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(54) **FINNED TUBE WITH INDENTATIONS**

(75) Inventors: **Jianying Cao**, Shanghai (CN); **Zhong Luo**, Shanghai (CN); **Yalin Qiu**, Shanghai (CN); **Jian Wu**, Shanghai (CN)

Correspondence Address:
BRADLEY ARANT ROSE & WHITE LLP
200 CLINTON AVE. WEST, SUITE 900
HUNTSVILLE, AL 35801 (US)

(73) Assignee: **Wolverine Tube, Inc.**, Huntsville, AL (US)

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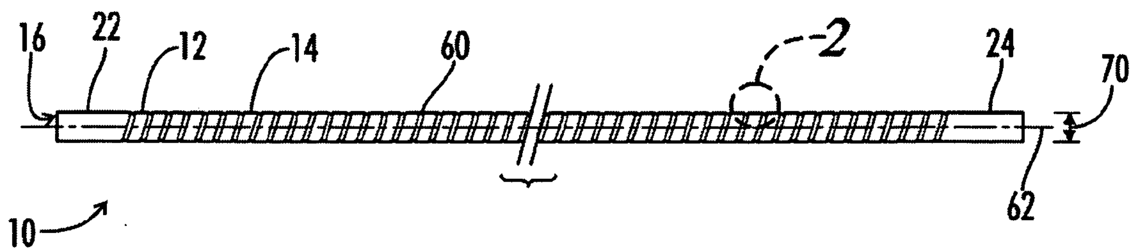
(57) **ABSTRACT**

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.



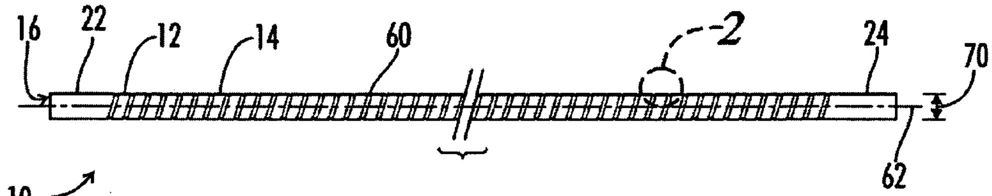


FIG. 1

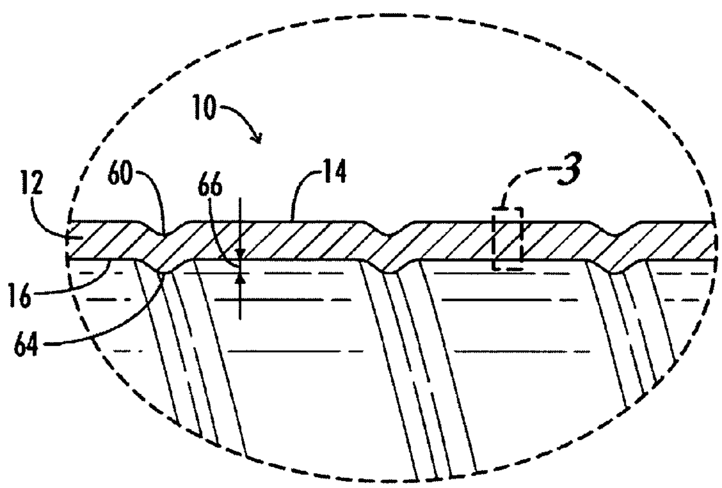


FIG. 2

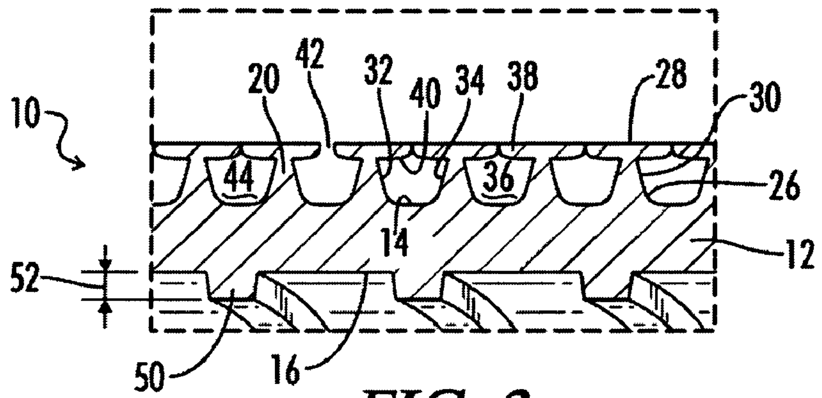

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FIG. 3

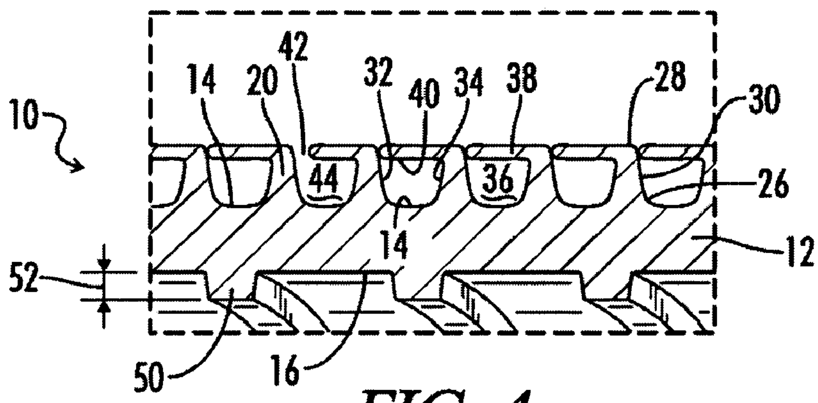
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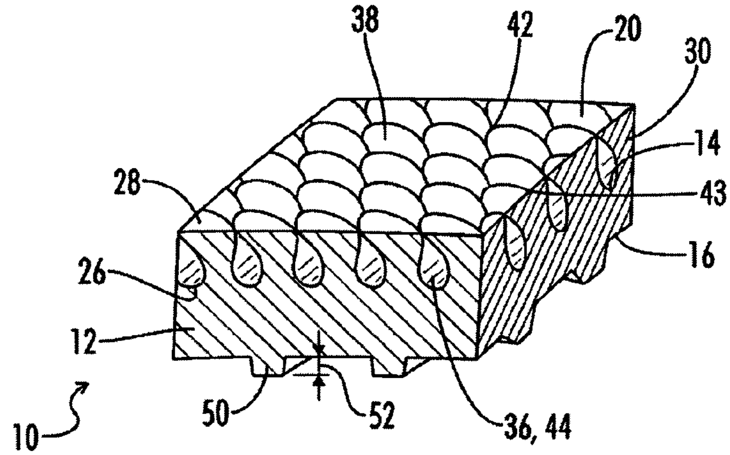
FIG. 4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36, 44

FIG. 5

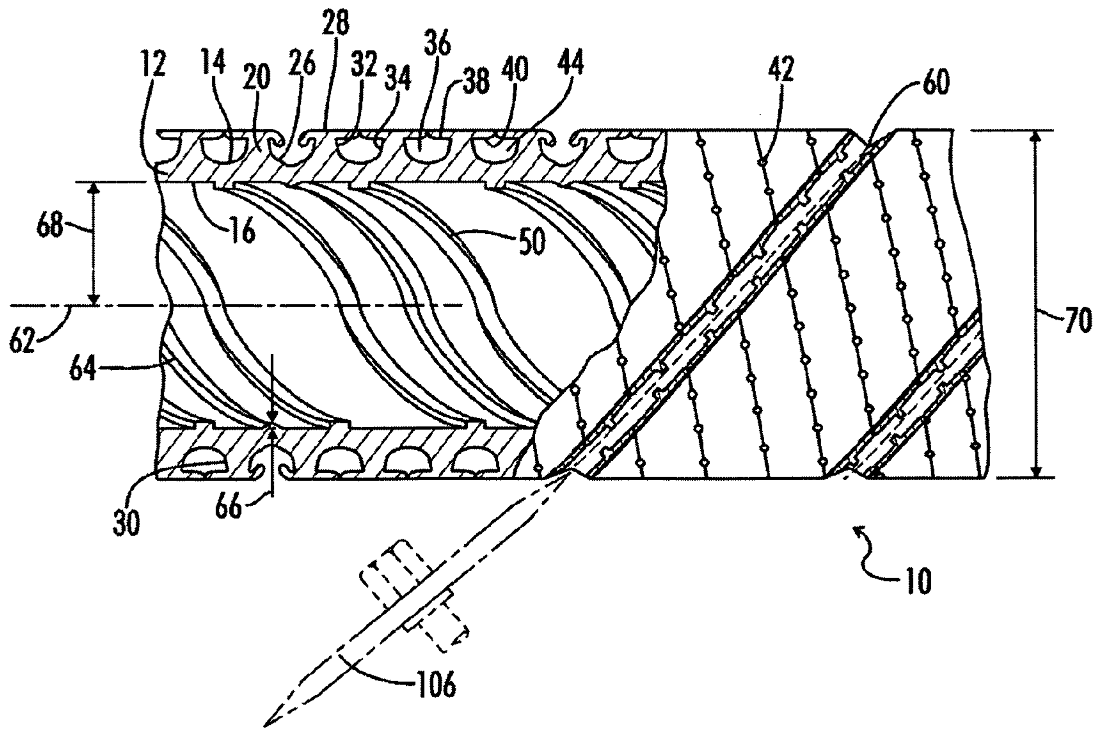
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FIG. 6

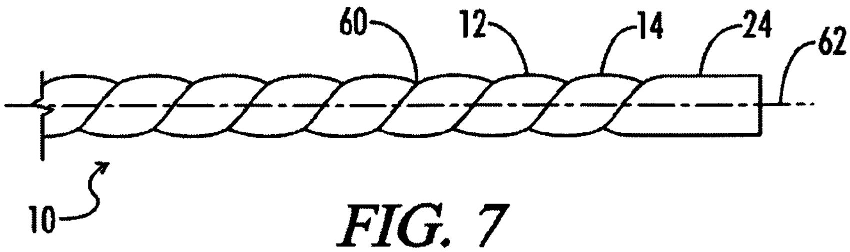

FIG. 7

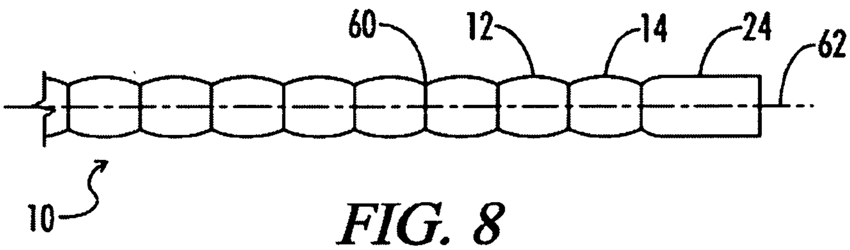

FIG. 8

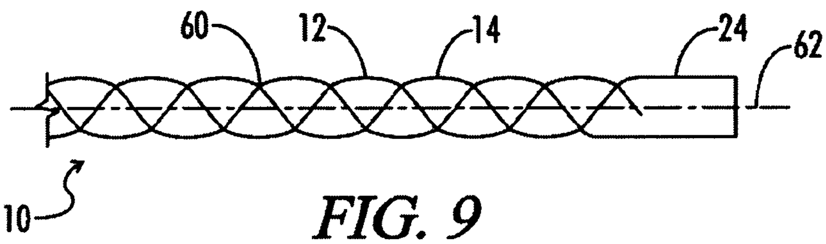

FIG. 9

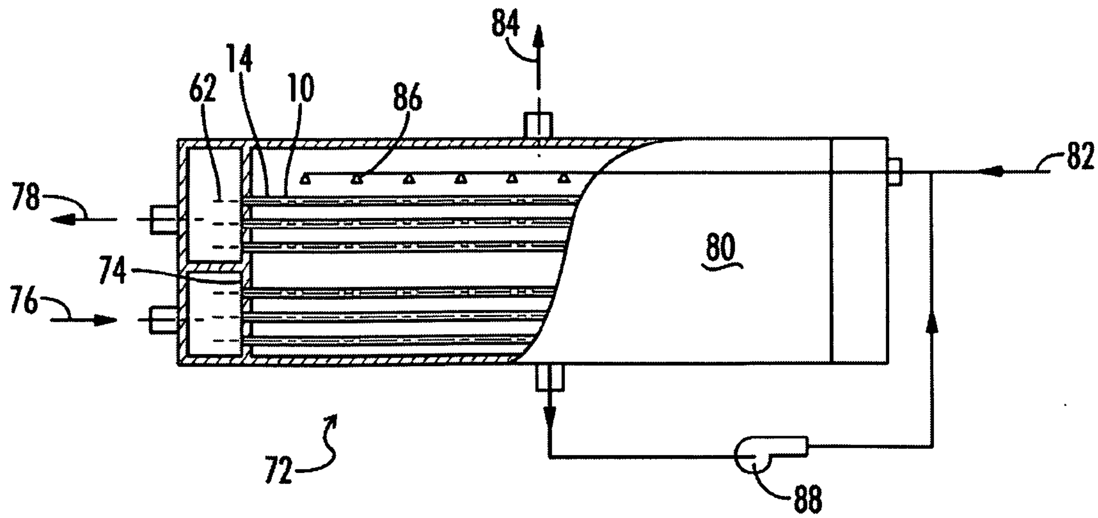

FIG. 10

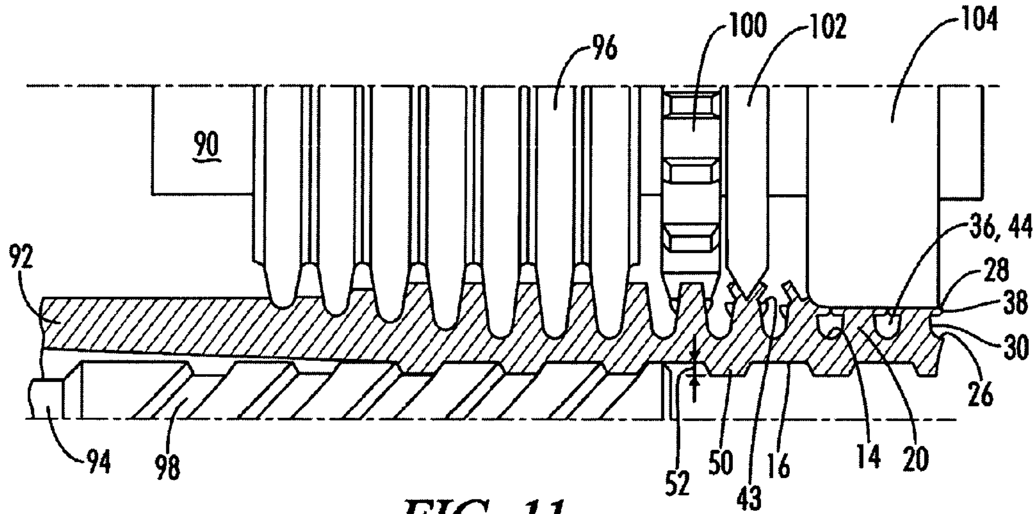
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FIG. 11

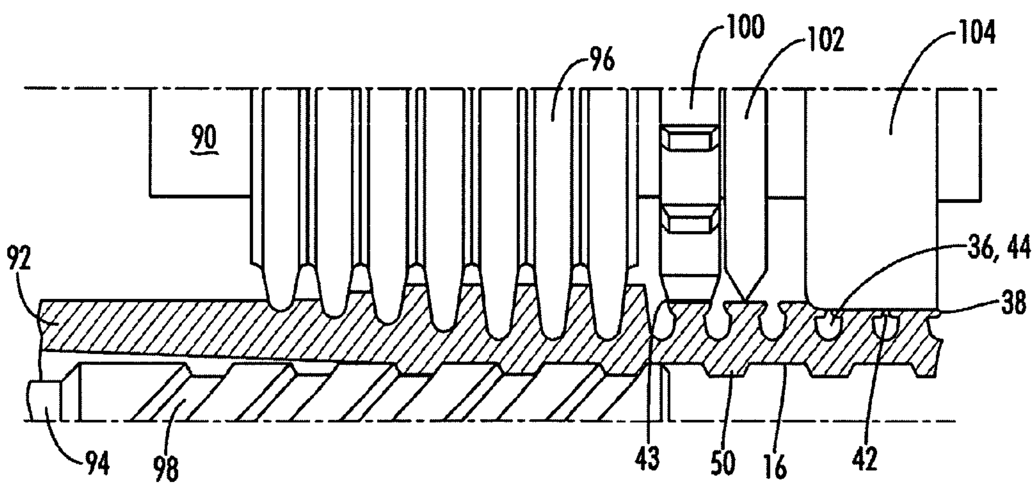
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FIG. 12

FINNED TUBE WITH INDENTATIONS

[0001] This invention claims priority to Chinese Patent Application Number ZL200720068218.6, which was filed on Mar. 27, 2007.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The current invention describes finned tubes used for heat transfer, such as the tubes used in shell and tube heat exchangers.

[0004] 2. Description of the Related Art

[0005] 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.

[0006] 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.

[0007] 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.

[0008] 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.

[0009] 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.

[0010] 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 spayed 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.

[0011] There are many designs of finned tubes in existence, but changes which improve heat transfer are still possible.

BRIEF SUMMARY OF THE INVENTION

[0012] 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

[0013] FIG. **1** is a side view of a tube with indentations.

[0014] 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.

[0015] 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.

[0016] FIG. **4** is a side sectional view of a finned tube.

[0017] FIG. **5** is a perspective view of a portion of a finned tube.

[0018] FIG. **6** is a side partial sectional view of a finned tube with indentations.

[0019] FIG. **7** is a side view of one embodiment of a tube with an indentation.

[0020] FIG. **8** is a side view of a second embodiment of a tube with indentations.

[0021] FIG. **9** is a side view of a third embodiment of a tube with indentations.

[0022] FIG. **10** is a side partial sectional view of heat exchanger.

[0023] 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.

[0024] 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

[0025] 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

[0026] 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.

[0027] 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.

[0028] 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.

[0029] 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.

[0030] 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.

[0031] 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.

[0032] 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.

[0033] 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

[0034] 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 enclose areas where vapor can escape and more liquid can be introduced.

[0035] 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.

[0036] Small holes in the enclosed area allow for the small quantity of liquid to escape after is 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.

[0037] 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

[0038] One embodiment of the finned tube **10** of the current invention is shown in different perspectives in FIGS. **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.

[0039] 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

[0040] 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**.

[0041] 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**.

[0042] 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**.

[0043] 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**.

[0044] 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**.

[0045] 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.

[0046] 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 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

[0047] 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.

[0048] 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

[0049] 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.

[0050] 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**.

[0051] 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

[0052] 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**.

[0053] 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 hydra chlorofluorocarbons (HCFCs), which have many regulations controlling their use, so means of using less refrigerants are desirable.

[0054] 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**.

[0055] 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

[0056] 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.

[0057] 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 filming 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**.

[0058] 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**.

[0059] 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.

[0060] 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

[0061] 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.

[0062] 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.

[0063] 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.

[0064] 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.

[0065] 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.

[0066] The hole **64** defined in the barrier **58** can have an area between 0.01 and 0.2 square millimeters.

[0067] The tube wall **92** thickness can vary between 0.75 and 3 mm.

[0068] 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 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.

[0069] The nominal tube outside diameter **70** can range between 12 and 39 mm.

[0070] 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.

I claim:

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.

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