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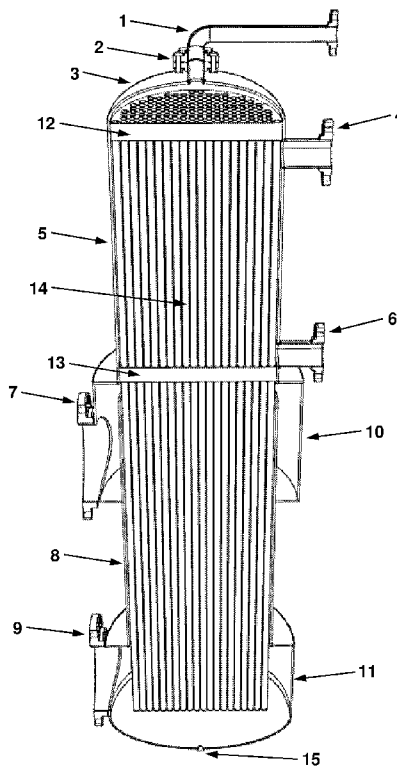


Figure 2

(57) Abstract: A heat exchanger includes number of bolted flanges and a number of heat pipes for heating and cooling liquids entering the heat exchanger. One of the bolted flanges connects a plenum housing to a relief valve piping. The relief valve piping remains closed during normal operation of the heat exchanger and opens to maintain pressure when operating pressure of the heat pipes increases above an acceptable level. The heat exchanger also includes a plenum plate, attached to a cold-side housing and the plenum housing, which seals a cold side of the heat exchanger from an upper plenum. The heat exchanger also includes a separation plate, connected to a cold-side housing and the hot-side exit vapor belt, which seals a cold side of the heat exchanger from a hot side of the heat exchanger.

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HEAT EXCHANGER

Technical Field

[0001] The present disclosure generally relates to heat exchangers, power generation, and heat recovery, including waste heat recovery. More particularly, the present disclosure relates to a thermosyphon heat exchanger.

Background

[0002] Organic Rankine Cycle (“ORC”) power plants exhibit high capital costs relative to other types of power plants. A substantial portion of the cost of an ORC power plant is attributed to the use of a secondary fluid system, which is needed to transfer heat from the heat source to the refrigerant working fluid. Direct heating of the working fluid (e.g., use of a direct evaporator to eliminate the secondary fluid system) is not cost-effective with traditional heat exchangers as the resulting exchangers are large and costly. Direct heating also carries the additional complication for high temperature heat sources of overheating the refrigerant to the point of decomposition. In addition to adding substantial cost to the ORC power plant, the secondary fluid system requires a significant parasitic electrical load to run the circulating pump(s) for the secondary fluid.

[0003] Additionally, multiple other heat exchanger applications suffer from high exchanger costs due to the low area-specific heat transfer rate of these exchangers (such as, for example, shell and tube heat exchangers). One such heat exchanger application is district heating, where waste heat such as engine exhaust is used to provide hot water in population centers. These applications include the situation where the cold fluid being heated must not exceed a specific temperature due to decomposition, flammability, evaporation, or some other reason.

[0004] Further problems exist with thermosyphon (wickless heat pipe) heat exchangers and heat pipe heat exchangers. Thermosyphons and heat pipes are typically implemented as individual sealed tubes or pipes that are closed at both ends, and which transfer heat via the circulation of an internal working fluid that evaporates in the hot end segment (where it cools objects or media external to the thermosyphon/heat pipe) and condenses in the cold end segment (where it heats objects or media external to the thermosyphon/heat pipe, and where the objects or media in the cold end segment are at lower temperature than the objects or media in the hot end segment). Such exchangers are high in cost due to the need to fill and seal each thermosyphon/heat pipe individually. Also, the charge cannot be cost-effectively tuned or adjusted due to the large number of thermosyphons/heat pipes in the exchanger. Additionally, in high temperature applications, the thermosyphons/heat pipes must be designed not only for design condition pressures, but also must be designed to withstand the very high pressures that would result from operating at maximum possible operating temperature (i.e. the temperature of the incoming hot flow, for the case where there is a loss of cold-side fluid flow), due to a completely sealed design. This higher design pressure requirement then results in thicker walls for the thermosyphons/heat pipes than if they were designed only for the design operating conditions, increasing cost and reducing heat transfer. Yet another problem with thermosyphons/heat pipe heat exchangers is that, when the charge is selected to achieve a target dry-out temperature, the required charge to achieve the target dry-out temperature is often not optimal for heat transfer. Finally, for some common working fluids such as water, the use of low cost materials such as stainless steel is generally considered unacceptable due to the buildup of non-condensable gases from the reaction of the water with the thermosyphon/heat pipe materials over time, such that the resulting non-condensable gases occupy significant volume in the

condensing section of the thermosyphon/heat pipe, reducing the effective condenser length and surface area, and reducing the performance of the thermosyphon/heat pipe. Therefore, there is a need for a heat exchanger system that solves the problems in the art.

Summary

[0005] The following presents a simplified summary of the disclosure in order to provide a basic understanding of some aspects of the disclosure. This summary is not an extensive overview of the disclosure. It is intended to neither identify key or critical elements of the disclosure nor delineate the scope of the system and method disclosed herein. Its sole purpose is to present some concepts of the disclosure in a simplified form as a prelude to the more detailed description that is presented later.

[0006] In one embodiment, a heat pipe heat exchanger includes thermosyphon/heat pipes open at the top to a common plenum located above the thermosyphons/heat pipes. This implementation allows for charging all tubes simultaneously (which results in lower cost); allows for cost-effective charge adjustment; allows for use of tube and working fluid material combinations considered incompatible due to buildup of non-condensable gases (for example, plenum provides a volume to collect these gases without reducing condenser section lengths and active cold-side surface area); and allows for reduction in the required vacuum for charging when using vacuum charging (for example, due to plenum volume being available to contain non-evacuated gases).

[0007] In one embodiment, a pressure relief system is provided on the plenum. This implementation allows for lower design pressure in high-temperature applications, since the design pressure is set by the relief pressure and not the maximum possible pressure resulting from a sealed system operating at maximum hot-side temperature, and reduces tube wall

thickness and increases heat transfer, both of which reduce cost. This implementation also allows independent control of both thermosyphon/heat pipe charge, and dry-out temperature, so that the charge may be set for maximum heat transfer, and the dry-out temperature set (via the relief system lift pressure) to limit cold-side fluid temperature to a specific value regardless of charge.

[0008] In one embodiment, a hot-side housing and vapor belts are arranged such as to achieve uniform flow distribution at the hot inlet via controlled diffusion, circumferential feed, and even pressurization of the tube bundle via the hot inlet vapor belt. This implementation also results in uniform flow distribution at the hot exit vapor belt via consistent flow turning and pressure loss around the circumference of the hot exit vapor belt, low pressure loss, and further results in a compact, low-cost arrangement.

[0009] The following description and the annexed drawings set forth in detail certain illustrative aspects of the disclosure. These aspects are indicative, however, of but a few of the various ways in which the principles of the system and method disclosed herein may be employed and the system and method disclosed herein is intended to include all such aspects and their equivalents. Other advantages and novel features of the system and method disclosed herein will become apparent from the following detailed description of the system and method disclosed herein when considered in conjunction with the drawings.

Brief Description of the Drawings

[0010] Figure 1 illustrates a thermosyphon heat exchanger in accordance with one embodiment; and

[0011] Figure 2 illustrates an internal view of a thermosyphon heat exchanger in accordance with one embodiment.

Description of Illustrative Embodiments

[0012] The system and method disclosed herein will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred implementations of the system and method disclosed herein are shown. The system and method disclosed herein may, however, be implemented in many different forms and should not be construed as limited to the implementations set forth herein. Rather, these implementations are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the system and method disclosed herein to those skilled in the art.

[0013] ORC power plants are employed as a means to convert waste heat into electricity, typically where the heat source is either too small or too low in temperature to cost-effectively employ a steam turbine power plant. For the case where the heat source is of high temperature such as engine exhaust, gas turbine exhaust, incinerators, or biomass boilers, there lies an additional concern when using common ORC working fluids, as they decompose at temperatures well below the temperature of the heat source. The current solution to the problem is to use a secondary fluid loop to transfer heat from the heat source to the ORC power plant. This secondary fluid loop represents a large portion of the cost of the ORC power plant, and reduces the performance due to the power requirement of the circulation pump(s) and heat losses in the secondary fluid loop system. Embodiments of the present invention allow for reduction in cost, complexity, and physical size of ORC power plants, while increasing performance, by replacing the entire secondary fluid loop system, along with the heat exchangers on both sides of the secondary fluid loop (i.e., the heat exchangers transferring heat from the heat source to the

secondary working fluid, along with the heat exchangers transferring heat from the secondary working fluid to the ORC working fluid), with a single heat exchanger in accordance with one embodiment. The result is an ORC power plant that is lower in cost, higher in performance, and is more compact than existing ORC power plants. These benefits then allow for more integration with the heat source, for further benefits in cost and performance.

[0014] In the present disclosure, the term “thermosyphons/heat pipes” is used to refer to thermosyphons (wickless heat pipes) or heat pipes (which have a wick). Embodiments of the present invention may be implemented by using thermosyphons or heat pipes. Embodiments of the subject invention solve all the above problems of ORC secondary fluid systems, traditional heat exchangers, and thermosyphon/heat pipe heat exchangers, via a thermosyphon/heat pipe heat exchanger that leverages the very high surface area-specific heat transfer rates of thermosyphons/heat pipes to provide a compact heat exchanger with lower cost than traditional heat exchangers, and in which the thermosyphons/heat pipes may be open on the top end to a common plenum that allows for simultaneous charging of all the thermosyphons/heat pipes. This lowers the time and cost of charging the thermosyphons/heat pipes, and also allows for cost-effective adjustment of the charge in the field.

[0015] Additionally, in one embodiment a pressure relief valve, pressure safety valve, or pressure relief system may be placed on the common plenum to which all thermosyphons/heat pipes are open, which results in significant reduction in maximum design pressure requirements for the thermosyphons/heat pipes in high temperature applications. This reduces required thermosyphon/heat pipe wall thickness which then results in increased heat transfer, and both reduced wall thickness and increased heat transfer then contribute to lower cost. It also allows for independent selection of both the optimal charge for heat transfer, and the dry-out

temperature, since the dry-out temperature is set by the relief pressure and is independent of the charge. In one embodiment, the common plenum also creates a volume in which non-condensable gases can collect without impact to the performance of the thermosyphons/heat pipes, such that previously-unacceptable low-cost materials can be used without negative impact to the performance of the heat exchanger.

[0016] Embodiments of the subject invention also resolve issues with use of a direct evaporator in ORC power plants, thereby reducing the cost and increasing the output of such plants. In addition to the advantages identified above, embodiments of the subject invention have the capability to prevent the overheating and decomposition of the ORC working fluid. This may be accomplished by setting the relief pressure for the pressure relief valve, pressure safety valve, or pressure relief system such that the pressure in the thermosyphons/heat pipes does not exceed a pre-determined value, in accordance with one embodiment. As the temperature in the thermosyphons/heat pipes is a function of working fluid chemistry, amount of working fluid installed in the thermosyphons/heat pipes (charge), and the pressure of the working fluid in the thermosyphons/heat pipes, the maximum temperature of the working fluid in the heat pipes may then be limited by the pressure relief valve, pressure safety valve, or pressure relief system. In accordance with one embodiment, the relief pressure may be set within the pressure range wherein the thermosyphons/heat pipes are actively exchanging heat, and the working fluid is in the two-phase region. In one embodiment where the working fluid pressure in the thermosyphons/heat pipes nears, equals, or exceeds the maximum allowable pressure (and corresponding temperature for working fluid chemistry and charge) for proper operation or at which the equipment is allowed to operate continuously, the resulting release of working fluid by the pressure relief valve, pressure safety valve, or pressure relief system will result in reduction

in thermosyphon/heat pipe charge while maintaining the operating pressure and temperature in the thermosyphons/heat pipes at acceptable levels. This reduction in charge may continue for as long as the pressure in the thermosyphons/heat pipes remains near the maximum allowable pressure, such that the pressure relief system continues to flow. In the case where the pressure relief system continues to flow until the working fluid is completely vaporized (dry-out), heat transfer between the hot and cold sides of the exchanger will then be essentially halted, as described below in accordance with one embodiment.

[0017] The thermosyphon/heat pipe working fluid and charge may be set such that the charge is completely vaporized at a pre-determined temperature (known in the art as the dry-out temperature). In the case that the temperature inside the thermosyphons/heat pipes reaches the dry-out temperature, the working fluid inside the thermosyphons/heat pipes, and in the common plenum cavity, is completely vaporized, and the heat transfer mechanism of the thermosyphons/heat pipes is then effectively turned off, as no liquid condensate returns to the evaporator section of the thermosyphons/heat pipes, essentially stopping any further heat transfer. An embodiment utilizes a pressure relief valve, pressure safety valve, or pressure relief system that allows for dry-out to be attained, as described above, at a desired pressure and temperature combination for any given charge, thereby allowing independent control over both the charge and the dry-out temperature in the design. This is advantageous since the heat transfer characteristics of the thermosyphons/heat pipes may not be optimal at the charge required by the desired dry-out temperature in a sealed thermosyphon/heat pipe system.

[0018] The relief pressure may be set below, at, or above the dry-out temperature of the selected working fluid and charge. Therefore, the relief pressure setting and/or the dry-out temperature may be set such that the working fluid remains below the decomposition

temperature of the ORC working fluid. This prevents the possibility of overheating the ORC working fluid as the thermosyphons/heat pipes will not transfer any significant heat once the dry-out temperature is reached inside the thermosyphons/heat pipes. Since the exchanger cold-side fluid is heated almost exclusively by the thermosyphons/heat pipes, and not directly receiving significant heat from the exchanger hot fluid (except at the separation plate, where reduced hot-side temperatures will exist in the case of hot fluid exit at the upper hot-side connection, or which can be insulated as needed to prevent direct heat transfer), in one embodiment the exchanger cold-side fluid is substantially isolated thermally from the hot-side fluid and the heat transfer is controlled passively by the thermosyphons/heat pipes.

[0019] An embodiment of the subject invention similarly resolves the above-identified issues for multiple other heat exchanger applications, via an exchanger with much lower cost than traditional heat exchangers, due to the high surface area-specific heat transfer rate of the thermosyphons/heat pipes, while providing a flexible means to protect the cold-side fluids from excessive temperatures. Additionally, the charge and fluid of the thermosyphons/heat pipes can be set such that the thermosyphon/heat pipe working fluid freezes at a pre-determined temperature set by the charge, which effectively turns off the heat transfer at and below this temperature. As with the relief pressure setting and dry-out temperature, this can be used for any number of purposes including protection of hot and/or cold-side exchanger fluids, or to limit heat transfer directly. Application of embodiments of the invention in the implementations described above may result in lower pressure loss due to low fluid velocities on both hot and cold sides of the exchanger.

[0020] Figure 1 illustrates a thermosyphon/heat pipe heat exchanger in accordance with one embodiment. The heat exchanger illustrated in Figure 1 includes Relief Valve Piping 1, Bolted

Flange 2, Plenum Housing 3, Bolted Flange 4, Cold-Side Housing 5, Bolted Flange 6, Bolted Flange 7, Hot-Side Housing 8, Bolted Flange 9, Hot-Side Housing Exit Vapor Belt10, and Hot-Side Housing Inlet Vapor Belt 11.

[0021] The Relief Valve Piping 1 may be implemented as piping for conveyance of pressurized fluids, such as piping in compliance with American National Standards Institute (ANSI) specifications. Bolted Flange 2 may be implemented as a piping flange such as piping flange in compliance with American Society of Mechanical Engineers (ASME), ANSI, Thermal Exchanger Manufacturing Association (TEMA), or metric nominal diameter (DN) flange specifications, and may include a gasket for sealing. Plenum Housing 3 may be implemented as a pressure vessel enclosing and sealing an open plenum that connects substantially (e.g., enough to freely communicate flow and pressure between the tubes and the plenum) the thermosyphons/heat pipes at the top end. Bolted Flange 4 may be implemented as a piping flange, such as piping flange in compliance with ASME, ANSI, TEMA, or metric DN flange specifications, and may include a gasket for sealing. Cold-Side Housing 5 may be implemented as a pressure vessel which may also be made from standard pressure piping, such as ANSI, or from rolled sheet, and which may enclose and seal the cold-side flow volume of the exchanger, may provide inlet and exit piping for the cold-side fluid flow, and may include an expansion joint to alleviate thermal stresses. Bolted Flange 6 may be implemented as a piping flange, such as piping flange in compliance with ASME, ANSI, TEMA, or metric DN flange specifications, and may include a gasket for sealing. Bolted Flange 7 may be implemented as a piping flange, such as piping flange in compliance with ASME, ANSI, TEMA, or metric DN flange specifications, may include a gasket for sealing, or may be clamped or may include any suitable means of conveyance. Hot-Side Housing 8 may be implemented as a pressure vessel which may

also be made from pressure piping, such as ANSI, or from rolled sheet, and which may enclose and seal the hot-side flow volume of the exchanger. Bolted Flange 9 may be implemented as a piping flange, such as ASME, ANSI, TEMA, or metric DN flange, and may include a gasket for sealing, or may be clamped or may include any suitable means of conveyance. Hot-Side Housing Exit Vapor Belt 10 may be implemented as a pressure vessel which may also be made from pressure piping, such as ANSI, or from rolled sheet, may enclose and seal the hot-side flow volume of the exchanger near the exit, and may provide for even flow distribution to the exit piping for the hot-side fluid flow. Hot-Side Housing Inlet Vapor Belt 11 may be implemented as a pressure vessel which may also be made from pressure piping, such as ANSI, or rolled sheet, and/or stamped sheet, may enclose and seal the hot-side flow volume of the exchanger near the inlet, and may provide for even hot-side flow distribution to the thermosyphons/heat pipes.

[0022] Operation of the heat exchanger illustrated in Figure 1 operates as follows, in accordance with one embodiment. Hot fluid enters through Bolted Flange 9, is distributed by Hot-Side Housing Inlet Vapor Belt 11 for optimal flow distribution within the hot-side flow volume of the exchanger, enters Hot-Side Housing 8 where it is cooled by the thermosyphons/heat pipes (illustrated in Figure 2), enters the Hot-Side Housing Exit Vapor Belt 10, which collects the hot-side flow evenly from around the circumference of Hot-Side Housing 8, and exits through Bolted Flange 7. Cold fluid enters through Bolted Flange 6, enters Cold-Side Housing 5 where it is heated by the thermosyphons/heat pipes, and exits through Bolted Flange 4. Bolted Flange 2 connects the Plenum Housing 3 to Relief Valve Piping 1. For normal operation, the pressure relief valve remains closed. For abnormal conditions where operating pressure of the thermosyphons/heat pipes increases above acceptable levels, the pressure relief valve, pressure safety valve, or pressure relief system will release thermosyphon/heat pipe

working fluid through Relief Valve Piping 1 to maintain pressure within pre-determined constraints.

[0023] Figure 2 illustrates an internal view of a thermosyphon heat exchanger in accordance with one embodiment. In the embodiment illustrated in Figure 2, the cold-side connections are located on the opposite side of Cold-Side Housing 5 shown in Figure 1. In one embodiment, all parts illustrated in Figure 1 are also present in the embodiment illustrated in Figure 2. The embodiment illustrated in Figure 2 also includes parts not illustrated in Figure 1. The additional parts identified in Figure 2 are Plenum Plate 12, Separation Plate 13, Thermosyphons/Heat Pipes 14, and Drain 15.

[0024] Plenum Plate 12 may be implemented as a plate to which the thermosyphons/heat pipes are welded, roll expanded, or otherwise attached, and which may separate the upper plenum from the cold side flow volume of the heat exchanger. Separation Plate 13 may be implemented as a plate to which the thermosyphons/heat pipes are welded, roll expanded, or otherwise attached, and which may separate the cold-side flow volume of the exchanger from the hot-side flow volume of the exchanger. Thermosyphons/Heat Pipes 14 may be implemented as thermosyphons (wickless heat pipes) or heat pipes (which have a wick), which may pass through both Plenum Plate 12 and Separation Plate 13 such that they pass through both the hot-side and cold-side flow volumes of the exchanger, and which may be open to Plenum Housing 3. Thermosyphons/Heat Pipes 14 may be welded, roll expanded, or otherwise attached and sealed at Plenum Plate 12 and Separation Plate 13, resulting in three, separate, fully-sealed sections of the exchanger, which are the hot fluid section, the cold fluid section, and the thermosyphon/heat pipe working fluid section. The working fluid section includes the internal volumes of the Thermosyphons/Heat Pipes 14 and the upper plenum to which they are open. Drain 15 may be implemented as an

opening near the bottom of the hot-side flow volume, may include an opening in the Hot Side Housing Inlet Vapor Belt 11, and may also include a removable cap, bolt, or other attachment.

[0025] In one embodiment, the operation of the additional parts identified in Figure 2 is as follows. In one embodiment, Plenum Plate 12 may be welded or otherwise connected to Cold-Side Housing 5 and Plenum Housing 3, and seals the cold side of the exchanger from the upper plenum. In one embodiment, Separation Plate 13 may be welded or otherwise connected to Cold-Side Housing 5 and Hot-Side Exit Vapor Belt 10, and seals the cold side of the exchanger from the hot side of the exchanger. Thermosyphons/Heat Pipes 14 may remove heat from the hot-side fluid flow and transport it to the cold-side fluid flow via the evaporation (in the hot-side fluid section) and condensation (in the cold-side fluid section) of an internal working fluid within Thermosyphons/Heat Pipes 14. The resulting flow field inside Thermosyphons/Heat Pipes 14 may be such that evaporated vapor rises from the hot-side flow section and into the cold-side flow section, while condensing liquid moves in the opposite direction due to the force of gravity, capillary action, or a combination of both gravity and capillary action. The working fluid and mass per unit volume of working fluid in Thermosyphons/Heat Pipes 14 may be selected for maximum heat transfer within the target operating temperature range of the application. Additionally, the working fluid and mass per unit volume of working fluid in Thermosyphons/Heat Pipes 14 may be selected such that heat transfer is essentially prevented (e.g., all or almost all of the heat transfer ceases) above or below pre-determined temperatures via the dry-out temperature (for upper temperature limit) and/or freezing temperature (for lower temperature limit) of the working fluid at the selected mass per unit volume in Thermosyphons/Heat Pipes 14. Drain 15 may serve as a mechanism for removing accumulated

liquid from the hot-side flow volume, for example, due to the use of cleaning liquids or spraying of water to clean Thermosyphons/Heat Pipes 14.

[0026] In one embodiment, the hot connections and hot housing vapor belts shown in Figures 1 and 2 are specifically designed for uniform flow distribution and low pressure loss. The hot housing inlet vapor belt may provide controlled diffusion of the flow from the hot inlet connection, along with a circumferential feed to the thermosyphons/heat pipes, and also force fluid evenly into the center of the tube bundle. The hot housing exit vapor belt may pull flow circumferentially from the tube bundle, and the extension of the hot housing into the hot housing exit vapor belt may provide for more uniform pressure loss around the circumference, both of which contribute to uniform flow.

[0027] For ease of reference, the embodiment illustrated in Figures 1 and 2 is referred to as a “first” embodiment, but persons of ordinary skill in the art would recognize that such first embodiment includes variations in implementation and operation. In the first embodiment, a common thermosyphon/heat pipe plenum is positioned at the top end of the thermosyphons/heat pipes, and includes hot and cold fluid connections as illustrated in Figures 1 and 2.

[0028] Another embodiment of the subject invention, referred to as a “second” embodiment for ease of reference, may include the addition of a center plenum within the separation plate, such that the thermosyphons/heat pipes are no longer continuous between the hot-side flow volume and the cold-side flow volume, and such that the additional plenum space between the hot-side flow volume and the cold-side flow volume provides additional thermal isolation between the hot and cold sides of the exchanger. In this second embodiment, the upper and lower thermosyphons/heat pipes may be aligned or not aligned, and may be of similar cross section or different cross section, as necessary to optimize internal fluid flow within the

thermosyphons/heat pipes, and/or maximize heat transfer. Such an arrangement may also be accomplished by cross-drilling the separation plate such that the tubes are connected by the cross-drilled holes. This second embodiment may also be used to affect a loop heat pipe design via use of inverter ducting or ducting to separate the condensed liquid from the vapor for each thermosyphon/heat pipe built into the center plenum.

[0029] Another embodiment of the subject invention, referred to as a “third” embodiment for ease of reference, may include the addition of a bottom plate/plenum assembly that connects the bottom of the thermosyphon/heat pipes, to allow for re-distribution of condensed thermosyphon/heat pipe working fluid among the thermosyphons/heat pipes, and to provide resistance to lateral displacement of the tubes.

[0030] Another embodiment may include the first, second, or third embodiment, for example, wherein either inlet vanes and/or internal flow baffles, which may be removable via access through the inlet and/or exit connections, may be used to effect more uniform flow distribution, including on either or both hot and cold side flows, in any number and any combination. Internal baffles may also be used to secure the thermosyphons/heat pipes from lateral motion caused, for example, by impinging flow from the hot inlet.

[0031] Another embodiment may include the first, second, or third embodiment, for example, wherein the holes in the top surface of the plenum plate have a rounded edge to facilitate condensate return. For the second embodiment this may also be applied to the plate at the bottom of the center plenum.

[0032] Another embodiment may include the first, second, or third embodiment, for example, wherein the tube pattern may be triangular or any geometric pattern known in the art for a heat exchanger tube array design.

[0033] Another embodiment may include the first, second, or third embodiment, for example, wherein the separation plate may be curved, bowl-shaped, or hemispherical to effect a more efficient pressure vessel.

[0034] Another embodiment may include the first, second, or third embodiment, for example, wherein the direction of flow for the hot and cold fluids may be in either direction, or combination of directions.

[0035] Another embodiment may include the first, second, or third embodiment, for example, wherein the thermosyphons/heat pipes are not circular in cross section, and/or which utilize textured or finned surfaces to improve heat transfer, or for any thermosyphons or heat pipes known in the art.

[0036] Another embodiment may include the first, second, or third embodiment, for example, wherein the hot-side housing and vapor belts, along with the cold-side housing, may have any manner, orientation, and configuration for their respective inlet and exit flows, or where either of both vapor belts are not required to be used in the design, and the hot side flanges are directly on the hot side housing. For example, the hot-side inlet vapor belt may be eliminated, and the hot-side housing extended to near or past the bottom of the thermosyphons/heat pipes, with connecting flange located on the bottom of the hot-side housing, to allow for piping the hot-side inlet directly into the bottom of the hot-side housing from underneath the exchanger.

[0037] Another embodiment may include the first, second, or third embodiment, for example, wherein any component or part of a component may be insulated to limit heat transfer from one component to another or to the environment.

[0038] Another embodiment may include the first, second, or third embodiment, for example, wherein a plate may be welded or otherwise attached on top of the plenum plate, which contains

holes of diameter less than that of the thermosyphons/heat pipes, to allow for more even fill during charging, to reduce tube-to-tube interactions during operation (including re-distribution of working fluid between tubes), and/or to reduce velocities and mixing in the upper plenum when in operation.

[0039] Another embodiment may include the first, second, or third embodiment, for example, wherein a hopper system is included as part of the hot inlet and/or hot exit vapor belts, to collect particulate matter from the hot-side flow.

[0040] In one embodiment, a thermosyphon/heat pipe heat exchanger is provided to leverage the high surface area-specific heat transfer rates of thermosyphons/heat pipes, to effect a compact and low-cost heat exchanger design, relative to traditional heat exchangers. Within the thermosyphon/heat pipe exchanger, a plenum located at the top end of the thermosyphons/heat pipes, to which the thermosyphons/heat pipes are open, allows for reduced cost and time for thermosyphon/heat pipe charging as the thermosyphons/heat pipes can be simultaneously charged with a uniform charge, and which for vacuum charging allows for lower vacuum requirements while maintaining acceptable thermosyphon/heat pipe performance as the plenum provides a volume to contain non-evacuated gases. This also allows for economical field-adjustment of the thermosyphon/heat pipe charge, and provides a volume for collection of non-condensable gases formed by reaction of the thermosyphons/heat pipe materials with the thermosyphon/heat pipe working fluid, without impact to the performance of the thermosyphons/heat pipes, such that previously-unacceptable low-cost materials can then be used without negative impact to the performance of the heat exchanger.

[0041] In one embodiment, a pressure relief valve, safety relief valve, or pressure relief system may be positioned on the plenum described above, which allows for reduction in

thermosyphon/heat pipe design pressure in high temperature applications, and a corresponding reduction in thermosyphon/heat pipe wall thickness which both increases thermosyphon/heat pipe heat transfer and reduces cost. This feature allows for implementation of pressure and temperature limits on the thermosyphon/heat pipe working fluid, and allows for independent design control over both the working fluid charge and the dry-out temperature, unlike sealed thermosyphon/heat pipe systems where the dry-out temperature is determined only by working fluid and charge. This valve may also be of the pressure safety valve type, with available manual operation for use when charging the thermosyphons/heat pipes, else an additional manual valve may be placed directly on the plenum, for example, for the purpose of charging the thermosyphons/heat pipes.

[0042] In one embodiment, the working fluid and charge of the thermosyphons/heat pipes may be set to place the freezing temperature and/or dry-out temperature of the thermosyphon/heat pipe working fluid to prevent further heat transfer above the dry-out temperature or below the freezing temperature. For the case of the dry-out temperature, this may be done to protect the exchanger cold-side fluid against overheating or decomposition, or in some cases to avoid vaporization of the cold-side fluid.

[0043] In one embodiment, the relief pressure may be set below, at, or above the dry-out temperature of the selected working fluid and charge. Thus, the relief pressure setting and/or the dry-out temperature may be set such that the cold-side fluid remains at or below the maximum allowable temperature.

[0044] One embodiment enables thermal isolation of the exchanger hot and cold fluids, such that minimal heat transfer occurs directly between the fluids and substantially all heat transfer is performed and controlled by the thermosyphons/heat pipes.

[0045] Implementations of the subject invention exhibit inherent low pressure loss on both sides of the heat exchanger, due to low fluid velocities and minimal requirements for pressure loss to increase heat transfer. Also, embodiments of the subject invention exhibit uniform flow distribution through the exchanger, with the provision to include inlet guide vanes and/or internal baffles as needed to further improve the flow distribution. Internal baffles may also be used as a means to secure the thermosyphons/heat pipes against lateral motion caused by impingement of flow from the hot inlet, or other sources of excitation.

[0046] In addition to measuring fluid flows, pressures, and temperatures in heat exchangers, embodiments of the subject invention provide for simple implementation of measurement of both the pressure and temperature in the thermosyphons/heat pipes, thereby ensuring proper charge, operating pressure margin, and allowing for identification of the degree to which non-condensable gases exist in the thermosyphon/heat pipe fluid volume.

[0047] Embodiments of the subject invention provide multiple features for ease of cleaning and maintenance. In one embodiment, with hot inlet and exit piping removed, direct access may be provided through the hot inlet and exit connections for cleaning of the hot side heat transfer surfaces of the thermosyphons/heat pipes, where particulate matter, soot, oil, scale, or other deposits may form, that reduce the heat transfer of the exchanger surfaces. Such cleaning may be performed via chemical agent, or pressure cleaning with liquid. This feature may be further enhanced via use of a square tube pattern for the thermosyphon/heat pipe array, thereby allowing direct use of mechanical cleaning tools via the resulting straight tube gaps (cleaning channels) across the entire width of the exchanger. A drain may be positioned at the bottom of the exchanger housing to allow evacuation of cleaning liquids and fouling debris removed from the heat transfer surfaces. For more complete cleaning, access features may be incorporated into the

hot housing to more directly access the thermosyphons/heat pipes. In addition, in accordance with one embodiment the heat exchanger design is well-suited for acoustic on-line cleaning.

[0048] Implementation of one embodiment results in low thermal stresses in all components of the exchanger. The thermosyphons/heat pipes may be connected (via welding or roll expansion, for example) to both the upper plenum plate and the separation plate, but are free to expand thermally in the hot section of the exchanger, where thermal growth and thermal stress concerns are greatest, due to built-in clearance between the bottom of the thermosyphon/heat pipe tubes and the bottom of the exchanger. For the cold section, which may be completely welded, the housing and thermosyphons/heat pipes may see similar thermal growth, thereby minimizing thermal stresses in this section of the exchanger. In one embodiment, for applications where cold section thermal stresses are unacceptably high, an expansion joint may be used in the cold housing.

[0049] Applications of the subject invention include, but are not limited to a direct evaporator ORC power plants; a district heating heat exchanger for heating of district water from high temperature waste heat sources such as gas engines; a heat exchanger for heating of fluids other than district water from high temperature waste heat sources such as gas engines; a heat exchanger for heating of volatile fluids such as fuel gas for power plants, or between volatile streams such as heaters used in oil and gas production and processing; a heat exchanger for applications for shell and tube or other conventional heat exchangers; and a heat exchanger for waste heat boiler applications, wherein an embodiment of the subject invention produces superheated or saturated steam, for process or power generation.

[0050] The foregoing description of possible implementations consistent with the method and system disclosed herein does not represent a comprehensive list of all such implementations or

all variations of the implementations described. The description of only some implementation should not be construed as an intent to exclude other implementations. For example, artisans will understand how to implement the system and method disclosed herein in many other ways, using equivalents and alternatives that do not depart from the scope of the system and method disclosed herein. Moreover, unless indicated to the contrary in the preceding description, none of the components described in the implementations are essential to the system and method disclosed herein. It is thus intended that the specification and examples be considered as exemplary only.

Claims:

1. A heat exchanger comprising:
 - a first bolted flange for receiving hot fluid into the heat exchanger;
 - a hot-side housing inlet vapor belt connected to said first bolted flange for distributing flow of said hot fluid within a hot-side flow volume of said heat exchanger;
 - a first set of one or more heat pipes for cooling the distributed flow of said hot fluid;
 - a hot side housing exit vapor belt for collecting hot-side flow evenly from around a circumference of a hot-side housing and for delivering the cooled fluid to a second bolted flange connected to said hot side housing exit vapor belt so that the cooled fluid leaves the heat exchanger through said second bolted flange;
 - a third bolted flange for receiving cold fluid into the heat exchanger;
 - a second set of one or more heat pipes for heating said cold fluid;
 - a fourth bolted flange for receiving the heated fluid so that the heated fluid leaves the heat exchanger through said fourth bolted flange; and
 - a fifth bolted flange for connecting a plenum housing to a relief valve piping;wherein said relief valve piping is connected to a pressure relief valve, pressure safety valve, or pressure relief system that remains closed during normal operation of the heat exchanger and opens to maintain pressure when operating pressure of the first and second set of heat pipes increases above a pre-determined limit for continuous operation of the exchanger .
2. The heat exchanger of claim 1, wherein the first set or the second set of heat pipes comprises one or more heat pipes with a wick.
3. The heat exchanger of claim 1, wherein the first set or the second set of heat pipes comprises one or more wickless heat pipes.

4. The heat exchanger of claim 1, further comprising a plenum plate attached to said second set of heat pipes and separating a plenum from cold side flow volume of the heat exchanger.

5. The heat exchanger of claim 4, wherein the second set of heat pipes are open at the top and open to said plenum by passing through said plenum plate or by holes in the plenum plate,

6. The heat exchanger of claim 1, further comprising a plenum plate connected to a cold-side housing and the plenum housing.

7. The heat exchanger of claim 6, wherein said plenum plate seals a cold side of the heat exchanger from an upper plenum.

8. The heat exchanger of claim 1, further comprising a separation plate connected to a cold-side housing and the hot-side exit vapor belt.

9. The heat exchanger of claim 8, wherein said separation plate seals a cold side of the heat exchanger from a hot side of the heat exchanger.

10. The heat exchanger of claim 8, wherein said separation plate contains an opening, hole, or a plenum within the separation plate, such that first set or the second set of heat pipes connected to the separation plate is open to the opening, hole, or plenum within the separation plate.

11. The heat exchanger of claim 1, further comprising a plate attached to the bottom of the first set of heat pipes, and which contains an opening, hole, or a plenum within the plate, such that heat pipes connected to the plate are open to the opening, hole, or plenum within the plate.

12. The heat exchanger of claim 1, wherein a hopper system is included as part of the hot inlet or hot exit vapor belts, to collect particulate matter from the hot-side flow.

13. The heat exchanger of claim 1, wherein said first and second sets of heat pipes form a

single set of continuous heat pipes.

14. The heat exchanger of claim 1, wherein said first and second sets of heat pipes are open to each other.

15. A heat exchanger comprising:

a first bolted flange open at the bottom of the heat exchanger for receiving hot fluid into the heat exchanger;

a first set of one or more heat pipes for cooling said hot fluid;

a set of second bolted flanges for receiving the cooled fluid so that the cooled fluid leaves the heat exchanger through said set of second bolted flanges;

a third bolted flange for receiving cold fluid into the heat exchanger;

a second set of one or more heat pipes for heating said cold fluid;

a fourth bolted flange for receiving the heated fluid so that the heated fluid leaves the heat exchanger through said fourth bolted flange; and

a fifth bolted flange for connecting a plenum housing to a relief valve piping;

wherein said relief valve piping is connected to a pressure relief valve, pressure safety valve, or pressure relief system that remains closed during normal operation of the heat exchanger and opens to maintain pressure when operating pressure of the first or second set of heat pipes increases above a pre-determined limit for continuous operation of the exchanger.

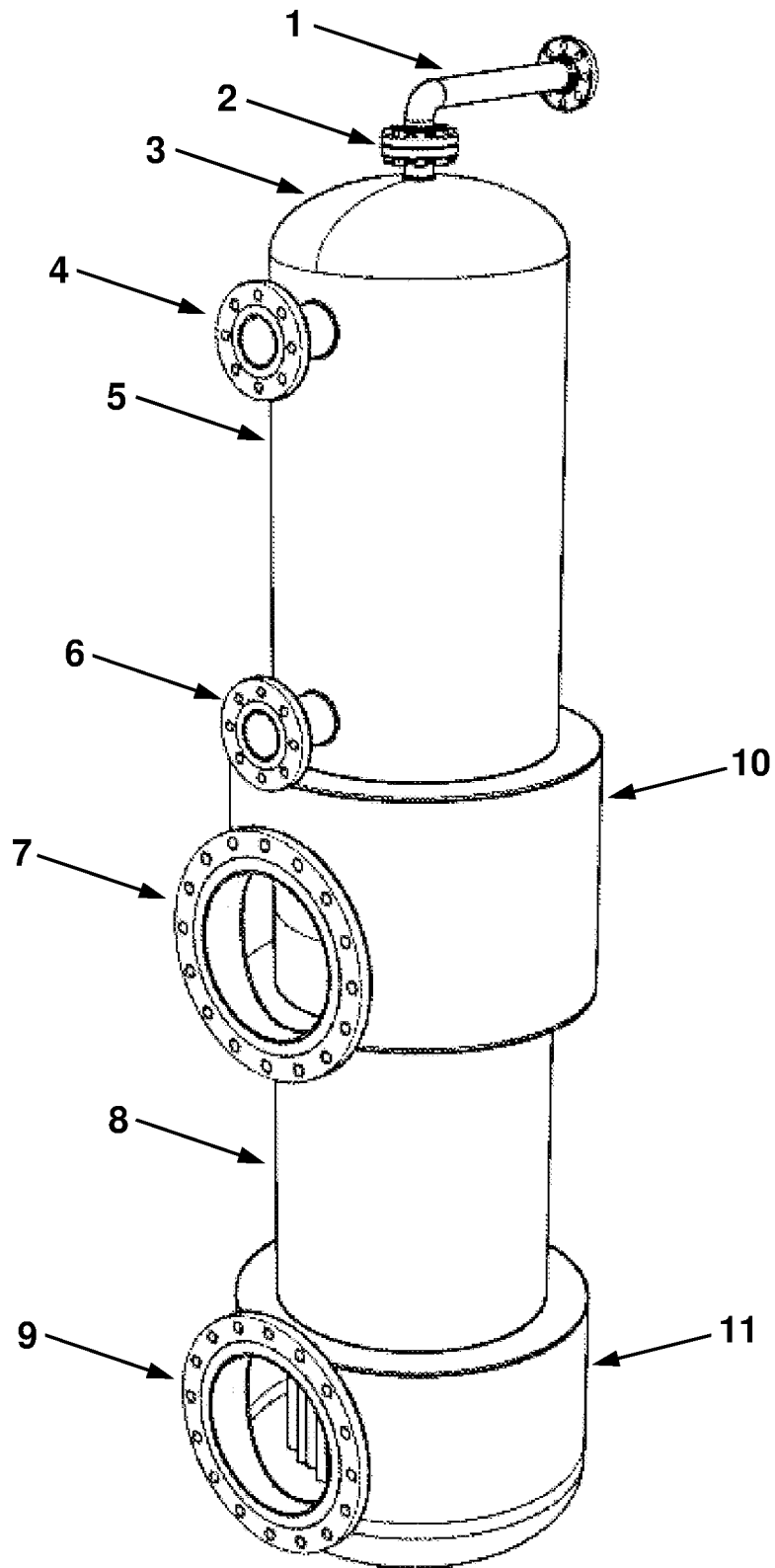


Figure 1

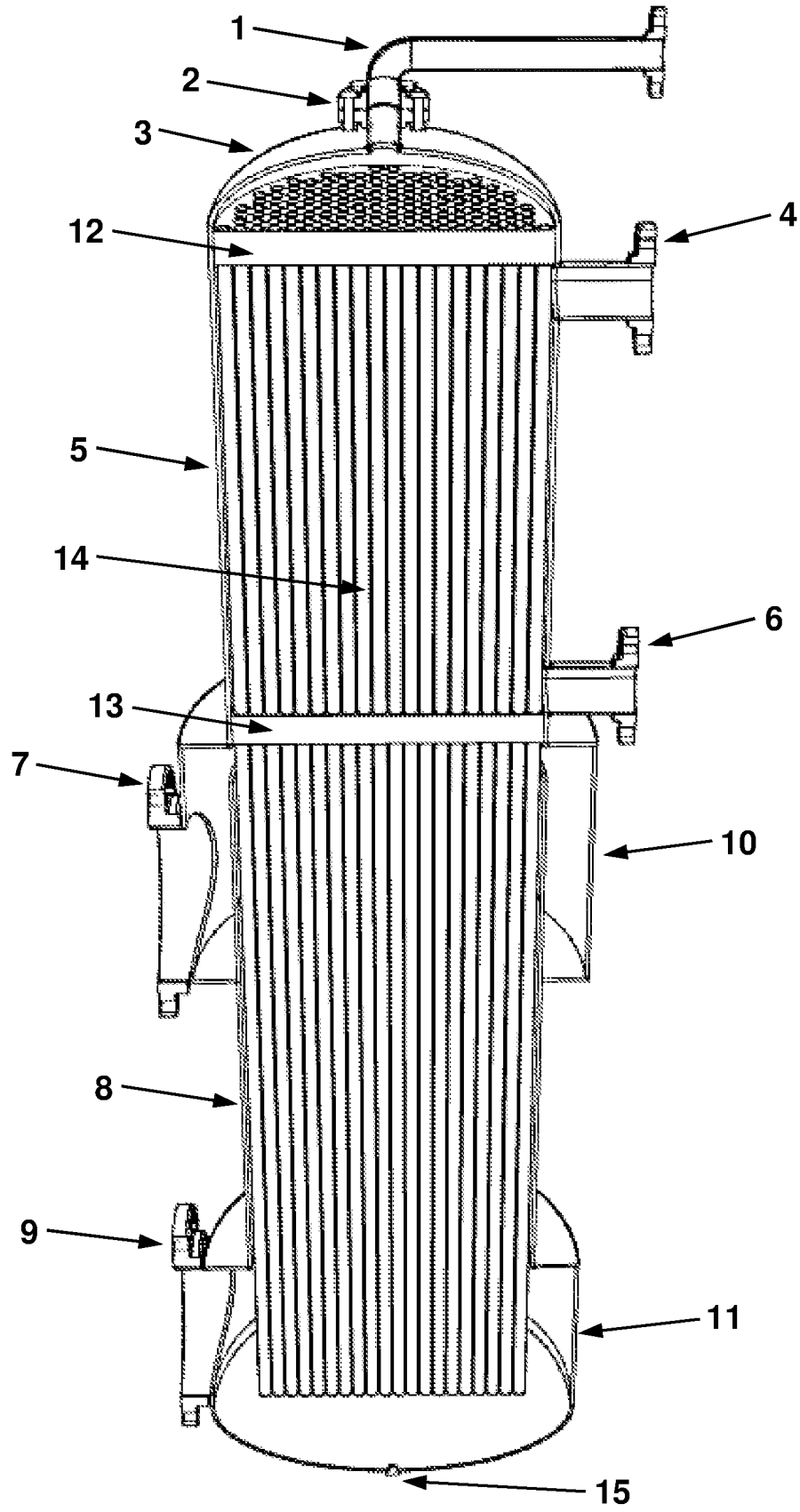


Figure 2

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/025848

A. CLASSIFICATION OF SUBJECT MATTER IPC(8) - F28F 27/00; B21D 53/02; F28D 15/00; F28D 15/02; F28D 15/04; F28F 9/26 (2016.01) CPC - F28F 27/02; F28D 15/00; F28F 9/0246 (2016.05) 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) - B21D 53/02; F28D 15/00; F28D 15/02; F28D 15/04; F28F 9/26; F28F 27/00 (2016.01) CPC - F28D 15/00; F28F 9/0246; F28F 27/02 (2016.05) Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched USPC - 165/128; 165/129 (keyword delimited) Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) PatBase, Google Patents, Google Scholar, Google Search terms used: wall thickness, pressurization, diffusion, heat pipes, vapor belt, relief valve, thermosyphon, bolted flange, separation plate, wick, hopper, heat exchanger, cold side, uniform flow distribution, collection belt, distributing belt		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,635,707 A (GENTRY) 13 January 1987 (13.01.1987) entire document	1-7, 11, 13-15
Y	US 2,513,178 A (JACKSON) 27 June 1950 (27.06.1950) entire document	1-7, 11, 13-15
Y	US 2012/0261102 A1 (HEBERT) 18 October 2012 (18.10.2012) entire document	1-7, 11, 13-15
Y	US 2006/0060329 A1 (IMURA et al) 23 March 2006 (23.03.2006) entire document	2, 3
Y	EP 0 469 260 A1 (ABB AIR PREHEATER, INC.) 05 February 1992 (05.02.1992) entire document	4-7, 11, 13, 14
A	US 2010/0315781 A1 (AGOSTINI) 16 December 2010 (16.12.2010) entire document	1-15
A	GB 842,484 A (COLCRETE LTD) 27 July 1960 (27.07.1960) entire document	1-15
A	US 2014/0008034 A1 (JACKOWSKI et al) 09 January 2014 (09.01.2014) entire document	1-15
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
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Date of the actual completion of the international search		Date of mailing of the international search report
26 May 2016		24 JUN 2016
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300		Authorized officer Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774