, each plural tubular body 40 may have a substantially similar construction as the other plural tubular bodies 40 or each may be unique or different from one another. For example, the plural tubular bodies 40 at the outer reaches of the bundle may be provided with first and second topologies 50, 51 that differ from those of the plural tubular bodies 40 at the interior of the bundle. In a similar fashion, in order to account for refrigerant pressure gradients in an elevational direction through the shell interior 25, the first and second topologies 50, 51 of the plural tubular bodies 40 at the lower portion of the shell interior 25 may differ from the first and second topologies 50, 51 of the plural tubular bodies 40 at the upper portion of the shell interior 25. As an example, the topologies of the plural tubular bodies 40 at the lower portion of the shell interior 25 may be configured for engagement with heavy liquid refrigerant condensate and the topologies of the plural tubular bodies 40 at the upper portion of the shell interior 25 may be configured for engagement with light liquid refrigerant condensate.

[0027] The plural tubular bodies 40 receive the second fluid from entrance fluid nozzles 60 and deliver the second fluid to exit fluid nozzles 61 at the first and second sections 501, 511, respectively. The entrance and exit fluid nozzles 60, 61 may therefore be coupled to the tube sheets 21, 22 and/or to the plural tubular bodies 40. The bundle of the plural tubular bodies 40 may be held together and supported within the shell 20 by tube supports 70, which structurally support the plural tubular bodies 40 at possibly multiple axial and circumferential locations.

[0028] With reference to FIGS. 2, 3 and 4, the first and second topologies 50, 51 may include differing tube diameters, hybridized internal geometries, hybridized external geometries, differing cross-sectional flow diameters, hybridized rifling, hybridized fluting, hybridized fin arrangements, hybridized groove arrangements, hybridized baffle arrangements, hybridized surface embossments and/or combinations thereof.

[0029] For example, as shown in FIG. 2 and as described above, the first topology 50 is formed along the first section 501 and is characterized by a first rifling of an outer surface of the tubular body 40 while the second topology 51 is formed along the second section 511 and is similarly characterized by a second rifling. Since a concentration of the second rifling is, however, greater than that of the first rifling, the number of rifling grooves-lands along the second section 511 is greater than the number of rifling grooves-lands along the first section 501. As such, heat transfer surface area is more prevalent at second section 511 than at first section 501 and the degree of heat transfer encouraged by the second topology 51 is greater than that of the first topology 50. Thus, if the second fluid moves through the tubular body 40 from the first section 501 to the second section 511 and has a larger heat flux at first section 501 than at second section 511, there is a lesser need for a high degree of rifling at first section 501 than at second section 511, which is served by the hybridized rifling of FIG. 2.

[0030] FIGS. 3 and 4 illustrate further embodiments of the invention in that FIG. 3 illustrates that the tubular body 40 could be provided with differing tube diameters, D1 and D2 along the first section 501 and the second section 511, respectively, while FIG. 4 illustrates that the surface of the tubular body 40 could be provided with surface embossments of a first concentration/dimension along the first section 501 and of a second concentration/dimension along the second section 511. It is to be understood that the embodiments discussed herein and provided in the figures are merely exemplary however and that other configurations and arrangements are possible. In particular, it is understood that the change from the first topology 50 to the second topology 51 may be gradual and, in fact, may occur along the axial length of the tubular body 40 with no particular border defined between them.

[0031] It is to be further understood that, where the tubular body 40 is supported by a leg 71 of the tube supports 70, the exterior surface of the tubular body 40 may be smoothed for mating with a corresponding surface of the tube support leg 71. This is shown schematically in FIG. 2 where the tube support leg 71 contacts the relatively smooth portion of the tubular body 40 at a location along the second section 511, which is surrounded by the features of the second topology 51. As shown, the smooth surface is axially and possibly circumferentially localized at the location of the tube support leg 71 and, in the cases of the tubular body 40 being bundled, the smooth surface will generally be found only on those outermost tubular bodies 40 actually contacting the tube support legs 71.

[0032] With reference to FIG. 5 and, in accordance with another aspect of the invention, the second fluid may be transmitted through the shell 20 in at least two passes. In this case, the heat exchanger 10 includes at least first and second fluidly communicative tubular bodies 401, 402, which may each be plural in number, to transmit a second fluid through the shell interior 25 in at least two-passes whereby heat transfer occurs between the first and second fluids along respective heat transfer portions 411. That is, as shown in FIG. 5, the first tubular body 40 receives the second fluid from entrance nozzles 60 and transmits the second fluid through the shell interior 25 in a first direction toward hair-pin tubular bodies 62. The second tubular body 40 transmits the second fluid from the hair-pin tubular bodies 62 through the shell interior 25 in a second direction, which may be substantially opposite the first direction, toward the exit fluid nozzles 61. Moreover, it is to be understood that additional pass configurations are possible in which case additional tubular bodies 40 will be employed to similar effects.

[0033] The heat transfer portion 411 of the first tubular body 401 has at least a first topology 50 and the heat transfer portion 411 of the second tubular body 402 has at least a third topology 52. More particularly, as shown in FIG. 5, the heat transfer portion 411 of the first tubular body 401 has first and second topologies 50, 51 in a similar construction as that of the tubular bodies 40 discussed above while the heat transfer portion 411 of the second tubular body 402 has third and fourth topologies 52, 53. In this way, with the first tubular body 401 disposed lower than the second tubular body 402, the first topology 50 of the first tubular body 401 can be adapted for the high heat flux at the coolant entrance as well as the high refrigerant pressure in the lower section of the shell interior 25 and the second topology 51 of the first tubular body 401 can be adapted for the low heat flux at the coolant hair-pin turn as well as the high refrigerant pressure in the lower section of the shell interior 25. By contrast, the third topology 52 of the second tubular body 402 can be adapted for the low heat flux at the coolant hair-pin turn as well as the low refrigerant pressure in the upper section of the shell interior 25 and the fourth topology 53 of the second tubular body 402 can be adapted for the high heat flux at the coolant entrance (now, the coolant exit) as well as the low refrigerant pressure in the upper section of the shell interior 25.

[0034] In accordance with yet another aspect of the invention and, with reference to FIG. 6, a shell and tube heat exchanger is provided as a condenser 600. The condenser 600 includes a shell 610 defining a first interior 611 and a sub-cooler 620 defining a second interior 621 in a lower elevational section of the first interior 611. An upper nozzle 630 and a lower nozzle 631 are coupled to the shell 610 such that a first fluid, such as refrigerant vapor, is communicated with the first and second interiors 611, 621 from an upper elevational location towards a lower elevational location.

[0035] First and second tubular bodies 640, 641 transmit a second fluid, such as water, through the first interior 611 whereby heat transfer occurs between the first and second fluids along the heat transfer portion 650 of the first tubular body 640 and the heat transfer portion 651 of the second tubular body 641. The first tubular body 640 is disposed within the upper elevational section of the first interior 611 and the second tubular body 641 is disposed below the first tubular body 640 within the first interior 611. As such, as the first fluid is communicated with the first interior 611, the first fluid may be communicated as vapor to the first tubular body 640 where the first fluid contacts the first tubular body 640 and condenses to form liquid. This liquid then falls toward the second tubular body 641 and interferes with contact between remaining first fluid vapor and the second tubular body 641.

[0036] A third tubular body 642 is disposed proximate to the lower elevational section of the first interior 611 and within the sub-cooler 620. That is, the second tubular body 641 is elevationally interposed between the first and third tubular bodies 640, 642. In this position, the third tubular body 642 transmits the second fluid through the second interior 621 and heat transfer occurs between the first and second fluids along a heat transfer portion 652 of the third tubular body 642. Since the first fluid is communicated with the second interior 621 in large part as a vapor in accordance with known sub-cooling methods, the problem of liquid interference between the first fluid and the third tubular body 642 may be avoided.

[0037] In accordance with embodiments, the heat transfer portion 651 of the second tubular body 641 has a unique or different topology at least as compared to the topologies of the respective heat transfer portions 650, 652 of the first and third tubular bodies 640, 642. This unique topology may, for example, include drainage grooves 660 and/or other similar features that encourage removal of the liquid phase first fluid from the heat transfer portion 651 of the second tubular body 641. The topologies of the respective heat transfer portions 650, 652 of the first and third tubular bodies 640, 642 may be similar to one another.

[0038] In accordance with yet another aspect of the invention and, with reference to FIG. 7, a shell and tube heat exchanger is provided as a condenser 700. The condenser 700 includes a shell 710 defining an interior 711. An upper nozzle 730 and a lower nozzle 731 are coupled to the shell 710 such that a first fluid, such as refrigerant vapor, is communicated with the interior 711 from an upper elevational location towards a lower elevational location.

[0039] First and second tubular bodies 740, 741 transmit a second fluid, such as water, through the interior 711 whereby heat transfer occurs between the first and second fluids along the heat transfer portion 750 of the first tubular body 740 and the heat transfer portion 751 of the second tubular body 741. The first tubular body 740 is disposed within an upper elevational section of the interior 711 and the second tubular body 741 is disposed below the first tubular body 740 within a lower elevational section of the interior 711. As such, as the first fluid is communicated with the interior 711, the first fluid may be communicated as vapor to the first tubular body 740 where the first fluid contacts the first tubular body 740 and condenses to form liquid. This liquid then falls toward the second tubular body 741 and interferes with contact between remaining first fluid vapor and the second tubular body 741.

[0040] In accordance with embodiments, the first tubular body 740 is provided as a low performance tube whereas the second tubular body is provided as a high performance tube. That is, the heat transfer portion 751 of the second tubular body 741 has a unique or different topology at least as compared to the topology of the heat transfer portion 750 of the first tubular bodies 740. This unique topology may, for example, include drainage grooves 760 and/or other similar features that encourage removal of the liquid phase first fluid from the heat transfer portion 751 of the second tubular body 741 or otherwise increase a degree of heat transfer permitted across the heat transfer portion 751 of the second tubular body 741. By contrast, the topology of the heat transfer portion 750 of the first tubular body 740 may be characterized by, for example, a uniform tubular surface. In this way, by using some high performance tubular bodies in locations where they are most effective and some low performance tubular bodies in locations where high performance is of limited utility, costs for the condenser 700 may be limited.

[0041] While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

CLAIMS:

1. A heat exchanger, comprising:

a shell extending between opposing tube sheets to define an interior;

nozzles coupled to the shell by which a first fluid is communicated with the interior; and

a tubular body extending between the opposing tube sheets to transmit a second fluid through the interior whereby heat transfer occurs between the first and second fluids along a heat transfer portion of the tubular body defined from respective planes of opposing faces of the opposing tube sheets,

the heat transfer portion having at least first and second topologies at first and second sections thereof, respectively, which are respectively disposed proximate to the respective planes of the opposing faces of the opposing tube sheets.

2. The heat exchanger according to claim 1, wherein the tubular body is plural in number.

3. The heat exchanger according to claim 2, wherein the first and second topologies for each plural tubular body are substantially similar.

4. The heat exchanger according to claim 2, wherein the at least first and second topologies for each plural tubular body are different from one another.

5. The heat exchanger according to claim 1, wherein the first section extends substantially from the first end of the heat transfer portion to a mid-section thereof and the second section extends substantially from the mid-section to the second end of the heat transfer portion.

6. The heat exchanger according to claim 1, further comprising:

fluid nozzles to deliver the second fluid to the tubular body; and

tube supports to structurally support the tubular body.

7. The heat exchanger according to claim 1, wherein the at least first and second topologies comprise differing tube diameters, hybridized internal geometries and/or hybridized external geometries.

8. A heat exchanger, comprising:

a shell extending between opposing tube sheets to define an interior;

nozzles coupled to the shell by which a first fluid is communicated with the interior; and

at least first and second fluidly communicative tubular bodies extending between the opposing tube sheets to transmit a second fluid through the interior whereby heat transfer occurs between the first and second fluids along respective heat transfer portions of the at least first and second tubular bodies defined from respective planes of opposing faces of the opposing tube sheets,

the respective heat transfer portions of the at least first and second tubular bodies having at least first and second topologies.

9. The heat exchanger according to claim 8, wherein the first and second tubular bodies are each plural in number.

10. The heat exchanger according to claim 9, wherein the at least first topologies for each plural first tubular body are substantially similar and the at least second topologies for each plural second tubular body are substantially similar.

11. The heat exchanger according to claim 9, wherein the at least first topologies for each plural first tubular body are different from one another and the at least second topologies for each plural second tubular body are different from one another.

12. The heat exchanger according to claim 8, wherein the first and second tubular bodies are disposed in lower and upper sections of the interior, respectively, with the second tubular body being downstream from the first tubular body.

13. The heat exchanger according to claim 12, wherein the respective heat transfer portion of the first tubular body has one or more topologies.

14. The heat exchanger according to claim 12, wherein the respective heat transfer portion of the second tubular body has one or more topologies.

15. The heat exchanger according to claim 8, further comprising:

fluid nozzles to deliver the second fluid to the tubular body;

tube supports to structurally support the tubular body; and

hair-pin tubular bodies to fluidly couple the first and second tubular bodies to one another.

16. The heat exchanger according to claim 8, wherein the at least first and second topologies comprise differing tube diameters, hybridized internal geometries and/or hybridized external geometries.

17. A heat exchanger, comprising:

a shell defining a first interior;

a sub-cooler defining a second interior in the first interior;

nozzles coupled to the shell by which a first fluid is communicated with the first and second interiors;

first and second tubular bodies to transmit a second fluid through the first interior whereby heat transfer occurs between the first and second fluids along respective heat transfer portions thereof; and

a third tubular body to transmit the second fluid through the second interior whereby heat transfer occurs between the first and second fluids along a heat transfer portion thereof,

the heat transfer portion of the second tubular body having a different topology as compared to those of the first and third tubular bodies.

18. The heat exchanger according to claim 17, wherein the second tubular body is elevationally interposed between the first and third tubular bodies.

19. The heat exchanger according to claim 17, wherein the heat transfer portions of the first and third tubular bodies have similar topologies.

20. The heat exchanger according to claim 17, wherein the topology of the heat transfer portion of the second tubular body encourages liquid drainage.

21. A heat exchanger, comprising:

a shell defining an interior;

nozzles coupled to the shell by which a first fluid is communicated with the interior; and

first and second tubular bodies to transmit a second fluid through upper and lower elevational sections of the interior, respectively, whereby heat transfer occurs between the first and second fluids along respective heat transfer portions thereof,

the heat transfer portion of the second tubular body having a different topology as compared to that of the first tubular body.

22. The heat exchanger according to claim 21, wherein the second tubular body comprises a high performance tubular body.

23. The heat exchanger according to claim 22, wherein the first tubular body comprises a low performance tubular body.

24. The heat exchanger according to claim 21, wherein the topology of the heat transfer portion of the second tubular body encourages liquid drainage.

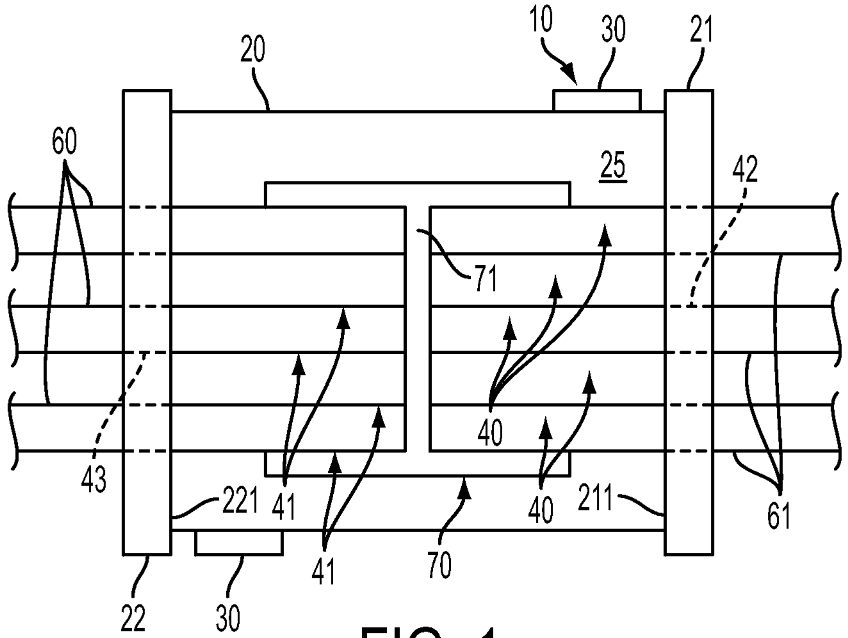

FIG. 1

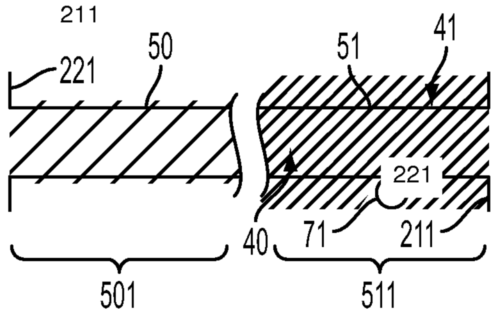

FIG. 2

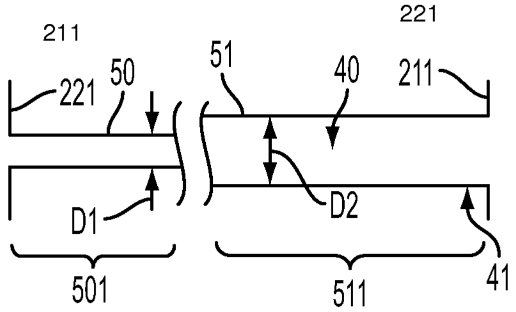

FIG. 3

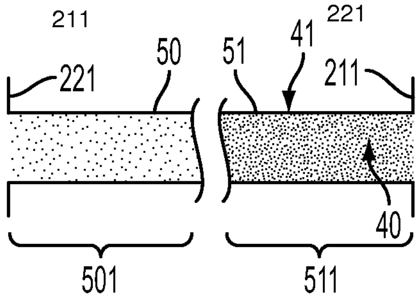

FIG. 4

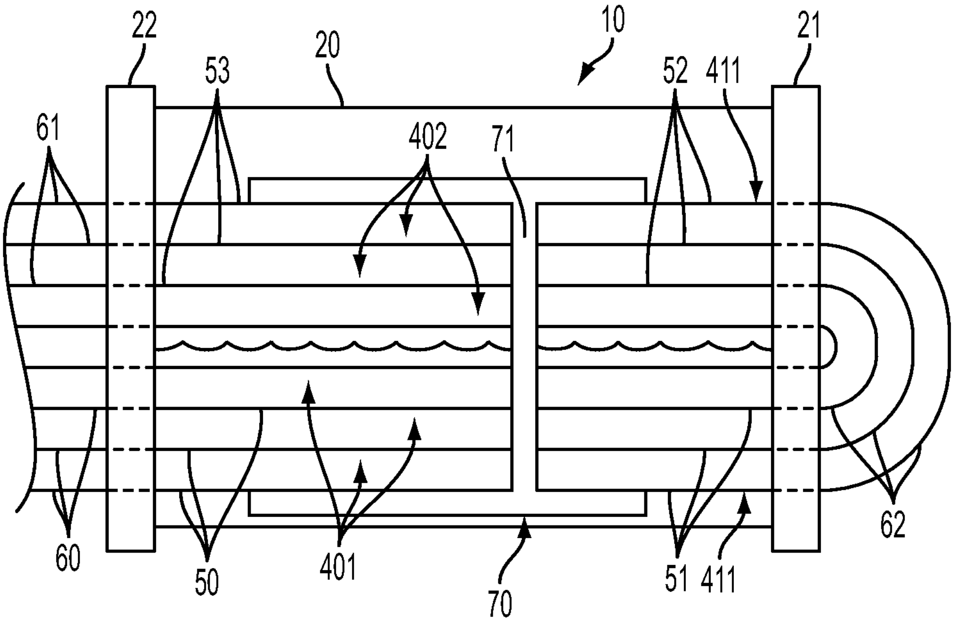
22
53
20
10
52
411
21
61
402
71
60
50
401
70
51
411
62

FIG. 5

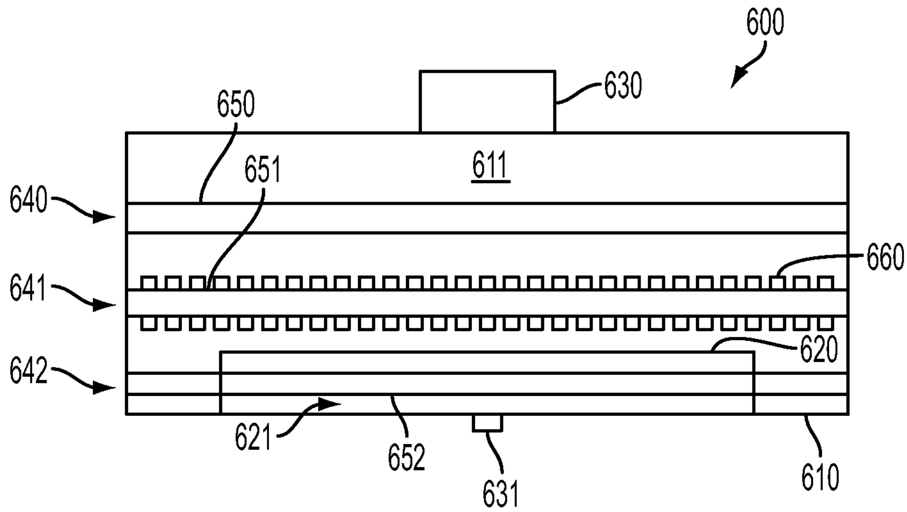
600
630
650
611
651
640
641
660
642
620
621
652
631
610

FIG. 6

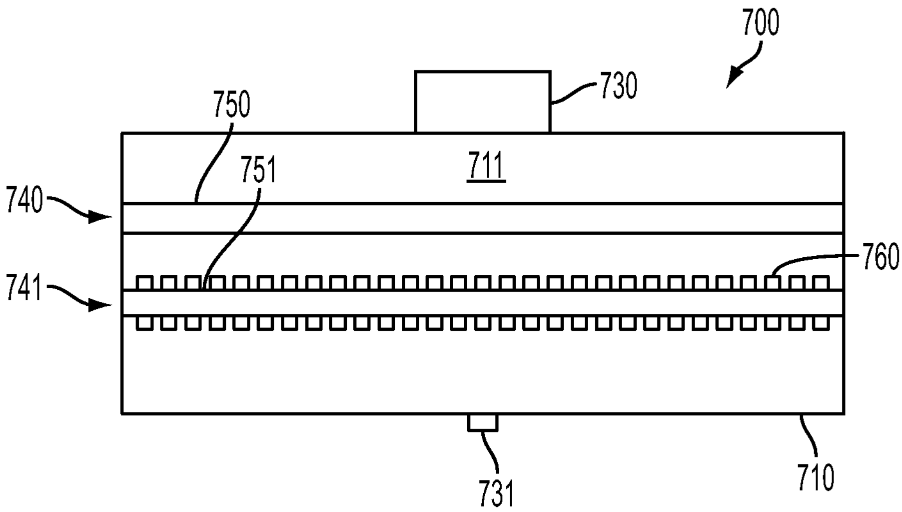

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/035197

A. CLASSIFICATION OF SUBJECT MATTER
INV. F28D7/16 F28F1/02 F28F17/00
ADD.

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)
F28D F28F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/083619 A1 (MASTER BASHIR I [US] ET AL) 14 April 2011 (2011-04-14) paragraph [0015] - paragraph [0024] -----	1-24
X	DE 10 2007 062826 A1 (BEHR GMBH & CO KG [DE]) 25 September 2008 (2008-09-25) paragraph [0019] - paragraph [0022]; figure 3 -----	1-24
A	JP 57 187589 A (HITACHI ENG SERVICE) 18 November 1982 (1982-11-18) figure 3 -----	1-24
A	US 2008/236803 A1 (CAO JIANYING [CN] ET AL) 2 October 2008 (2008-10-02) figure 10 -----	1-24

☐ 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
14 September 2012	26/09/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Bain, David

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2012/035197

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011083619 A1	14-04-2011	US 2011083619 A1	14-04-2011
		WO 2011043779 A1	14-04-2011
DE 102007062826 A1	25-09-2008	NONE	
JP 57187589 A	18-11-1982	NONE	
US 2008236803 A1	02-10-2008	NONE	