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(54) Title: FINNED TUBE WITH INDENTATIONS

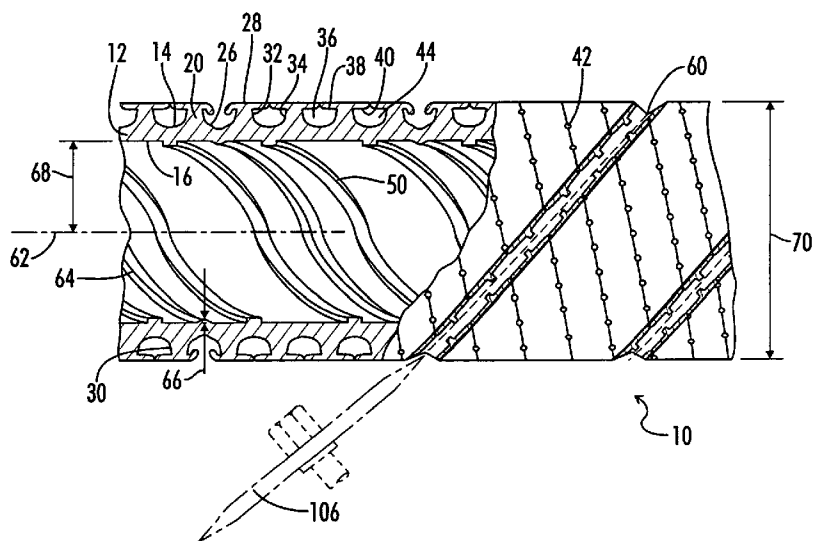


FIG. 6

(57) Abstract: A tube used for heat transfer has adjacent fins extending from an outer surface of the tube with a channel between the fins. The fins include a roof formed over the channel, and holes penetrate the roof into the channel. The fin, including the roof, is monolithic with the tube body. Helical ridges are formed on a tube inner surface, and the tube body includes an indentation in the outer surface which extends the tube body inner surface towards a tube axis.

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FINNED TUBE WITH INDENTATIONS

This invention claims priority to Chinese Patent Application Number ZL200720068218.6, which was filed on March 27, 2007.

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The current invention describes finned tubes used for heat transfer, such as the tubes used in shell and tube heat exchangers.

Description of the Related Art

[0002] Finned tubes have been used for heat transfer for many years. Heat flows from hot to cold, so heat transfer is accomplished by conducting heat from a warmer material to a cooler material. There is also heat given off when a material condenses from a vapor to a liquid, and heat is absorbed when a liquid vaporizes or evaporates from a liquid to a vapor. When finned tubes are used for heat transfer, the warmer material is on either the inside or the outside of the tube and the cooler material is on the other side. Usually the tube allows for the transfer of heat without mixing the warmer and cooler materials.

[0003] For cooling purposes, a cooling medium can be a liquid such as cooling water flowing through a shell and tube heat exchanger, or it can be a gas such as air blown over a finned tube. Similarly, a heating medium is usually either a liquid or a gas. Finned tubes are sometimes used instead of relatively smooth tubes because finned tubes tend to increase the rate of heat transfer. Therefore, a smaller heat exchanger with finned tubes may be able to transfer as much heat in a given application as a larger heat exchanger with relatively smooth tubes. The

design of finned tubes affects the rate of heat transfer and sometimes the tubes are designed differently for specific heat transfer applications. For example, finned tubes used for condensation tend to have different designs than finned tubes used for evaporation.

[0004] Examples of the prior art include finned tubes with helical fins formed on an outer surface of the tube. The tops of the fins have at least one groove to divide the fin top into at least two parts, thus forming a “Y” shape along the length of the fin. The fins can also be notched across the fin, and then helical indentations are formed by pressing into the tube outer surface. The fins are broken where the indentations are formed, and beads are formed on a tube inner surface where the fin is pressed down into the tube body. There are a plurality of beads formed on the inner surface along an imaginary line corresponding to where the indentation in the tube is formed.

[0005] Finned tubes also include fins formed to promote boiling on the outer surface. The fins are deformed at the top to essentially close off the channels defined between adjacent fins, except the closed off channels are open to the outside through pores penetrating into the channels. The pores can be of varying sizes, and there can be more than one sized pore on a single tube. There are a wide variety of finned tubes for evaporation which include various permutations of closed off channels between adjacent fins, with some sort of hole or pore penetrating into the closed off channels.

[0006] Some finned tubes are produced by attaching fin material to a relatively smooth tube so the fins are not formed from the material of the tube body. This increases the area available for heat transfer, which does improve heat transfer rates, but the interface between the fin and the tube does cause some resistance to heat flow. The fins attached to the tube can

extend radially from a tube axis so they stand straight up from the tube, but they can also be curved or bent in various ways to improve heat transfer.

[0007] Finned tubes are often used in evaporators, such as those used in air conditioners. Most air conditioning evaporators are a flooded type of evaporator, where the finned tube is submerged in a pool of liquid refrigerant. The surface of a tube in a flooded evaporator is constantly wet with the refrigerant, and evaporated gas bubbles through the liquid pool to escape. It is also possible to use a drip evaporator, where the liquid refrigerant is circulated and dripped or sprayed on top of the tubes, and the tubes are not immersed in liquid. This allows for the use of less refrigerant, and tends to be more energy efficient. Keeping all areas of the heat transfer tube wet improves the boiling efficiency of a drip evaporator, and tube designs which improve the wetted area of a tube are beneficial.

[0008] There are many designs of finned tubes in existence, but changes which improve heat transfer are still possible.

BRIEF SUMMARY OF THE INVENTION

[0009] A tube used for heat transfer has adjacent fins extending from an outer surface of the tube with a channel between the fins. The fins are formed from the material of the tube outer surface, so the fins are monolithic with the tube body. The fins include an upper portion which is deformed into a roof over the channel, and there are holes penetrating the roof into the channel. Helical ridges are formed on a tube inner surface, and an indentation is defined in the tube body outer surface that extends the tube body inner surface towards a tube axis.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

- [0010] Fig. 1 is a side view of a tube with indentations.
- [0011] Fig. 2 is the enlarged portion from the circle labeled "2" in Fig. 1. Fig. 2 shows a side sectional view of a tube with indentations with the details of the fins and ridges not shown.
- [0012] Fig. 3 is the enlarged portion from the rectangle labeled "3" in Fig. 2. Fig. 3 shows a side sectional view of a finned tube.
- [0013] Fig. 4 is a side sectional view of a finned tube.
- [0014] Fig. 5 is a perspective view of a portion of a finned tube.
- [0015] Fig. 6 is a side partial sectional view of a finned tube with indentations.
- [0016] Fig. 7 is a side view of one embodiment of a tube with an indentation.
- [0017] Fig. 8 is a side view of a second embodiment of a tube with indentations.
- [0018] Fig. 9 is a side view of a third embodiment of a tube with indentations.
- [0019] Fig. 10 is a side partial sectional view of heat exchanger.
- [0020] Fig. 11 is a side partial sectional view of an arbor forming a finned tube with material from a fin in front of a tooth on the notching disc.
- [0021] Fig. 12 is a side partial section view of an arbor forming a finned tube showing a notching disc tooth forming a notch in a fin.

DETAILED DESCRIPTION

[0022] The finned tube of the current invention is intended to be used for heat transfer, and primarily for phase change on the tube outer surface. This tube is designed to especially enhance boiling or evaporation, but it could also be used for condensation or non-phase change heat transfer. The tube is designed to promote boiling on the tube outer surface with a heating medium, such as a liquid, flowing inside the tube. The heating medium is cooled by the evaporation on the tube outer surface. The tube is often utilized in the construction of shell and tube heat exchangers, but other uses are possible.

Heat Transfer Principles

[0023] The following discussion is directed towards evaporation, and particularly towards evaporation using a drip type evaporator. The current invention could also be used for other heat transfer applications as well, and this discussion is not intended to limit the scope of the invention.

[0024] When heat is transferred from one material to another material, the larger the temperature difference between the two materials, the faster the rate of heat transfer. This basically means if you want to heat something up faster, put it against a hotter surface, and if you want to cool something off faster, put it against a colder surface. This is true for a conductive material or an insulating material.

[0025] A refrigerant on the tube exterior absorbs the heat of vaporization as it changes from a liquid to a gaseous state, and this heat of vaporization is ultimately absorbed from the liquid flowing inside the tube. This cools the liquid in the tube. The design of the fins on the

tube outer surface increase heat transfer by several different mechanisms. The fins increasing surface area of the tube, and the fins form boiling nucleation sites which serve to promote boiling. The more surface area on a condensing tube, the more rapid the flow of heat. When fins are formed on a tube it increases the surface area of the tube, which serves to increase the rate of heat transfer across the tube. Other deformations in the tube outer surface which increase surface area will also tend to increase the rate of heat transfer.

[0026] When heat is transferred from a liquid inside a tube to a vapor formed by boiling a liquid on the tube outside, the heat transfer is considered in several distinct steps. The same basic steps apply when heat is transferred through a barrier, such as a tube wall, between any two mediums with different temperatures. The first step is transfer of heat from the liquid inside the tube to the tube inner surface. Liquid flowing through the tube tends to form an essentially stagnant layer on the tube inner surface. In laminar flow, there is a second liquid layer next to the stagnant layer that is moving slowly, or just sliding by the stagnant layer. Then there is a third layer next to the second, which is moving a little bit faster, and so on such that the fastest flowing liquid is furthest from the tube wall. These layers tend to insulate the tube wall and hinder the flow of heat.

[0027] In turbulent flow, there is still a stagnant layer next to the inside tube wall, but the rest of the liquid is flowing and mixing together as one large mass. The stagnant layer still tends to insulate the tube from the main body of the liquid, but the mixing promotes heat transfer by keeping a larger temperature differential between the stagnant layer and the next liquid layer. In either case, anything which disturbs the static layer or promotes more mixing helps to reduce the insulating effect within the tube, and therefore increases the rate of heat transfer.

[0028] After heat is transferred from the main body of liquid to the stagnant layer, it has to flow across the stagnant layer. Then, heat has to flow across the interface between the stagnant layer and the tube inner surface. Any interface provides some resistance to heat flow. After heat flows to the tube inner surface, it has to flow through the tube to the tube outer surface. To facilitate this heat flow, heat transfer tubes are usually made out of a material which readily conducts heat, or a heat conductor. Copper is one material which is considered to be a good conductor of heat. Then, the heat flows across the interface between the tube outer surface to any liquid contacting the outer surface. There can be heat flow across a stagnant liquid layer on the tube outer surface, and then the liquid absorbs the heat and boils. The boiling liquid absorbs a specific amount of heat, called the heat of vaporization, to change from the liquid state to the vapor state.

[0029] An interface between the fins and the tube exists if the fins are constructed separately from the tube, and then attached. This is true if the fin and tube are constructed of the same material, such as copper, or from different materials. Any interface causes some resistance to heat flow. If the fins are formed from the tube wall, there is no interface and heat flow is improved. In this discussion, fins formed from the tube wall are referred to as being monolithic with the tube, and it is preferred that fins be monolithic with a tube to minimize resistance to heat flow.

[0030] The tube should be made from a malleable substance so the fins can be formed from the tube without cracks or breaks forming in the tube wall. Cracks or breaks limit the structural integrity and strength of a tube, and can also provide resistance to heat flow. Generally these tubes are used in shell and tube heat exchangers, and the ends of the tubes are affixed in tube sheets of the heat exchanger. A malleable tube can be easier to install in a heat exchanger

tube sheet. The tube should also be constructed from a material which readily conducts heat. Copper is often used in tube construction because of its malleability and heat conducting

Special Evaporation Principles

[0031] Evaporation tubes have specific design features which are different than those features preferred for a condensation tube. Evaporation tubes are typically immersed in the liquid to be evaporated, so the tube outer surface is constantly wet. Factors which can enhance evaporation include providing a nucleation site for the initial formation of bubbles, providing enclosed areas where liquid can be superheated, and providing holes or access ports to the enclosed areas where vapor can escape and more liquid can be introduced.

[0032] Nucleation sites for boiling are often very small imperfections or sharp points on the boiling surface. An enclosed area on a tube provides for a relatively small quantity of liquid to be essentially surrounded by heat transferring surfaces from the finned tube, so the amount of heat transfer surface area per volume of liquid is large. This allows for the liquid to be rapidly heated to facilitate boiling or vaporization. This can result in the liquid being temporarily superheated, which is when the temperature of the liquid is greater than the liquid's boiling temperature. Vapors are less dense than liquids, so when a liquid vaporizes it expands. If the vaporizing liquid is enclosed, it produces pressure as it vaporizes. Vapors also expand as they are heated, so heating of a vapor in an enclosed area also increases pressure.

[0033] Small holes in the enclosed area allow for the small quantity of liquid to escape after it has vaporized, and the pressure from vaporization tends to push the vapor out of the hole. Normally, surface tension would reduce liquid flow through small holes, unless there is a large enough pressure difference to force or push the liquid through the hole. The escaping vapor

leaves a reduced pressure in the enclosed area, which draws liquid in through the small holes after the vapor has escaped, and the process repeats. This serves as a sort of pumping action, where liquids are drawn into enclosed area, vaporized, and pushed out of the enclosed areas.

[0034] The small hole in the enclosed area has to be small enough to prevent a liquid from freely flowing through the hole. The small holes can be one continuous hole, as long as it serves to prevent the liquid from freely flowing into the enclosed area. To prevent a liquid from flowing through a continuous hole or a series of small holes, there must be a hole gap small enough that the liquid surface tension prevents the liquid from passing. Reference in this description to several small holes is intended to include one long hole with a gap small enough to prevent liquid from flowing through, such that the long hole serves the same function as several small holes. The long hole serves essentially as several small holes which are connected together.

Finned Tube Main Body

[0035] One embodiment of the finned tube **10** of the current invention is shown in different perspectives in Figures 1, 2 and 3. This discussion focuses on the embodiment shown, but this discussion is not intended to be limiting. Other embodiments are possible, and will be apparent to one skilled in the art.

[0036] The tube **10** includes a main body **12** which has an outer surface **14** and an inner surface **16**. The main body **12** is the base for any shapes or structures on the outer or inner surface **14**, **16**. This main body **12** should be made of a material which conducts heat readily. Metals are generally good conductors and are frequently used for the construction of tubes of the current invention. Copper is a particularly common metal used for tube **10** construction, but

aluminum, other metals, various alloys and even non-metallic materials are also possible. The material should also be malleable or formable such that the various structures on the inner and outer surface 14, 16 can be formed without damaging the integrity of the tube body 12. This allows for the structures to be formed from the tube body 12, which results in the structures being monolithic with the tube body 12.

Tube Fins

[0037] The tube 10 has at least one fin 20 formed on its outer surface 14. The fin 20 generally protrudes or extends circumferentially from the tube body outer surface 14, and is usually helical. The tube 10 often has a first end 22 and a second end 24 without any fins 20 which facilitates forming a seal between a tube end 22, 24 and a heat exchanger tube sheet. These ends 22, 24 are generally smooth. There is typically some transition area between the smooth ends 22, 24 and the finned portion of the tube 10.

[0038] It is possible that one single fin 20 is helically wound around the entire length of the finned portion of the tube 10. It is also possible that there will be a plurality of fins 20 helically winding around the tube 10. In either case, when looking at a section of the tube body outer surface 14, it will appear as though there are several adjacent circumferential fins 20 protruding from the tube body outer surface 14. When viewed along the axial direction of the tube 10, fin 20 sections next to each other are referred to as adjacent fins 20, despite the fact that they might be the same fin 20 helically wrapping around the tube body outer surface 14. The fin 20 is formed from the material of the tube body 12, so the fin 20 is monolithic with the tube body 12.

[0039] Each fin 20 has several parts including a fin base 26, a fin top 28, and a fin side wall 30. The fin base 26 is at the point where the fin 20 connects to the tube body outer surface 14. The fin top 28 is opposite the fin base 22 and is the highest point of the fin 20 relative to an axis of the tube 62. The fin side wall 30 includes a left side wall 32 and a right side wall 34 opposite the left side wall 28. A channel 36 is defined between two adjacent fins 20 over the tube body 12 such that the channel 36 is between a right side wall 34 of one fin 20 and a left side wall 32 of an adjacent fin 20. The fin 20 can be approximately perpendicular to the tube body 12 such that the fin 20 extends essentially straight out from the tube body outer surface 14. In such a case, the fin 20 would extend radially from the tube 10. It is also possible for the fin 20 to be positioned at other angles to the tube body outer surface 14.

[0040] The fin 20 also has a fin upper portion 38, which is deformed or molded from the fin 20 to form a roof 40 over the channel 36. The fin upper portion 38 can be split to extend both left and right of the fin 20, as in Fig. 3, or the fin upper portion 38 can be deformed in just one direction from the fin 20, as shown in Figs. 4 and 5. The roof 40 does not have to completely cover the channel 36, and there should be holes 42 or pores 42 defined by and penetrating the roof 40 to into the channel 36. Notches 43 can be formed in the fin top 28 to define the holes 40, but the holes 40 can be formed in other ways as well. The roof 40, the left and right fin side walls 32, 34, and the tube body outer surface 14 define a boiling cavity 44, which is basically an enclosed channel 36.

[0041] The boiling cavity 44 is very effective at promoting boiling or evaporation on the tube exterior. Liquid in the boiling cavity 44 is surrounded on four sides by tube surfaces which transfer heat to the liquid. The tube surfaces facing the liquid in the boiling cavity 44 are the tube outer surface 14, the left and right fin side walls 30, 32, and the roof 40. A liquid droplet in

the boiling cavity 44 has a relatively low volume with a relatively high surface area in contact with the boiling cavity surfaces 14, 30, 32, 40, which results in the liquid being heated rapidly. As the liquid boils and turns into a gas, it expands and increases the pressure inside the boiling cavity 44. This forces the boiled gas out through a roof hole 42, and the exiting gas leaves a partial vacuum or low pressure inside the boiling cavity 44.

[0042] The partial vacuum inside the boiling cavity 44 facilitates motion. The partial vacuum pulls and moves drops of liquid inside the boiling cavity 44 which were next to the exiting gas into the location where the exiting gas was, which serves to agitate the moving liquid drop and thereby promote heat transfer. Also, when the vaporized gas exits the boiling cavity 44, the low pressure produced pulls more liquid from somewhere along the outside of the cavity 44 through a roof hole 42 into the cavity 44. Without the low pressure in the boiling cavity 44, surface tension would tend to prevent liquids from readily passing through the roof holes 42 into the boiling cavity 44, so the pressure has to be enough to overcome the liquid surface tension. This action of moving and mixing liquids inside the boiling cavity 44 combined with pushing out vaporized gas and pulling in additional outside liquids is referred to as a pumping action, and it greatly increases the rate of heat transfer and vaporization of liquids.

[0043] The fin 20 can be deformed or shaped in a wide variety of ways, such as forming wings or side fins (not shown) extending from the fin side wall 30 below the roof 40 to form an upper and lower boiling cavity 44. Many different boiling or evaporation fin 20 configurations are possible within the current invention. The size of the boiling cavity 44 and the roof holes 42 can be varied, and specific sizes are more efficient for certain compounds. For example, if the tube 10 were to be used for the refrigerant R22, different sized holes 42 and boiling cavity 44 dimensions would be employed than if the tube 10 were to be used for the refrigerant R123.

Inner Surface Ridges

[0044] Heat transfer across the tube 10 can be improved by providing better transfer of heat between the tube body inner surface 16 and a liquid within the tube 10. A ridge 50 or a plurality of ridges 50 can be defined on the tube body inner surface 16 to help facilitate more rapid heat transfer, and these ridges 50 can be monolithic with the tube body 12. The ridges 50 on the inner surface 16 are generally helical and have a depth 52 and a frequency or pitch. The frequency is the number of ridges 50 within a set distance. The ridges 50 are also set at different cut angles relative to the tube axis 62. There can be several ridges 50 formed within the tube 10, and the number of ridges 50 allows for a predetermined cut angle, ridge depth 52, and frequency. The number of ridges 50 is referred to as the number ridge heads or the number of ridge starts.

[0045] The depth 52 and the frequency of the ridges 50 can vary, and the cut angle can be set to cause the cooling liquid to swirl within the tube 10. A swirling liquid tends to increase heat transfer by increasing the amount of agitation within the cooling liquid. Agitation tends to minimize or eliminate the layers of fluid in laminar flow, and agitation also tends to minimize the thickness of the stagnant layer of fluid next to the tube inner surface 16. Additional measures which can induce vortexes and local agitation at or very near the tube inner surface 16 further reduce the stagnant layer of fluid next to the tube inner surface 16, and thereby increase heat transfer. However, variations and 3-dimensional contours or texture also tend to increase the resistance to flow within a tube 10, so more pressure is required to push a given amount of fluid through a pipe in the same amount of time. A larger ridge depth 52 and a smaller ridge frequency tend to increase the rate of heat transfer, but they also increase the resistance to flow inside the tube 10.

Tube Indentations

[0046] Referring now to Fig 6, the tube 10 includes indentations 60 defined and depressed into the outer surface 14 such that the inner surface 16 protrudes or extends towards the tube axis 62 directly opposite the indentation 60 in the outer surface 14. This basically means the indentation 60 goes through the tube body 12 and pushes the inner surface 16 inward. This inner surface protrusion is referred to as a rib 64, which is the inner surface 16 counterpart to the outer surface 14 indentation 60. The indentation 60 loops around the tube 10, and the loops can be in a variety of forms. For example, the loops can be helical as shown in Fig. 7, or they can be a plurality of radial indentations 60 which form successive rings around the tube 10 as shown in Fig. 8, or they can be a plurality of indentations 60 helically looping around the tube 10 in opposite directions as shown in Fig. 9. Other indentation 60 patterns are possible, and are within the scope of the current invention.

[0047] Referring now to Figs. 3 and 6, the ribs 64 on the inner surface 16 affect fluid flow patterns inside the tube 10. The rib 64 projects into the tube 10, and fluid flowing over the rib 64 tends to form vortexes and eddies downstream from the rib 64. These vortexes decrease the stagnant fluid layer next to the inner surface 16, and therefore increase the heat transfer rate inside the tube 10. The rib 64 should not form a barrier which significantly impedes flow through the tube 10, so the rib 64 cannot have a rib height 66 greater than a tube inner radius 68. The rib height 66 is the height from the top of the rib 60 to the tube inner surface 16. Preferably, the ratio of the rib height 66 to a nominal tube outside diameter 70 is between 0.02 and 0.2, where the nominal tube outside diameter 70 is measured from the fin tops 28.

[0048] A helical rib 64 and the corresponding indentation 60 can wrap around the tube 10 either in the same direction as the internal ridges 50, or in the opposite direction of the internal ridges 50. If the rib 64 wraps in the same direction as the ridges 50, the rate of heat transfer and the resistance to flow is not increased as much as if the rib 64 wraps the opposite direction as the ridges 50. The ridges 50 induce a swirling flow direction, and the rib 64 also induces a swirling flow direction, as long as both are helical. When the rib 64 spirals counter to the ridge 50, the change in induced flow direction between the rib 64 and the ridges 50 accounts for the greater heat exchange rate and resistance to flow. The double helical indentation 60, and thus the double helical rib 64, is particularly effective when the inside liquid flow rate is relatively low, and discontinuous rib 64 belts are particularly effective when the inside liquid flow is laminar. The rib direction and height 66 can be set to keep the tube resistance to flow within a 1.5 fold increase of the resistance to flow without the rib 64.

Tube Use in a Heat Exchanger

[0049] The tube 10 is often used in a heat exchanger 72, as shown in Figs. 1 and 10. The tube first and second ends 22, 24 are fixed to two tube sheets 74 with a tube side inlet 76 and a tube side outlet 78 for fluid flow through the tube 10 interior. The tubes 10 are contained inside a shell 80. In the example shown, the heat exchanger 72 is a dual pass heat exchanger 72 with fluid entering and exiting from the same side of the heat exchanger 72 for flow through the tubes 10. There is also a shell side inlet 82 and a shell side outlet 84 for flow past the outside of the tube 10. The heat exchanger 72 shown is a drip exchanger, with shell side fluid being collected at the bottom of the shell 80 and recirculated to a spray device 86 positioned above the tube 10 by a pump 88.

[0050] A drip exchanger 72 or drip evaporator 72 uses less refrigerant than a flooded evaporator. The flooded evaporator has the shell 80 filled with liquid refrigerant such that the tubes 10 are immersed in liquid, but the drip evaporator 72 is mostly filled with gas or vapors. The drip evaporators 72 tend to be more energy efficient than the flooded type, and they use less refrigerant. Often the refrigerants used are chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs), which have many regulations controlling their use, so means of using less refrigerants are desirable.

[0051] For an evaporator tube 10 to function most efficiently, the outer surface 14 (or the evaporating surface, which can be the inner surface) should be kept wet with liquid to be evaporated. With a flooded heat exchanger, the tube outer surface 14 is immersed in liquid, so keeping the surface wet is not a consideration. With a drip evaporator, there can be portions of a tube outer surface 14 which are not wet, and which therefore cannot evaporate any liquids. The way a liquid flows over a tube 10, the type of spray device 86 used to distribute the liquid, and other factors can affect the rate of evaporation. It has been noted that tubes 10 with indentations 60 tend to keep more of the tube outer surface 14 wet than tubes 10 without indentations 60. This may be because the indentations 60 serve to collect and re-distribute the liquid along the tube 10, or because the indentations 60 allow for easier liquid access to the tube boiling cavities, or it may be due to other reasons. Whatever the reason, measurements of overall heat transfer rates with tube indentations 60 have shown increases of up to 20% over heat transfer rates for tubes 10 without indentations 60.

[0052] A heat exchanger 72 with tubes 10 that are 20% more efficient can utilize tubes 10 that are 20% shorter, or fewer tubes 10 with larger diameters can be used. By changing the heat exchanger 72 design, pressure drop issues from tubes 10 with a higher flow resistance can

be addressed. It should be noted the tubes **10** of the current invention also can be used in flooded type evaporators. The internal rib increases the tube internal heat exchange rate, which can benefit the tube overall heat exchange rate.

Tube Forming Process

[0053] Finned tubes **10** are generally formed from relatively smooth tubes **10** with a tube finning machine, which is well known in the industry. The tube finning machine includes an arbor **90** as seen in Figs. 11 and 12, with further reference to Fig. 3. Frequently, a tube finning machine will include three or more arbors **90** positioned around the tube **10**, so the tube **10** is held in place by the arbors **90**. The arbors **90** are positioned and angled such that each complements the others. A tube **10** is provided and fed through the finning machine such that a tube wall **92** is positioned between the arbor **90** and an inner support **94**. The arbor **90** deforms the tube outer surface **14**, and the inner support **94** can deform the tube inner surface **16**. Actually, the arbors **90** hold various tools or discs, and the tools contact and shape the tube outer surface **14**, so the arbors **90** serve as a form of tool holder. The tube wall **92** is generally rotated relative to the arbor **90** and moves axially with the inner support **94** as it rotates.

[0054] The arbor **90** generally includes several fin forming discs **96** which successively deform the tube wall **92** to form one or more helical fins **20** on the tube outer surface **14**. Successive finning discs **96** tend to project deeper into the tube wall **92** such that fins **20** are formed and pushed upwards by the finning discs **96**. The inner support **94** can include recesses **98** such that helical ridges **50** are formed on the tube inner surface **16** as fins **20** are formed on the tube outer surface **14**.

[0055] After the fin forming discs 96 have formed the fins 20, various other discs can be included on the arbor 90 to further deform and define aspects of the final tube 10. There are a wide variety of discs which can be included to produce many different shapes, include a boiling cavity 44. One of many examples is shown. After the fin forming discs 96, a notching disc 100 notches the fin top 28. The notching disc 100 has teeth which press into the fin 20 to form the notch 43. In Fig. 11, a portion of the fin 20 is shown in front of the notching disc tooth, and in Fig. 12, the tube wall 92 is shown sectioned such that there is no material shown in front of the notching disc tooth forming the notch 43. The notch 43 becomes a hole 42 in the roof 40 as the fin 20 is further deformed. The fin splitting disc 102 splits the fin top 28. Then, a flattening disc 104 flattens the fin tops 28 to form the roof 40. The roof 40 can be formed with a small gap between adjacent fin tops 28 to produce the hole 42, or other methods can be used to produce the hole 42.

[0056] After the fins 20 and the inner ridges 50 are formed, the indentation 60 is produced in a subsequent step, as shown in Fig. 6. An indentation disc 106 is rolled over the tube 10. The indentation disc 106 cuts through the fin 20 and the boiling cavity 44, and presses inward on the tube inner surface 16 to form the rib 64. The indentation disc 106 cuts into and interrupts the boiling cavity 44, and can provide relatively easy access by a fluid to the boiling cavity 44 at discrete locations.

[0057] This is one example of how the various deformations of the original relatively smooth tube 10 are produced. There are other possible orders and designs of discs and tools which can be used as well.

Example Dimensions

[0058] The dimensions of the current invention can vary, but example dimensions are provided below which will give the reader an idea as to at least one embodiment of the current invention.

[0059] The inter-fin distance is the distance between a center point of two adjacent fins **20** and this distance can be between 0.3 and 0.7 millimeters.

[0060] The fin **20** has a thickness between the left and right side wall **32, 34**, and this thickness can be between 0.1 and 0.5 millimeters.

[0061] The fin **50** has a height measured from the fin base **22** to the fin top **24**, and the fin height can be between 0.3 and 1.5 millimeters.

[0062] The ridge **74** formed on the tube body inner surface **16** has a depth **52**, and this depth can be between 0.1 and 0.5 millimeters. The internal ridge angle with the axis **62** can be set at 46°, and the ridge starts can vary between 8 and 50.

[0063] The hole **64** defined in the barrier **58** can have an area between 0.01 and 0.2 square millimeters.

[0064] The tube wall **92** thickness can vary between 0.75 and 3 mm.

[0065] The indentations **60** have an indentation depth and a pitch, wherein the pitch is the distance between two adjacent indentations measured axially along the tube **10**. The indentation depth can be a ratio of the nominal tube outside diameter **70**, and the ratio can be between 0.02 and 0.2, with the indentation depth ranging between 0.25 to 7 mm. The indentation pitch can

also be a ratio with the nominal tube outside diameter 70, and this ratio can be 0.25 to 2, with the pitch ranging between 3 and 75 mm.

[0066] The nominal tube outside diameter 70 can range between 12 and 39 mm.

[0067] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed here. Accordingly, the scope of the invention should be limited only by the attached claims.

CLAIMS

What is claimed is:

1. A finned tube comprising:
 - a tube body having an outer surface, an inner surface, and an axis;
 - at least one monolithic fin defined on the tube body outer surface such that, in the axial direction, the tube outer surface has adjacent fins, wherein a channel is defined between adjacent fins, and wherein the fin has an upper portion deformed to form a roof over the channel, and wherein the roof defines holes penetrating in to the channel;
 - a plurality of helical ridges defined on the tube body inner surface;
 - at least one helical indentation defined in the tube body outer surface such that the indentation extends the tube body inner surface towards the tube axis.

2. A finned tube comprising:
 - a tube body having an inner surface;
 - a helical ridge defined on the tube body inner surface; and
 - an indentation defined in the tube body, the indentation looping around the tube.

3. The finned tube of claim 2 wherein the indentation is helical, and wherein the indentation spirals around the tube in the opposite direction of the ridge.

4. The finned tube of claim 2 wherein the indentation is helical, and wherein the indentation spirals around the tube in the same direction as the ridge.

5. The finned tube of claim 2 wherein the indentation further comprises a plurality of indentations forming successive rings around the tube.
6. The finned tube of claim 2 wherein the indentation further comprises a plurality of helical indentations spiraling around the tube body in opposite directions.
7. The finned tube of claim 2 wherein the tube body includes an outer surface, the finned tube further comprising a monolithic helical fin defined on the tube body outer surface such that the tube body outer surface includes adjacent fins when viewed axially, wherein a channel is defined between adjacent fins, and wherein the fin includes an upper portion deformed to form a roof over the channel.
8. The finned tube of claim 7 wherein the tube body outer surface, adjacent fins, and the roof define a boiling cavity, and wherein the roof defines a plurality of roof holes penetrating into the boiling cavity.
9. The finned tube of claim 8 wherein the fins include a fin top having notches, and the notches define the roof holes.
10. The finned tube of claim 2 wherein the tube is comprised of copper.
11. A finned tube comprising:
a tube body having an outer surface;

a monolithic fin defined on the outer surface such that the outer surface includes adjacent fins viewed in the axial direction, wherein a channel is defined between adjacent fins, and wherein the fins include an upper portion deformed into a roof over the channel; and an indentation defined in the tube body, the indentation looping around the tube.

12. The finned tube of claim 11 wherein the indentation is helical.
13. The finned tube of claim 11 wherein the indentation further comprises a plurality of helical indentations spiraling around the tube in opposite directions.
14. The finned tube of claim 11 wherein the indentation further comprises a plurality of indentations forming successive rings around the tube body.
15. The finned tube of claim 11 wherein the tube body further includes an inner surface, the finned tube further comprising a helical ridge defined on the tube body inner surface.
16. The finned tube of claim 15 wherein the indentation is helical and the indentation spirals around the tube in the opposite direction as the ridge.
17. The finned tube of claim 15 wherein the indentation is helical and the indentation spirals around the tube in the same direction as the ridge.

18. The finned tube of claim 15 wherein the tube body outer surface, adjacent fins, and the roof define a boiling cavity, and the roof defines a plurality of holes penetrating into the boiling cavity.
19. The finned tube of claim 18 wherein the indentation interrupts the boiling cavity.
20. The finned tube of claim 11 wherein the tube is comprised of copper.

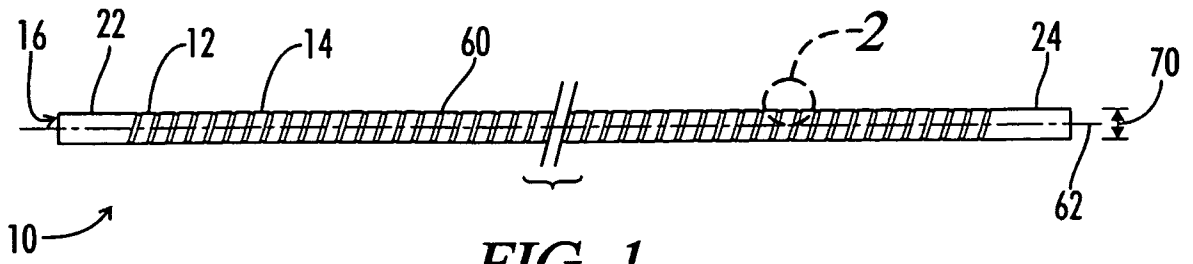


FIG. 1

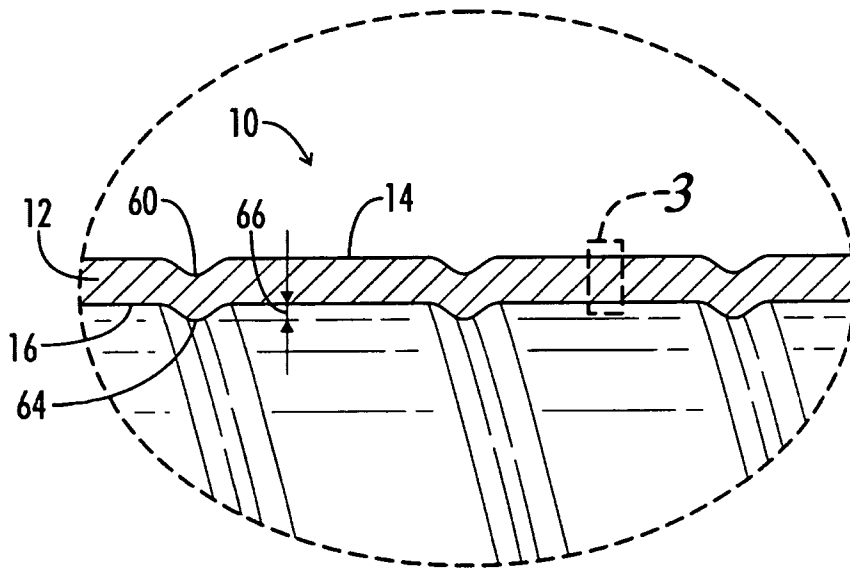


FIG. 2

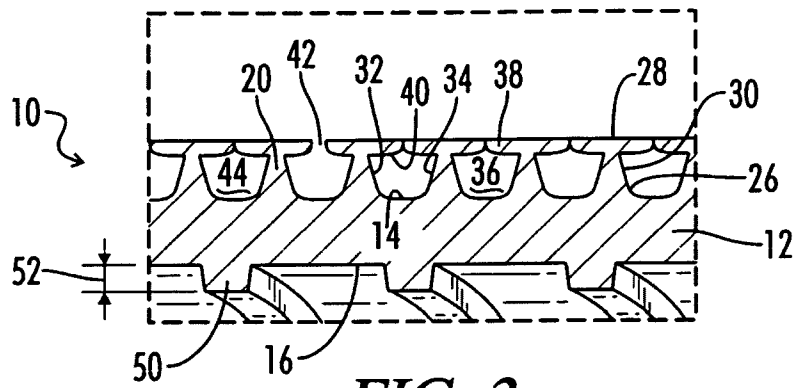


FIG. 3

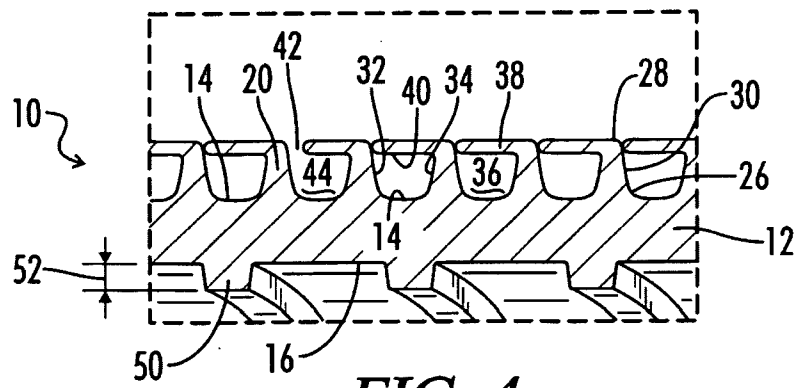
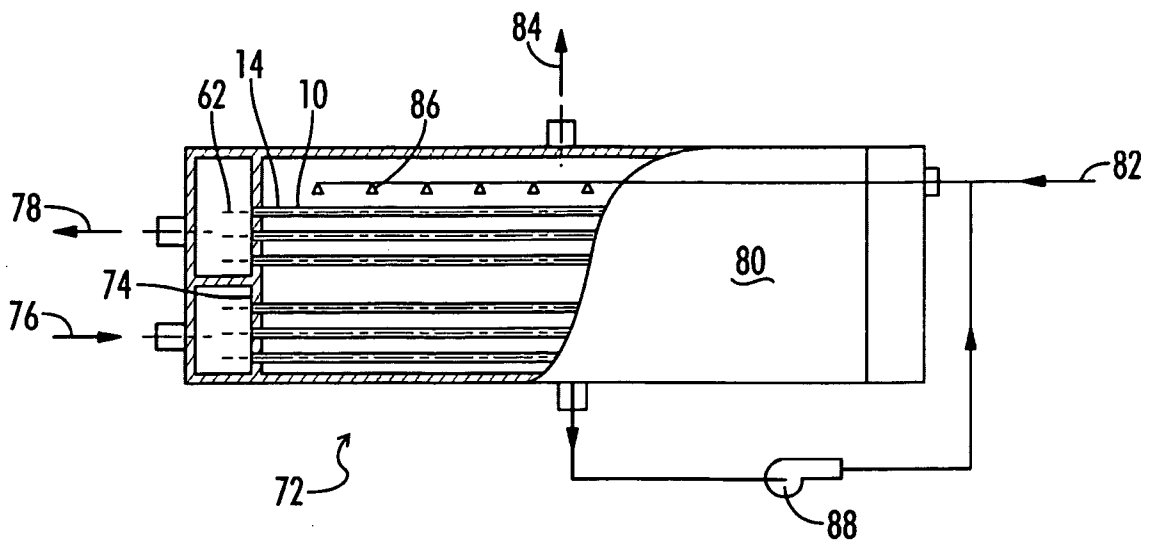
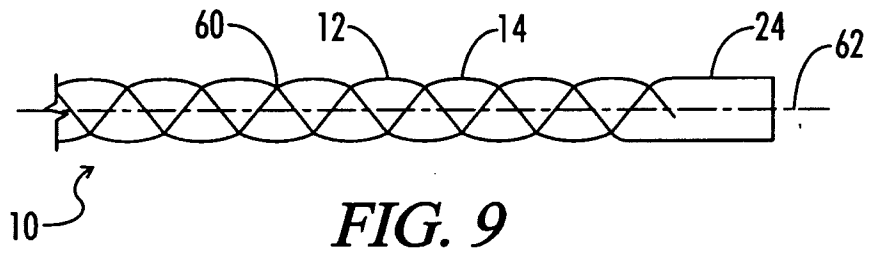
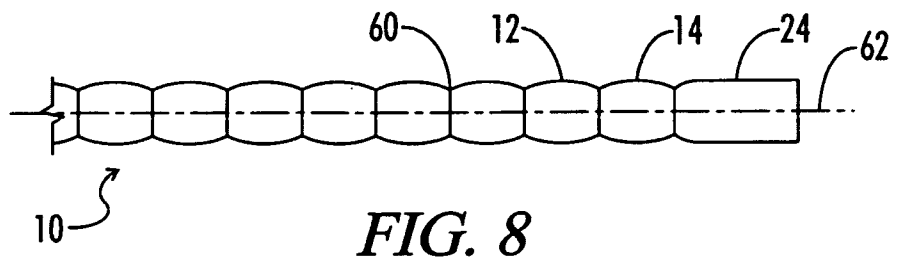
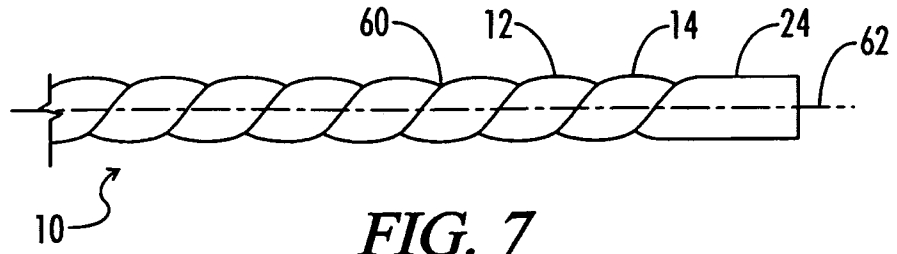


FIG. 4



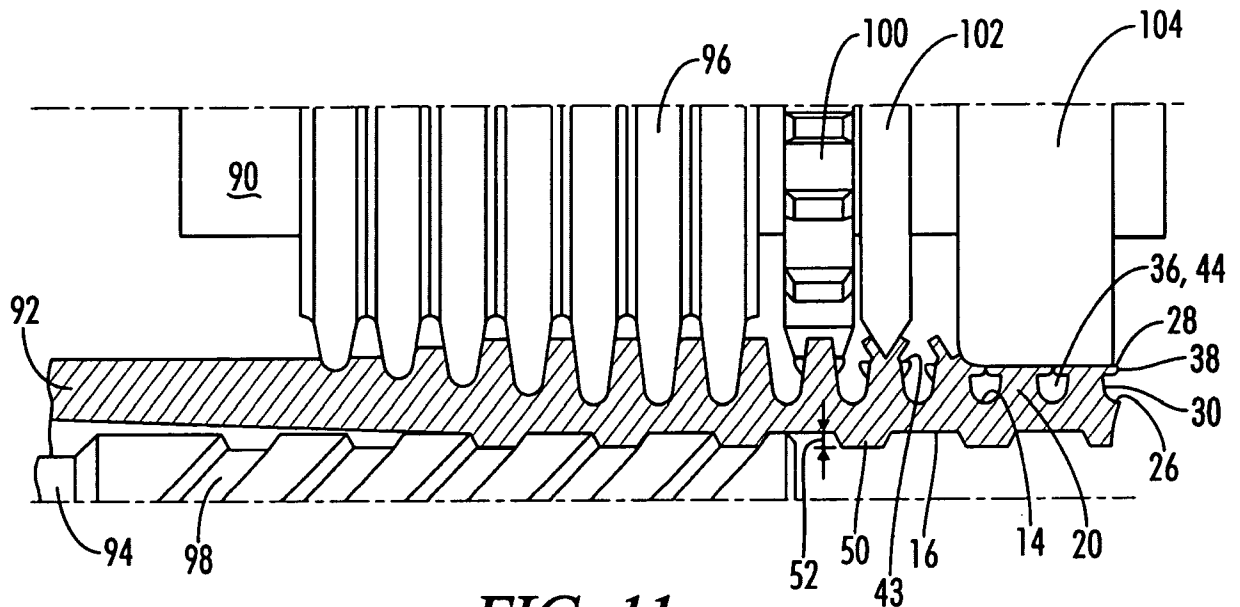


FIG. 11

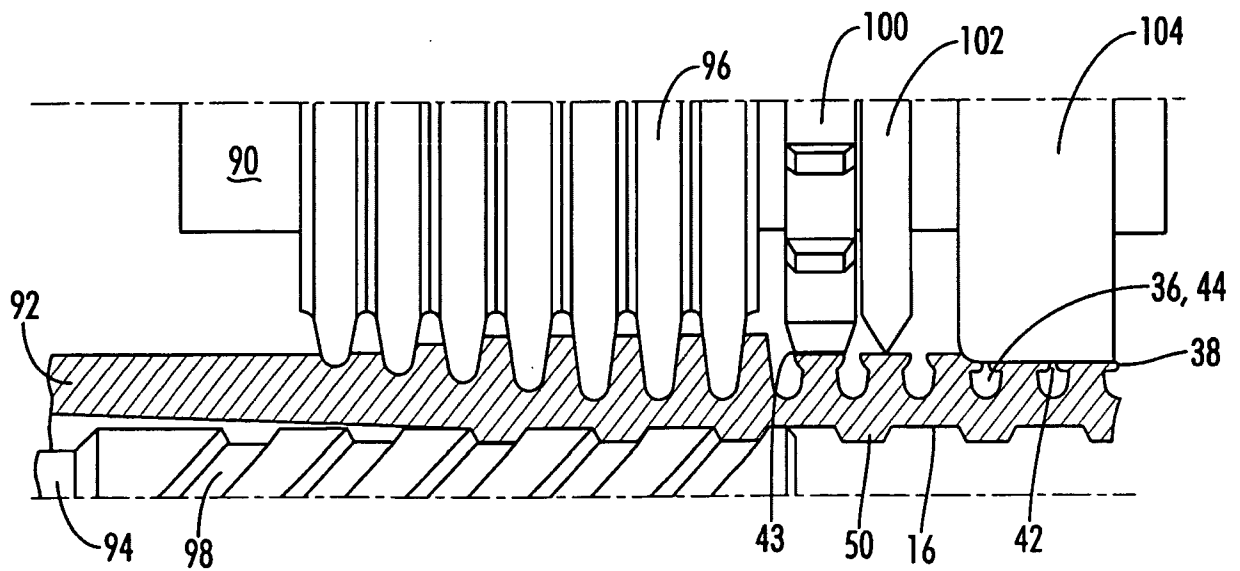


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2008/058272

| A. CLASSIFICATION OF SUBJECT MATTER IPC(8) - F28F 1/42 (2008.04) USPC - 165/179 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) IPC(8) - F28F 1/42 (2008.04) USPC - 29/890.045, 890.046, 890.048, 890.049; 72/370.16, 370.18, 370.19; 138/38, 122; 165/177, 179, 182, 183, 184 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) Patbase and Google Patent Search | | |
| C. DOCUMENTS CONSIDERED TO BE RELEVANT | | |
| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
| X — Y | US 4,330,036 A (SATO et al) 18 May 1982 (18.05.1982) entire document | 2-3 ----- 4-20 |
| Y | US 5,697,430 A (THORS et al) 16 December 1997 (16.12.1997) entire document | 1, 7-20 |
| Y | US 2004/0244958 A1 (DILLEY et al) 09 December 2004 (09.12.2004) entire document | 1, 4, 6, 13, 17 |
| Y | US 3,171,389 A (THROCKMORTON et al) 02 March 1965 (02.03.1965) entire document | 5, 14 |
| <input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> | | |
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| Date of the actual completion of the international search 29 July 2008 | | Date of mailing of the international search report 04 AUG 2008 |
| Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201 | | Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774 |