

INDIRECT HEAT EXCHANGER

BACKGROUND AND SUMMARY OF THE INVENTION

The present invention relates to heat exchangers, and more particularly, to an indirect
5 heat exchanger comprised of a plurality of tube run circuits. Each circuit is comprised of a tube
having a plurality of tube runs and a plurality of return bends. Each tube may have the same
surface area from near its connection to an inlet header to near its connection to an outlet header.
However, the geometry of the tube run is changed as the tube runs extend from the inlet to near
the outlet header. In one case, the horizontal cross sectional dimension of the tube runs decrease
10 as the tube runs extend to near the outlet header. Such decrease in horizontal cross sectional
dimension may be progressive from the near the inlet header to near the outlet header or each
coil tube run may have a uniform horizontal cross sectional dimension, with at least one
horizontal cross section dimension of tube runs decreasing nearer to the outlet header.

In particular, an indirect heat exchanger is provided comprising a plurality of circuits,
15 with an inlet header connected to an inlet end of each circuit and an outlet header connected to an
outlet end of each circuit. Each circuit is comprised of a tube run that extends in a series of runs
and return bends from the inlet end of each circuit to the outlet end of each circuit. In the
embodiments, the tube runs may have return bends or may be one long straight tube with no
return bends such as with a steam condenser coil. Each circuit tube run has a pre-selected
20 horizontal cross sectional dimension near the inlet end of each coil circuit, and each circuit tube
run has a decreasing horizontal cross sectional dimension as the circuit tube extends from near
the inlet end of each circuit to near the outlet end of each coil circuit.

The embodiments presented start out with a larger tube geometry either in horizontal cross sectional dimension or cross sectional area in the first runs near the inlet header and then have a reduction or flattening (at least once) in the horizontal cross-sectional dimension of tube runs proceeding from the inlet to the outlet and usually in the direction of airflow. A key advantage towards progressive flattening in a condenser is that the internal cross sectional area needs to be the largest where the least dense vapor enters the tube run. This invites gas into the tube run by reducing the internal side pressure drop allowing more vapor to enter the tube runs. The reduction of horizontal tube run cross sectional dimension, or flattening of the tube in the direction of air flow accomplishes several advantages over prior art heat exchangers. First, the reduced projected area reduces the drag coefficient which imposes a lower resistance to air flow thereby allowing more air to flow. In addition to airflow gains, for condensers, as refrigerant is condensed there is less need for interior cross sectional area as one progresses from the beginning (vapor-low density) to the end (liquid – high density) so it is beneficial to reduce the internal cross sectional area as the fluid flows from the inlet to the outlet allowing higher internal fluid velocities and hence higher internal heat transfer coefficients. This is true for condensers and for fluid coolers, especially fluid coolers with lower internal fluid velocities. In one embodiment shown, the tube may start round and the geometric shape is progressively streamlined for each group of two tube runs. The decision of how many tube runs have a more streamlined shape and a reduction in the horizontal cross sectional dimension and how much of a reduction is required is a balance between the amount of airflow improvement desired, the amount of internal heat transfer coefficient desired, difficulty in degree of manufacturing and allowable internal tube side pressure drop.

Typical tube run diameters covering indirect heat exchangers range from 1/4" to 2.0"

however this is not a limitation of the invention. When tube runs start with a large internal cross sectional area and then are progressively flattened, the circumference of the tube and hence

50 surface area remain essentially unchanged at any of the flattening ratios for a given tube diameter while the internal cross sectional area is progressively reduced and the projected area in the air flow external to the indirect heat exchanger is also reduced. The general shape of the flattened tube may be elliptical, ovoided with one or two axis of symmetry, a flat sided oval or any streamlined shape. A key metric in determining the performance and pressure drop benefits of
55 each pass is the ratio of the long (vertical) side of the oval to the shortest (horizontal) side. A round tube would have a 1:1 ratio. The level of flattening is indicated by increasing ratios of the sides. This invention relates to ratios ranging from 1:1 up to 6:1 to offer optimum performance tradeoffs. The optimum maximum oval ratio for each indirect heat exchanger tube run is dependent on the working fluid inside the coil, the amount of airside performance gain desired,
60 the desired increase in internal fluid velocity and increase of internal heat transfer coefficients, the operating conditions of the coil, the allowable internal tube side pressure drop as well as the manufacturability of the desired geometry of the coil. In an ideal situation, all these parameters will be balanced to satisfy the exact need of the customer to optimize system performance, thereby minimizing energy and water consumption.

65 The granularity of the flattening progression is an important aspect of this invention. At one extreme is a design where by the amount of flattening is progressively increased through the length of multiple passes or tube runs of each circuit. This could be accomplished through an automated roller system built into the tube manufacturing process. A similar design with less granularity would involve at least one step reduction such that one or more passes or tube runs of

70 each circuit would have the same level of flattening. For example, one design might have the first tube run with no degree of flattening, as would be the case with a round tube, and the next three circuit tube runs would have one level of compression factor (degree of flattening) and the final four tube run passes would have another level (higher degree) of compression factor. The least granular design would have one or more passes or tube runs of round tube followed by one
75 or more passes or tube runs of a single level of flattened tube. This could be accomplished with a set of rollers or by supplying a top coil with round tubes and the bottom coil with elliptical or flattened tubes. Yet another means to manufacture the different tube geometric shapes would be to stamp out the varying tube shapes and weld the plates together as found in 4,434,112. It is likely that heat exchangers will soon be designed and produced via 3D printer machines to the
80 exact geometries to optimize heat transfer as proposed in this invention.

The tube run flattening could be accomplished in-line with the tube manufacturing process via the addition of automated rollers between the tube mill and bending process. Alternately, the flattening process could be accomplished as a separate step with a pressing operation after the bending has occurred. The embodiments presented are applicable to any
85 common heat exchanger tube material with the most common being galvanized carbon steel, copper, aluminum, and stainless steel but the material is not a limitation of the invention.

Now that the tube circuits can be progressively flattened thereby reducing the horizontal cross sectional dimension, it is possible now to extremely densify the tube run circuits without choking external air flow. The proposed embodiments thusly allow for “extreme densifying” of
90 indirect heat exchanger tube circuits. A method described in U.S patent 6,820,685 can be employed to provide depression areas in the area of overlap of the U-bends to locally reduce the diameter at the return bend if desired. In addition, users skilled in the art will be able to

manufacture return bends in tube runs at the desired flattening ratios and this is not a limitation of the invention.

95 Another way to manufacture a change in geometrics shape is to employ the use of a top and bottom indirect heat exchanger. The top heat exchanger may be made of all round tubes while the bottom heat exchanger can be made with a more streamlined shape. This conserves the heat transfer surface area while increasing overall air flow and decreasing the internal cross sectional area. Another way to manufacture a change in geometric shape is to employ the use of
100 a top and bottom indirect heat exchanger. The top heat exchanger may be made of all round tubes while the bottom heat exchanger can be made with a reduction in circuits compared to the top coil. This reduces the heat transfer surface area while increasing overall air flow and decreasing the internal cross sectional area. As long as the top and bottom coils have at least one change in geometric shape or number of circuits, the indirect heat exchange system would be in
105 accordance with this embodiment.

It is an object of the invention to start out with large internal cross sectional area tube runs then progressively reduce the horizontal cross sectional dimension of tube runs as they progress from the inlet to the outlet to reduce the drag coefficient and allow more external airflow.

110 It is an object of the invention to start out with large internal cross sectional area tube runs then progressively reduce the horizontal cross sectional dimension of the tube runs as they progress from the inlet to the outlet to allow the lowest density fluid (vapor) to enter the tube run with very little pressure drop to maximize internal fluid flow rate.

115 It is an object of the invention to start out with large internal cross sectional area tube runs then progressively reduce the horizontal cross sectional dimension of tube runs as they progress from the inlet to the outlet to allow for extreme tube circuit densification without choking external airflow.

 It is an object of the invention to start out with large internal cross sectional area tube runs then progressively reduce the horizontal cross sectional dimension of tube runs as they progress from the inlet to the outlet to increase the internal fluid velocity and increase internal heat transfer coefficients in the direction of internal fluid flow path.

 It is an object of the invention to start out with large internal cross sectional area tube runs then progressively reduce the horizontal cross sectional dimension of tube runs as they progress from the inlet to the outlet on condensers to take advantage of the fact that as the vapor condenses, there is less cross sectional area needed resulting in higher internal heat transfer coefficients with more airflow hence more capacity.

 It is an object of the invention to start out with large internal cross sectional area tube runs then progressively reduce the horizontal cross sectional dimension of tube runs as they progress from the inlet to the outlet by balancing the customer demand on capacity desired and allowable internal fluid pressure drop to customize the indirect heat exchanger design to meet and exceed customer expectations.

 It is an object of the invention to change a circuits tube run geometric shape at least once along the circuit path to allow simultaneously balancing of the external airflow, internal heat transfer coefficients, cross sectional area and heat transfer surface area to optimize heat transfer.

It is an object of the invention to change a plate coil's geometric shape at least once along the circuit path to allow simultaneously balancing of the external airflow, internal heat transfer coefficients, cross sectional area and heat transfer surface area to optimize heat transfer.

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BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Fig. 1 is a side view of a prior art indirect heat exchanger including a series of serpentine tube runs;

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Fig. 2A is an end view of an indirect heat exchanger in accordance with the first embodiment of the present invention;

Fig. 2B is an end view of an indirect heat exchanger in accordance with a second embodiment of the present invention;

Fig. 3 is a side view of one circuit from the indirect heat exchanger in accordance with the first embodiment of the present invention;

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Fig.4A is an end view of an indirect heat exchanger in accordance with a third embodiment of the present invention;

Fig.4B is an end view of an indirect heat exchanger in accordance with a fourth embodiment of the present invention;

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Fig.5 is an end view of an indirect heat exchanger in accordance with a fifth embodiment of the present invention;

Fig.6 is an end view of two indirect heat exchangers in accordance with a sixth embodiment of the present invention;

Fig. 7A is an end view of two indirect heat exchangers in accordance with a seventh embodiment of the present invention;

160 Fig. 7B is an end view of two indirect heat exchangers in accordance with a eighth embodiment of the present invention;

Fig. 7C is an end view of two indirect heat exchangers in accordance with a ninth embodiment of the present invention;

165 Fig. 8 is an end view of two indirect heat exchangers in accordance with a tenth embodiment of the present invention;

Figs. 9 is a 3-D view of an indirect heat exchanger in accordance with an eleventh embodiment of the present invention.

Fig. 10A, Fig 10B and Fig 10C are partial perspective views of the eleventh embodiment of the present invention;

170 Fig 11A is an end view of an indirect heat exchanger in accordance with a twelfth embodiment of the present invention;

Fig. 11B is a 3-D view of the twelfth embodiment of the present invention.

DETAILED DESCRIPTION

Referring now to Figure 1, a prior art evaporative cooled coil product 10 which could be
175 a closed circuit cooling tower or an evaporative condenser. Both of these products are well known and can operate wet in the evaporative mode, partially wet in a hybrid mode or can operate dry, with the spray pump 12 turned off when ambient conditions or lower loads permit. Pump 12 receives the coldest cooled evaporatively sprayed fluid, usually water, from cold water sump 11 and pumps it to primary spray water header 19 where the water comes out of nozzles or
180 orifices 17 to distribute water over indirect heat exchanger 14. Spray water header 19 and

nozzles 17 serve to evenly distribute the water over the top of the indirect heat exchanger 14. As the coldest water is distributed over the top of indirect heat exchanger 14, motor 21 spins fan 22 which induces or pulls ambient air in through inlet louvers 13, up through indirect heat exchanger 14, then through drift eliminators 20 which serve to prevent drift from leaving the unit, and then the warmed air is blown to the environment. The air generally flows in a counterflow direction to the falling spray water. Although Figure 1 is shown with axial fan 22 inducing or pulling air through the unit, the actual fan system may be any style fan system that moves air through the unit including but not limited to induced and forced draft in a generally counterflow, crossflow or parallel flow with respect to the spray . Additionally, motor 21 may be belt drive as shown, gear drive or directly connected to the fan. Indirect heat exchanger 14 is shown with an inlet connection pipe 15 connected to inlet header 24 and outlet connection pipe 16 connected to outlet header 25. Inlet header 24 connects to the inlet of the multiple serpentine tube circuits while outlet header 25 connects to the outlet of the multiple serpentine tube circuits. Serpentine tube runs are connected with return bend sections 18. Return bend sections 18 may be continuously formed into the circuit called serpentine tube runs or may be welded between straight lengths of tubes. It should be understood that the process fluid direction may be reversed to optimize heat transfer and is not a limitation to embodiments presented. It also should be understood that the number of circuits and the number of passes or rows of tube runs within a serpentine indirect heat exchanger is not a limitation to embodiments presented.

Referring now to Figure 2A, indirect coil 100 is in accordance with a first embodiment of the present invention. Figure 2A shows eight circuits and eight passes or tube rows of embodiment 100. Indirect heat exchanger 100 has inlet and outlet headers 102 and 104 and is comprised of tube runs 106, 107, 108, 109, 110, 111, 112, and 113. Tube runs 106 and 107 are a

pair of identical geometry round tubes and have equivalent tube diameters 101. Tube runs 108
205 and 109 are another pair of tube runs having a different geometry compared to tubes run pairs
106 and 107 with equivalent shapes having reduced horizontal dimensions D3 and increased
vertical dimension D4 with respect to round tubes 106 and 107. The ratio of D4 to D3 is usually
greater than 1.0 and less than 6.0. Further, indirect heat exchanger tube run 108 and 109 may
have a uniform ratio of D4 to D3 along its length as shown, or a uniformly increasing ratio of D4
210 to D3 along its length. The pair of tube runs 110 and 111 have yet a different geometry and have
equivalent shapes with reduced horizontal dimensions D5 and increased vertical dimension D6
with respect to tube runs 108 and 109. The ratio of D6 to D5 is usually greater than 1.0, less than
6.0 and is also greater than ratio D4 to D3. Further, tube run 110 and 111 may have a uniform
ratio of D6 to D5 along its length as shown, or a uniformly increasing ratio of D6 to D5 along its
215 length. The pair of tube runs 112 and 113 have yet a different geometry and have equivalent
shapes with reduced horizontal dimensions D7 and increased vertical dimension D8 with respect
to tube runs 110 and 111. The ratio of D8 to D7 is usually greater than 1.0, less than 6.0 and also
greater than ratio D6 to D5. Further, tube runs 112 and 113 may have a uniform ratio of D8 to
D7 along its length as shown, or a uniformly increasing ratio of D8 to D7 along its length. Tube
220 run 106 is connected to inlet header 102 of indirect heat exchanger 100 and tube run 113 is
connected to outlet header 104. In a preferred embodiment arrangement, the tubes are round at
the inlet having a 1.0 vertical to horizontal tube run dimension ratio and are progressively
flattened up to a vertical to horizontal tube run dimension ratio near 3.0 near the outlet. The
practical limits of horizontal to vertical dimension ratios are between 1.0 for round tubes and
225 may be as high as 6. It should be understood in this first embodiment, that as the vertical to
horizontal tube run dimension ratio increases, the tube runs become flatter and more streamlined

which allows more airflow while keeping the internal and external surface area constant. It should be noted that in the first embodiment, the horizontal dimension is progressively reduced from the inlet to the outlet of the tube runs while the vertical dimension is progressively increased from the inlet to the outlet. It should be further understood that the tube shapes can start as round and be progressively flattened as shown, can start as flattened and be progressively more flattened or start out streamlined and become more streamlined. When dealing with elliptical shapes, the B/A ratio is usually greater than 1 and refers to the major and minor axis respectively. It should be further understood that the first tube run could be elliptical with a B/A ratio close to 1.0 and progressively increase the B/A elliptical ratio from the inlet to the outlet. It should be understood that the first embodiment shows progressively reduced horizontal dimensions and progressively increased vertical dimensions from the first to the last tube run and that the initial shape, whether round, elliptical or streamlined is not a limitation of the embodiment. It should further be understood that every two passes may have the same tube shape as shown or the entire tube may be progressively flattened or streamlined. The decision on how to make the indirect heat exchanger circuits is a balance between the amount of airflow improvement desired, difficulty in degree of manufacturing and allowable internal tube side pressure drop.

Referring now to Figure 2B, indirect coil 150 is in accordance with a second embodiment of the present invention. Figure 2B shows eight circuits and eight passes or tube rows of embodiment 150. Indirect heat exchanger 150 has inlet and outlet headers 102 and 104 and is comprised of tube runs 106, 107, 108, 109, 110, 111, 112, and 113. Tube runs 106 and 107 in Figure 2B are not round as they were in Fig 2A, instead they are a pair of tube runs having initial horizontal dimension D1 and initial vertical dimension D2. Tube runs 108 and 109 are another

250 pair of tube runs having a different geometry compared to tubes run pairs 106 and 107 with
equivalent shapes having reduced horizontal dimensions D3 and increased vertical dimension D4
with respect to round tubes 106 and 107. The ratio of D4 to D3 is usually greater than 1.0 and
less than 6.0 and the ratio of D4 to D3 is usually larger than the ratio of D2 to D1. Further,
indirect heat exchanger tube run 108 and 109 may have a uniform ratio of D4 to D3 along its
255 length as shown, or a uniformly increasing ratio of D4 to D3 along its length. The pair of tube
runs 110 and 111 have yet a different geometry and have equivalent shapes with reduced
horizontal dimensions D5 and increased vertical dimension D6 with respect to tube runs 108 and
109. The ratio of D6 to D5 is usually greater than 1.0, less than 6.0 and is also greater than ratio
D4 to D3. Further, tube run 110 and 111 may have a uniform ratio of D6 to D5 along its length
260 as shown, or a uniformly increasing ratio of D6 to D5 along its length. The pair of tube runs
112 and 113 have yet a different geometry and have equivalent shapes with reduced horizontal
dimensions D7 and increased vertical dimension D8 with respect to tube runs 110 and 111. The
ratio of D8 to D7 is usually greater than 1.0, less than 6.0 and also greater than ratio D6 to D5.
Further, tube runs 112 and 113 may have a uniform ratio of D8 to D7 along its length as shown,
265 or a uniformly increasing ratio of D8 to D7 along its length. Tube run 106 is connected to inlet
header 102 of indirect heat exchanger 100 and tube run 113 is connected to outlet header 104. In
one arrangement, the tubes begin nearly round at the inlet having a vertical to horizontal tube run
dimension ratio near 1.0 and are progressively flattened up to a vertical to horizontal tube run
dimension ratio near 3.0 near the outlet. The practical limits of horizontal to vertical dimension
270 ratios are between 1.0 for round tubes and may be as high as 6. It should be understood in this
second embodiment, that as the vertical to horizontal tube run dimension ratio increases, the tube
runs become flatter and more streamlined which allows more airflow while keeping the internal

and external surface area constant. It should be noted that in this second embodiment, the horizontal dimension is progressively reduced from the inlet to the outlet of the tube runs while the vertical dimension is progressively increased from the inlet to the outlet. It should be further understood that the tube shapes can start slightly flattened, as compared to the first embodiment shown in Fig 2A which started with round tubes, and then be progressively flattened as shown or start out streamlined and become more streamlined. When dealing with elliptical shapes, the B/A ratio is usually greater than 1 and refers to the major and minor axis respectively. It should be further understood that the first tube run could be elliptical with a B/A ratio close to 1.0 and progressively increase the B/A elliptical ratio from the inlet to the outlet. It should be understood that the second embodiment shows progressively reduced horizontal dimensions and progressively increased vertical dimensions from the first to the last tube run and that the initial shape, whether round, elliptical or streamlined is not a limitation of the embodiment. It should further be understood that every two passes may have the same tube shape as shown or the entire tube may be progressively flattened or streamlined. The decision on how to make the indirect heat exchanger circuits is a balance between the amount of airflow improvement desired, difficulty in degree of manufacturing and allowable internal tube side pressure drop.

Referring now to Figure 3, circuit 103 from the first embodiment of Figure 2 is shown from a side view for understanding how each circuit may be constructed. Tube runs 106, 107, 108, 109, 110, 111, 112 and 113 are also shown from sectional view AA. Tube runs 106 and 107 are generally round tubes and have equivalent tube diameters 101. Tube run 106 has round U-bend 120 connecting it to tube run 107. Tube run 107 is connected to tube run 108 with transition 115. Transition 115 starts as round on one end and transitions to the shape of D4 to D3 ratio at the other end. Transition 115 can be simply pressed or casted from a die, extruded, or

can be a fitting which is typically welded or brazed into the tube runs. Transition 115 can also be pressed into the tube when the tube is going through the serpentine bending operation. The method of forming transition 115 is not a limitation of the invention. Round U-bends 120 can be formed to nest to the next return bend such that the number of circuits in the indirect heat exchanger may be densified as taught in 6,820,685. U-bends 120 may also be mechanically flattened while the tube runs are being bent and assume the general shape at each tube run pass which would be a changing return bends shape throughout the coil circuit. The previous discussion is the same for transitions 115, 116 and 117. Tube runs 108 and 109 have equivalent and reduced horizontal dimensions D3 and increased vertical dimension D4. The ratio of D4 to D3 is usually greater than 1.0 and less than 6.0. Further, coil tube run 108 and 109 may have a uniform ratio of D4 to D3 along its length as shown, or a uniformly increasing ratio of D4 to D3 along its length. Tube runs 110 and 111 have equivalent and reduced horizontal dimensions D5 and increased vertical dimension D6. The ratio of D6 to D5 is usually greater than 1.0, less than 6.0 and also greater than ratio D4 to D3. Further, tube runs 110 and 111 may have a uniform ratio of D6 to D5 along its length as shown, or a uniformly increasing ratio of D6 to D5 along its length. Tube runs 112 and 113 have equivalent and reduced horizontal dimensions D7 and increased vertical dimension D8. The ratio of D8 to D7 is usually greater than 1.0, less than 6.0 and also greater than ratio D6 to D5. Further, tube run 112 and 113 may have a uniform ratio of D8 to D7 along its length as shown, or a uniformly increasing ratio of D8 to D7 along its length.

Referring now to Figure 4A, indirect heat exchanger 200 is in accordance with a third embodiment of the present invention. Embodiment 200 has eight circuits and eight passes or tube runs. Embodiment 200 has at least one reduction in horizontal dimension and one increase in vertical dimension within the circuit tube runs. Indirect heat exchanger 200 has inlet and

outlet headers 202 and 204 respectively and is comprised of coil tubes having run lengths 206,
320 207, 208, 209, 210, 211, 212 and 213. It should be noted that tube runs 206, 207, 208 and 209
have equivalent tube diameters 201. Embodiment 200 also has tube runs 210, 211, 212, and 213
each having equivalent horizontal cross section dimensions D3 and equivalent vertical cross
section dimensions D4. The ratio of D4 to D3 is usually greater than 1.0, less than 6.0 and the
vertical dimension D4 is larger than tube diameter 201 while the horizontal dimension D3 is less
325 than tube diameter 201. In one arrangement of the third embodiment, the first ratio is greater
than or equal to 1.0 and less than 2.0 (it's equal to 1.0 with round tubes) and the second ratio is
greater than the first ratio but less than 6.0. Of note is that in the third embodiment of Figure 4A,
each circuit tube run length has at least one change in geometric shape as the circuit tube run
extends from the inlet to the outlet. The decision of how many tube runs have reduced
330 horizontal cross section dimensions as shown with Figures 6 and 7 is a balance between the
amount of airflow improvement desired, difficulty in degree of manufacturing and allowable
internal tube side pressure drop and is not a limitation of the invention.

Referring now to Figure 4B, indirect heat exchanger 250 is in accordance with a fourth
embodiment of the present invention. Embodiment 250 has eight circuits and eight passes or
335 tube runs. Embodiment 250 has at least one reduction in horizontal dimension and increase in
vertical dimension within the circuit tube runs. Indirect heat exchanger 250 has inlet and outlet
headers 202 and 204 respectively and is comprised of coil tubes having run lengths 206, 207,
208, 209, 210, 211, 212 and 213. It should be noted that unlike the embodiment shown in
Figure 4A, which started with round tubes in the first passes or rows, embodiment 250 has tube
340 runs 206, 207, 208 and 209 each having equivalent horizontal cross section dimensions D1 and
equivalent vertical cross section dimensions D2. The ratio of D2 to D1 is usually greater than

1.0 and less than 6.0. Embodiment 250 also has tube runs 210, 211, 212, and 213 each having equivalent horizontal cross section dimensions D3 and equivalent vertical cross section dimensions D4. The ratio of D4 to D3 is usually greater than 1.0, less than 6.0 and usually
345 larger than the ratio of D2 to D1. In one arrangement of the fourth embodiment, the first ratio (D2/D1) is greater than or equal to 1.0 and less than 2.0 (D2/D1 is greater than 1.0 as shown) and the second ratio (D4/D3) is greater than the first ratio but less than 6.0. Of note is that in the fourth embodiment of Figure 4B, each circuit tube run length has at least one change in geometric shape as the circuit tube run extends from the inlet to the outlet. The decision of how
350 many tube runs have reduced horizontal cross section dimensions is a balance between the amount of airflow improvement desired, difficulty in degree of manufacturing and allowable internal tube side pressure drop and is not a limitation of the invention.

Referring now to Figure 5, indirect heat exchanger 300 is in accordance with a fifth embodiment of the present invention. Embodiment 300 has eight circuits and eight passes or
355 tube runs where each pair of tube runs have a different diameter and has progressively smaller diameters from the inlet tube run 306 to the outlet tube run 313. Embodiment 300 has inlet and outlet headers 302 and 304 respectively and is comprised of coil tubes having tube runs 306, 307, 308, 309, 310, 311, 312 and 313. It should be noted that the pair of tube runs 306 and 307 have diameter D1, tube runs 308 and 309 have tube diameter D2, tube runs 310 and 311 have tube
360 diameter D3, and tube runs 312 and 313 have tube diameter D4. It should be noted that there are progressively smaller tube run diameters proceeding from the inlet tube run 306 to the outlet tube run 313 and that $D1 > D2 > D3 > D4$. It is possible to have every tube run be a different diameter or there can only be one change in tube run diameter within the tube circuit runs and these both would still be in accordance with the fifth embodiment. The tubes are shown in the fifth

365 embodiment as round but each tube could be flattened or streamlined as well to provide even more airflow and the actual geometry is not a limitation of the invention. The decision on how many tube runs have a different diameter is a balance between the amount of airflow improvement desired, difficulty in degree of manufacturing and allowable internal tube side pressure drop. Tubes runs of differing diameters may be joined together by being welded or
370 brazed, joined by a reducing coupling, joined by sliding the smaller diameter tube inside the larger diameter tube and then brazing or could be mechanically fastened. The means of connecting tubes runs of differing diameters is not a limitation of the invention. The fifth embodiment has a reduction in cross sectional area, a reduction in tube surface area with an increase in external airflow.

375 Referring now to Figure 6, sixth embodiment 450 is shown with at least two indirect heat exchangers 400 and 500. Embodiment 450 has top indirect heat exchanger 400 with eight circuits and four passes or tube runs and bottom indirect heat exchanger 500 also has eight circuits and four passes or tube runs. Top indirect heat exchanger 400 is positioned on top of bottom indirect heat exchanger 500 such that there are a total of eight circuits and eight passes or
380 tube runs for the entire indirect heat exchanger of embodiment 450. Top indirect coil 400 has inlet and outlet headers 402 and 404 and is comprised of a tube runs 406,407,408 and 409 having generally round tube runs of the same diameter 465. It should be understood that tube runs 406,407,408 and 409 are four passes and comprise one of the eight circuits of indirect coil 400 and that the coil tubes are connected by Ubends that are not shown. Bottom indirect heat
385 exchanger 500 has inlet and outlet headers 502 and 504 and is comprised of tube runs 510,511,512 and 513. Tube runs in the bottom indirect heat exchanger 500 all have the same D2 to D1 ratio which is usually larger than 1.0, less than 6.0 and vertical dimension D2 is greater

than top indirect tube run diameter 465. It should be understood that tube runs 510, 511, 512 and 513 are four passes and comprise one of the eight circuits of indirect heat exchanger 500 and that the tube runs are connected by Ubends that are not shown. It should be further understood that all tubes shown in bottom indirect heat exchanger 500 have generally the same flattened tube shape and same D2 to D1 ratio. Top indirect heat exchanger outlet header 404 is connected to bottom indirect heat exchanger 500 inlet header 502 via connection piping 520 as shown.

Alternatively, inlet headers 402 and 502 may be connected in together in parallel and outlet headers 404 and 504 may be connected in parallel (not shown). Note that bottom indirect heat exchanger 500 may instead employ smaller diameter tubes or simply a more streamlined tube shape than the top indirect heat exchanger 400 tube runs and still be in accordance with the sixth embodiment. Top indirect heat exchanger 400 is shown with round tubes but as shown in Figure 4B, the tubes in top indirect section 400 may start with a less flattened shape than the bottom indirect heat exchange section 500 and still be in accordance with the sixth embodiment. Top and bottom indirect heat exchanger tube runs may all also be elliptical with the top indirect heat exchanger tube runs B/A ratio being smaller than the bottom indirect heat exchanger tube run B/A ratio and still is in accordance with the sixth embodiment. The decision on the geometry difference between the top and bottom indirect heat exchangers is a balance between the amount of airflow improvement desired, difficulty in degree of manufacturing and allowable internal tube side pressure drop.

Now referring to Figure 7A, 7B and 7C the seventh, eighth and ninth embodiments are shown respectively. To further increase heat exchange efficiency of the sixth embodiment shown in Figure 6, seventh embodiment 550 is shown in Figure 7A with gap 552 separating top indirect heat exchanger 400 and bottom indirect heat exchanger 500. Gap 552, which is greater

than one inch in height, allows more rain zone cooling of the spray water by allowing direct contact between the air flowing and the spray water generally flowing downward. Another way to further increase the heat exchange efficiency of the sixth embodiment 450 of Figure 6 is to add direct heat exchange section 554 between top indirect heat exchange section 400 and bottom indirect heat exchange section 500 as shown in eighth embodiment 560 in Figure 7B. Adding direct section 554, which is at least one inch in height, allows spray water cooling between indirect heat exchange sections 400 and 500 by allowing direct heat exchange between the air flowing and the spray water which is flowing generally downward. To achieve a hybrid mode of operation of sixth embodiment 450 shown in Figure 6, secondary spray section 556 is added between top indirect heat exchange section 400 and bottom indirect heat exchange section 500 as shown in ninth embodiment 570 in Figure 7C. Adding secondary spray section 556 allows bottom indirect heat exchanger 500 to operate wet when top heat exchange section 400 may run dry which saves water and adds a hybrid mode of operation.

Referring now to Figure 8, tenth embodiment 650 is shown with at least two indirect heat exchangers 600 and 700. Embodiment 650 has top indirect heat exchanger 600 with eight circuits and four passes or tube runs. Note however, that bottom indirect heat exchanger 700 has a reduction in the number of circuits compared to top indirect heat exchange section 600. In this case, bottom indirect section 700 has six circuits while top indirect section 600 has eight circuits. Top indirect heat exchanger 600 is positioned on top of bottom indirect heat exchanger 700 such that there are a total of eight tube runs but note that the reduction of horizontal tube projection is accomplished by changing the number of circuits hence changing the geometry of projected tubes in the airflow direction. This change in geometry between the top and bottom indirect sections 600 and 700 respectively decreases total tube cross section area, reduces total tube heat

transfer surface area while increases external airflow. Top indirect heat exchange section 600
435 has inlet and outlet headers 602 and 604 and is comprised of a tube runs 606,607,608 and 609
having generally round tube runs of the same diameter 665. It should be understood that tube
runs 606,607,608 and 609 are four passes and comprise one of the eight circuits of indirect heat
exchange section 600 and that the tube runs are connected by return bends that are not shown.
Bottom indirect heat exchange section 700 has inlet and outlet headers 702 and 704 and is
440 comprised of tube runs 710, 711, 712 and 713 all having generally round tube runs of the same
diameter 765 which is generally the same diameter as tube run diameters 665. It should be
understood that tube runs 710, 711, 712 and 713 are four passes and comprise one of the six
circuits of indirect heat exchanger 700 and that the tube runs are connected by return bends that
are not shown. Top indirect heat exchanger outlet header 604 is connected to bottom indirect
445 heat exchanger 700 inlet 702 via connection piping 620 as shown. Alternatively, inlet headers
602 and 702 may be connected in together in parallel and outlet headers 604 and 704 may be
connected in parallel (not shown). Note that top and bottom indirect heat exchange sections 600
and 700 respectively may employ the same tube shape, whether round, elliptical, flattened, or
streamlined. It is the reduction of circuits in bottom heat exchange section 700 which is the
450 methodology to reduce the horizontal projected tube geometry to increase air flow, increase
internal fluid velocity and internal heat transfer coefficients in the tenth embodiment 650. The
decision on the geometries used, and the difference in the number of circuits between the top and
bottom indirect heat exchanger sections is a balance between the amount of airflow improvement
desired, difficulty in degree of manufacturing and allowable internal tube side pressure drop. As
455 was shown in Figure 7A, 7B and 7C in how to further increase heat exchange efficiency of the
sixth embodiment which included two indirect heat exchanger sections, the same can be done

with the tenth embodiment where top indirect heat exchanger 600 and bottom indirect heat exchanger 700 can be separated by adding a gap greater than one inch as shown in Figure 7A or by adding a direct heat exchange section as shown in Figure 7B. To add a hybrid mode of operation to the tenth embodiment, a secondary spray section may be added between the two indirect heat exchangers 600 and 700 as shown in Figure 7C.

Now referring to Figure 9, eleventh embodiment 770 is shown as an air cooled steam condenser. Steam header 772 feeds steam to tube runs 774. Tube runs 774 are fastened to steam header 772 and condensate collection headers 779 by various techniques including welding and oven brazing and is not a limitation of the invention. Wavy fins 804 are fastened to tube runs 774 by various techniques such as welding and oven brazing and is not a limitation of the invention. The purpose of wavy fins 804 is to allow heat to transfer from the tube to the fin to the flowing air stream. As the steam condenses in tube runs 774, water condensate is collected in condensate collection headers 779. Fan motor 776 spins fan 777 to force air through steam condenser wavy fins 804. Fan deck 775 seals off the pressurized air leaving fan 777 so it must exit through wavy fins 804. There are multiple parallel tube run circuits 774 and to show the details of the change in geometry of the tube runs 774 and wavy fins 804, two circuits shown within dotted lines 800 are shown in Figures 10A, 10B, and 10C for clarity.

Now referring to Figure 10A, 10B& 10C, eleventh embodiment 770 from Figure 9 is redrawn to show two tube runs in Figure 10A which is a detailed view of tube runs 774 from Figure 9. It should be noted that tube runs 774 have no return bends but instead are one long tube run. The length of the tube runs are typically a few feet up to a hundred feet and is not a limitation of the invention. The tube run circuits 774 are shown with just two of many (hundreds) of repeated parallel tube runs now with tube runs 774 and wavy fins 804. Wavy fins

480 804 are typically installed to each side of tube run 802 and function to increase the heat transfer from the air being forced through the wavy fins 804 to indirectly to condense the steam inside tube runs 774. Tube runs 774 have a round internal cross section at the top (having maximum internal cross sectional area at the steam connection) with diameter 865 shown in Figures 10C. Tube run 774 is then progressively flattened from the top to the bottom such that the horizontal
485 cross section dimension D5 is less than diameter 865 and the ratio of D6 to D5 is usually greater than 1 and less than 6. In the case of starting with a non-round shape, such as with micro channels for example, the ratio may be increase upwards to 20.0. The key to this embodiment is a change in geometric shape from the top to the bottom and can be any shape that is more streamlined near the bottom than the top and is not limited to a flattened shape. The distance
490 between tube runs 774 can be seen at 838 at the top and wider dimension 840 at the bottom. The width of wavy fins 804 is 850 at the top and a wider dimension 852 at the bottom. This progressively widening of wavy fin 804 allows more contact area between the tube as one progresses from the top to bottom and more finned surface area as one travels from top to bottom which increases overall heat transfer to tube run 774. Referring to Figure 10C where wavy fin
495 804 has been removed for clarity, it can be seen that tube run 774 is round with diameter 865 at the top and is flattened with width D5 and length D6. As was discussed with all the other embodiments, the progressive flattening can be done in steps having a uniform flattening dimension every few feet or the tube runs may have a uniformly increasing ratio of length to width (shown as D6 to D5 at the bottom) along its entire length as shown in Figure 10C. There
500 are multiple improvements of the eleventh embodiment of Figure 10 over prior art. First, the internal cross sectional area is at a maximum at the top where the vapor to be condensed enters the tube. This allows the entering low density gas to flow at a higher flow rate with a lower

pressure drop. Later as the vapor condenses, the need for internal cross sectional area is reduced because there is a much denser fluid having both vapor and condensate in the flow path and the geometry change allows optimum use of heat transfer surface area. In addition, the external and internal surface area is the same at the top and bottom of each tube run yet as the horizontal cross sectional dimension is progressively reduced, more air is invited to flow as the tube run is progressively flattened. In addition, the reduced horizontal cross sectional dimension with respect to the air flow path increases internal fluid velocities and internal heat transfer coefficients while allowing more external air to flow which increases the ability to condense more vapor. Another advantage is that as the tube run is flattened the wavy fin may be increased in size in both width and length if desired, and the fin to tube contact area increases as one proceeds from the tip to the bottom of the tube run which increases heat transfer to the tube.

Now referring to Figure 11, an end view and 3D view of a twelfth embodiment of the present invention is shown as 950. Indirect heat exchange section 950 consists of indirect heat exchange plates 952 where, in a closed circuit cooling tower or evaporative condenser, evaporative water is sprayed on the external side of the plates and air is also passed on the external side of the plates to indirectly cool or condense the internal fluid. Inlet plate header 951 allows the fluid to enter the inside of the plates and exit heat 953 allows fluid inside the plates to exit back to the process. Of particular note is that centerline top spacing 954 and centerline bottom spacing 954 between the plates are uniform and generally equal while exterior plate air spacing gap 956 is purposely smaller than air spacing 957. Thus, the plates have a tapered shape in decreasing thickness from adjacent the inlet end to adjacent the outlet end. This change in plate geometry accomplishes many of the same benefits shown in all the other embodiments. In twelfth embodiment 950 there is essentially the same heat transfer surface area, a progressive

reduction of internal cross sectional area from the inlet (top) to the outlet (bottom) and a progressively larger air gap 956 at the top compared to 957 at the bottom which allows more airflow, increases internal fluid velocity and increases internal heat transfer coefficients as one travels from the top to the bottom. The decision on the geometries used and the progressive air gaps between the top and bottom indirect plate heat exchanger sections is a balance between the amount of airflow improvement desired, difficulty in degree of manufacturing and allowable internal plate side pressure drop.

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WHAT IS CLAIMED IS:

- 550 1. An indirect heat exchanger comprising:
a plurality of coil circuits,
an inlet header connected to an inlet end of each coil circuit and an outlet header
connected to an outlet end of each coil circuit,
each coil circuit comprised of a circuit tube that extends in a series of run lengths and
555 return bends from the inlet end of each coil circuit to the outlet end of each coil circuit,
each circuit tube run length having a decreasing horizontal cross sectional dimension and
an increasing vertical cross sectional dimension as the circuit tube run length extends from near
the inlet end of each coil circuit to near the outlet end of each coil circuit.
2. The indirect heat exchanger of claim 1
- 560 wherein each circuit tube has a cross sectional area that decreases from the inlet end of
each coil circuit to the outlet end of each coil circuit.
3. The indirect heat exchanger of claim 1
- wherein a first ratio of the vertical cross sectional dimension of each circuit tube run
length to the horizontal cross sectional dimension of each circuit tube run length exists near the
565 inlet end of each coil circuit, and a second ratio of the vertical cross sectional dimension of each
circuit tube run length to the horizontal cross sectional dimension of each circuit tube run length
exists near the outlet end of each coil circuit, and wherein the second ratio is larger than the first
ratio.
4. The indirect heat exchanger of claim 3
- 570 wherein the first ratio is between 1.0 and 2.0, and the second ratio is greater than the first
ratio but less than 6.0.

5. The indirect heat exchanger of claim 1

wherein each circuit tube is comprised of galvanized steel, stainless steel, aluminum, or copper.

575 6. The indirect heat exchanger of claim 1

wherein each circuit tube run length has a progressively decreasing horizontal cross sectional dimension and a progressively increasing vertical cross sectional dimension as each circuit tube extends from near the inlet end of each coil circuit to near the outlet end of each coil circuit.

580 7. The indirect heat exchanger of claim 1

wherein each circuit tube being comprised of a series of run lengths and return bends from the inlet end of each coil circuit to the outlet end of each coil circuit,

and wherein each individual circuit tube run length is of a uniform horizontal cross sectional dimension and a uniform vertical cross sectional dimension between return bends, and

585 wherein the horizontal cross sectional dimension of circuit tube run lengths decrease nearer to the outlet end of each circuit tube and the vertical cross sectional dimension of each circuit tube run lengths increase nearer to the outlet end of each coil circuit.

8. The indirect heat exchanger of claim 1

wherein each circuit tube return bend is circular in cross section.

590 9. The indirect heat exchanger of claim 1

wherein each circuit tube run length at the inlet end of each coil circuit as connected to the inlet header is circular in cross section.

595 10. An indirect heat exchanger comprising:
a plurality of coil circuits,
an inlet header connected to an inlet end of each coil circuit and an outlet header
connected to an outlet end of each coil circuit,
each coil circuit comprised of a circuit tube that extends in a series of run lengths and
600 return bends from the inlet end of each coil circuit to the outlet end of each coil circuit,
each circuit tube run length having a pre-selected horizontal cross sectional dimension for
its entire length,
with the horizontal cross sectional dimension of circuit tube entire run lengths decreasing
as the circuit tubes extend from near the inlet end of each coil circuit to near the outlet end of
605 each coil circuit.

11. The indirect heat exchanger of claim 10
wherein each circuit tube run length has a cross sectional area that decreases from the
inlet end of each coil circuit to the outlet end of each coil circuit.

12. The indirect heat exchanger of claim 10
610 wherein a first ratio of the vertical cross sectional dimension of each circuit tube run
length to the horizontal cross sectional dimension of each circuit tube run length exists near the
inlet end of each coil circuit, and a second ratio of the vertical cross sectional dimension of each
circuit tube run length to the horizontal cross sectional dimension of each circuit tube run length
exists near the outlet end of each coil circuit, and wherein the second ratio is larger than the first
615 ratio.

13. The indirect heat exchanger of claim 12

wherein the first ratio is between 1.0 and 2.0, and the second ratio is greater than the first ratio but less than 6.0.

14. The indirect heat exchanger of claim 10

620 wherein each circuit tube is comprised of galvanized steel, stainless steel, aluminum, or copper.

15. The indirect heat exchanger of claim 10

wherein each circuit tube run length has a progressively decreasing horizontal cross sectional dimension and a progressively increasing vertical cross sectional dimension as the
625 circuit tube run length extends from near the inlet end of each coil circuit to near the outlet end of each coil circuit.

16. The indirect heat exchanger of claim 10

wherein each circuit tube is comprised of a series of run lengths and return bends from the inlet end of each coil circuit to the outlet end of each coil circuit,

630 and wherein each individual circuit tube run length is of a uniform horizontal cross sectional dimension and a uniform vertical cross sectional dimension between return bends, and wherein the horizontal cross sectional dimension of each run length decreases nearer to the outlet end of each circuit tube and the vertical cross sectional dimension of each run length increases nearer to the outlet end of each coil circuit.

635 17. The indirect heat exchanger of claim 10

wherein each circuit tube is comprised of a series of run lengths and return bends from the inlet end of each coil circuit to the outlet end of each coil circuit, and each circuit tube return bend is circular in cross section.

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18. An indirect heat exchanger comprising:

a plurality of coil circuits,

an inlet header connected to an inlet end of each coil circuit and an outlet header
connected to an outlet end of each coil circuit,

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each coil circuit comprised of a circuit tube that extends in a series of run lengths and
return bends from the inlet end of each coil circuit to the outlet end of each coil circuit,

each circuit tube run length having a horizontal cross section at the inlet end of each coil
circuit and a vertical cross section at the inlet end of each coil circuit,

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each circuit tube run length having a decreasing horizontal cross sectional dimension and
an increasing vertical cross sectional dimension as the circuit tube run length extends from near
the inlet end of each coil circuit to near the outlet end of each coil circuit.

19. The indirect heat exchanger of claim 18

wherein each circuit tube has a cross sectional area that decreases from the inlet end of
each coil circuit to the outlet end of each coil circuit.

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20. The indirect heat exchanger of claim 18

wherein a first ratio of the vertical cross sectional dimension of each circuit tube run
length to the horizontal cross sectional dimension of each circuit tube run length exists near the
inlet end of each coil circuit, and a second ratio of the vertical cross sectional dimension of each
circuit tube run length to the horizontal cross sectional dimension of each circuit tube run length
exists near the outlet end of each coil circuit, and wherein the second ratio is larger than the first
ratio.