

HEAT EXCHANGER

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 63/608,514 filed December 11, 2023, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure relates to heat exchangers and, more specifically, to fin-and-tube heat exchangers.

BACKGROUND

[0003] Fin-and-tube heat exchangers, or finned tube heat exchangers, include a tube having an interior for receiving a first fluid such as water. The fin-and-tube heat exchanger has a series of fins along the length of the tube for transferring heat to, or receiving heat from, a second fluid such as air that contacts the fins.

[0004] Fin-and-tube heat exchangers may be used in cooling towers or other heat rejection apparatuses. One common type of fin-and-tube heat exchanger is a dry coil, eight row fin-and-tube heat exchanger as shown in FIG. 3. The term “row” refers to a vertical pattern of tubes in the figure. The tube of the eight row fin-and-tube heat exchanger includes tubes having many straight runs of the tubes, sometimes fifty or more, in each row. The fins are densely packed along the straight runs, with collars of one fin abutting an adjacent fin to maintain the spacing of the fins. U-bends connect the straight runs of the tubes and facilitate the flow of process fluid from an inlet header, through the tubes, and to an outlet header.

[0005] The heat rejection apparatus has one or more fans that cause air to flow through the heat exchanger to transfer heat from a process fluid in the straight runs of the heat exchanger to the air flowing across the exterior surfaces of the heat exchanger. For situations where less heat transfer is needed, a dry coil, six row fin-and-tube heat exchanger as shown in FIG. 6 may be used. The six row fin-and-tube

heat exchanger may have the same tube diameter as the corresponding eight row fin-and-tube heat exchanger.

[0006] Generally speaking, heat exchangers with more tubes and more fin surface provide more heat transfer to the adjacent air. When given a fixed row height for a heat exchanger to be designed, an engineer will evaluate how many rows of tubes are required to meet the heat transfer requirements, typically starting at three rows, then four, then six, then eight, etc., and stopping when the heat transfer requirements are met. However, adding more rows of tubes and more fin area adds commensurately more material and associated costs to the production of the heat exchanger.

SUMMARY

[0007] In accordance with one aspect of the present disclosure, a heat exchanger is provided that includes fins having openings and tubes extending in the openings of the fins for receiving a process fluid. The fins extend from the tubes to transfer heat between the process fluid and air contacting the fins. The fins each have a length, a width perpendicular to the length, and a thickness perpendicular to the length and the width, wherein the length of the fin is larger than the width of the fin and the width of the fin is larger than the thickness of the fin. The tubes and fins are arranged to have air directed across the fins in a direction transverse to the length of the fins. The tubes include a first row of tubes aligned along the length of the fins and having a first distance between centers of adjacent tubes of the first row, the first distance extending along the length of the fins. The tubes further include a second row of tubes adjacent the first row and aligned along the length of the fins. The second row of tubes has a second distance between centers of adjacent tubes of the second row, the second distance extending along the length of the fins. The first row and the second row of tubes have a third distance between centers of adjacent tubes of the first and second rows. The third distance extends along the width of the fins and is larger than the first distance and the second distance. The heat exchanger further includes a widthwise spacing between the adjacent tubes of the first and second rows that is larger than a first lengthwise spacing between the adjacent tubes of the first row. The widthwise spacing is also larger than a second lengthwise spacing between the adjacent tubes of the second row. In this manner, the enlarged widthwise spacing

provides larger openings between the fins and tubes to reduce airflow pressure drop and to increase airflow velocity through the heat exchanger and to increase the amount of fin surface near each tube.

[0008] In one embodiment, the ratio of the third distance to at least one of the first distance and the second distance is in a range of approximately 1.04 to approximately 1.5. For example, the ratio of the third distance to the first distance and the ratio of the third distance to the second distance are each in the range of approximately 1.04 to approximately 1.5. This range has been discovered to provide a heat transfer capability for a fin-and-tube heat exchanger with six rows of tubes that is similar to the heat transfer capability of a similarly sized fin-and-tube heat exchanger with eight rows of tubes. Counterintuitively, the heat exchanger may provide the similar heat exchange capability with fewer rows of tubes, which is a significant material savings since each row of tubes may have fifty or more tubes. Further, the ratio of the third distance to at least one of the first distance and the second distance in the range of approximately 1.04 to approximately 1.5 permits the six-row heat exchanger to be both backwards-compatible and lower cost than a similarly sized eight-row heat exchanger, whereby the overall fin width of the six row heat exchanger matches the fin width of the eight row heat exchanger, but contains fewer rows of tubes, and therefore requires less material to manufacture.

BRIEF DESCRIPTION OF DRAWINGS

[0009] FIG. 1 is a perspective view of a heat rejection apparatus that utilizes a pair of inclined, dry coils to transfer heat from a process fluid to ambient air;

[0010] FIG. 2 is a dry coil that may be utilized in a heat rejection apparatus similar to FIG. 1;

[0011] FIG. 3 is a cross-sectional view of a prior art eight-row fin-and-tube heat exchanger;

[0012] FIG. 4 is a cross-sectional view taken across line 4-4 in FIG. 2 and showing six rows of tubes;

[0013] FIG. 5 is a cross-sectional view of another embodiment of a heat exchanger having six rows of tubes and two spacer rows separating the rows of tubes;

- [0014] FIG. 6 is a cross-sectional view of a prior art six tube fin-and-coil heat exchanger;
- [0015] FIG. 7 is a table showing prime, total, and effective surface areas of the prior art heat exchanger of FIG. 3, the prior art heat exchanger of FIG. 6, and the heat exchanger of FIG. 4;
- [0016] FIG. 8 is a computational fluid dynamics (CFD) air pressure map of air flowing across a fin of the eight-row heat exchanger of FIG. 3;
- [0017] FIG. 9 is a CFD air pressure map of air flowing across a fin of the six-row heat exchanger of FIG. 4;
- [0018] FIG. 10 is a CFD air pressure map of air flowing across a fin of the six-row heat exchanger of FIG. 5;
- [0019] FIG. 11 is a cross-sectional view of a heat exchanger having eight rows of openings formed in the fins of the heat exchanger, six rows of the openings having tubes extending therein, and two of the rows are empty and do not have tubes therein;
- [0020] FIG. 12 is a cross-sectional view taken across line 12-12 in FIG. 11 showing collars of the fins fixed onto tubes extending through the fins and spacing the fins along the tubes;
- [0021] FIG. 13 is a cross-sectional view taken across line 13-13 in FIG. 11 showing the absence of tubes in one of the empty rows of the fins;
- [0022] FIG. 14 is a view similar to FIG. 13 of an alternative embodiment of the heat exchanger of FIG. 11 wherein the openings of the empty row of the fin have been removed to reduce air pressure drop through the heat exchanger;
- [0023] FIG. 15 is a cross-sectional view of the heat exchanger of FIG. 3;
- [0024] FIG. 16 is a cross-sectional view of the heat exchanger of FIG. 6; and
- [0025] FIG. 17 is a cross-sectional view of the heat exchanger of FIG. 4.

DETAILED DESCRIPTION

- [0026] In accordance with one aspect of the present disclosure, a heat exchanger is provided having fins and rows of tubes extending through the fins. The fins each have a length, a width perpendicular to the length, and a thickness perpendicular to the

length and width. The length of each of the fins is larger than a width of the fin and the width of the fin is significantly larger than the thickness of the fin.

[0027] The tubes have a longitudinal spacing or pitch between tubes of adjacent rows that is greater than a transverse spacing or pitch between tubes of one of the rows. The increased longitudinal spacing provides an opportunity for the air flow, which is directed in a longitudinal direction through the heat exchanger, to recover velocity and increase the rate of air flow across the fins and coils. In one embodiment, the heat exchanger has six rows of tubes and provides approximately the same heat transfer capacity as an eight-row fin-and-coil heat exchanger having similar sized fins when a fan is used to generate airflow through the heat exchanger. Further, the six row fin-and-coil heat exchanger can be used as a drop-in-replacement for the eight-row fin-and-coil heat exchanger since the outer dimensions of the two heat exchangers are the same.

[0028] Regarding FIG. 1, a heat rejection apparatus, such as a dry cooler 10 is provided that receives heated process fluid from an industrial process such as a computer data center or an HVAC system. The dry cooler 10 has an outer structure 11, such as frame 13, as well as one or more air inlets 17 and one or more air outlets 20. The dry cooler 10 has coils 12, 14 inclined relative to one another and one or more fans 16 that draw air into the air inlets 17. The fans 16 direct the air in directions 18, 19 into the coils 12, 14 and upward through the outlets 20 of the dry cooler 10 in direction 22. The coils 12, 14 receive heated process fluid, such as water or a mixture of water and glycol, and the flow of air through the coils 12, 14 permits the coils 12, 14 to transfer heat from the process fluid to the airflow. The dry cooler 10 returns the cooled process fluid back to the industrial process.

[0029] Regarding FIG. 2, a coil 30 is provided that may be utilized with a heat rejection apparatus similar to the dry cooler 10 of FIG. 1. The coil 30 includes an inlet header 34 to receive process fluid and an outlet header 32 to return cooled process fluid back to an industrial process or another downstream heat transfer apparatus, as a few examples.

[0030] The coil 30 includes a heat exchanger 48 having tubes 50 that extend along the length of the coil 30 transverse to a direction 36 of air flow through the coil 30. The tubes 50 are circular as shown in FIG. 4, but may have elliptical or obround shapes in

other embodiments. The tubes 50 include a first run 44 that extends from the inlet header 34, a U-bend 42, and a run 40 that returns fluid to the outlet header 32. The coil 30 may be forty feet long with blocks 58 of fins 54 that have been fixed to the tubes 50.

[0031] Regarding FIG. 4, a cross-sectional view of the coil 30 is provided to show that the tubes 50 extend through openings 52 of the fins 54 of the coil 30. The tubes 50 are organized in six rows 59 including rows 62, 64, 122. Each row 59 is offset in a transverse direction from an adjacent row 59. Further, each row 59 may have more than twelve, such as more than fifty, such as sixty-eight tubes, per row. In one approach, the coil 30 has ten fins 51 per inch along the tubes 50. A fan or other airflow generator directs air in direction 130 into the heat exchanger 48. The airflow enters the heat exchanger 48 at row 62 of the tubes 50 and exits the heat exchanger 48 at the row 122 of the tubes 50.

[0032] FIG. 3 is a cross-sectional view of a prior art fin-and-tube heat exchanger 70 with eight rows 72 of tubes 74. The tubes 74 have an outer diameter of 0.5 inches. The heat exchanger 70 has fins 80 each having a width 82 of, for example, 8.66 inches. The prior art heat exchanger 70 has a transverse distance 84 of 1.25 inches between centers of the tubes in row 72A. Further, the prior art heat exchanger 70 has longitudinal distance 86 of 1.083 inches between the centers of tubes 74A, 74B in adjacent rows 72A, 72B. The air is directed in longitudinal direction 90 through the heat exchanger 70. The heat exchanger 70 has a distance 92 of, for example, 0.29 inches between side edges 94 and the tubes 74 in side rows 72A, 72C.

[0033] Regarding FIG. 4, the heat exchanger 48 has fins 51 with a width 100 that may be the same as the width 82 of the prior art heat exchanger 70, such as 8.66 inches, but six rows 59 of tubes 50 instead of eight rows. The tubes 110, 112 of row 62 have a transverse distance 114 between centers 110A, 112A of the tubes 110, 112 and a first lengthwise spacing 115 between the tubes 110, 112. The heat exchanger 48 has a longitudinal distance 116 between a center 110A of the tube 110 of row 60 and a center 118A of the tube 118 of row 64. The tubes 118, 119 of row 64 have a second lengthwise spacing 121 therebetween. The heat exchanger 48 has a widthwise spacing 117 between the tubes 50 of rows 62, 64 that is wider or larger than the first and second lengthwise spacings 115, 121. The enlarged widthwise spacing 117 provides

additional open area between the fins 51 through which air may travel, which reduces the air pressure drop across the heat exchanger 48 and the increases the airflow velocity through the heat exchanger 48. The widthwise spacing 117 is shown forming an air passageway between the fins 51 in FIG. 17.

[0034] The longitudinal distance 116 may be in the range of approximately 1.3 inches to approximately 1.9 inches, such as 1.300 inches to 1.875 inches, such as 1.4 inches to 1.5 inches. The longitudinal distance 116 is greater than a transverse distance 114 between tubes 110, 112 of the same row 62. The transverse distance 114 is in the range of approximately 1.0 inches to approximately 1.5 inches, such as 1.25 inches. The ratio of the longitudinal distance 116 to the transverse distance 114 may be in the range of approximately 1.04 to approximately 1.5. The term “approximately,” when used herein with respect to numerical values, may be understood to encompass +/- 5% of the associated numerical value.

[0035] Further, the heat exchanger 48 has an edge distance 120 between centers of the tubes of rows 62, 122 and side edges 124, 126 of the fin 51. The edge distance 120 plus half of the diameter of the tubes 52 is approximately half of the distance 116. The side edges 124, 126 may be straight or corrugated. The longitudinal distance 116 for a six row fin-and-tube heat exchanger may be obtained from the longitudinal distance of a corresponding eight row fin-and-tube heat exchanger using the following equation:

$$\text{Longitudinal Distance}_{6\text{ Tube}} = \text{Longitudinal Distance}_{8\text{ Tube}} * 8/6$$

[0036] The increased longitudinal distance of fins 51 provide additional spacing to reduce the air pressure drop across the heat exchanger 48 compared to the heat exchanger 70. Further, the fewer rows 59 of tubes 50 of the heat exchanger 48 provides fewer structures between the fins of the heat exchanger 48 which also reduces the air pressure drop across the heat exchanger 48. Moreover, depending on the circuiting of the tubes 50, the fewer rows 59 of tubes 50 may cause the velocity of the process fluid in the tubes 50 to be increased for a given process fluid flow rate as compared to the heat exchanger 70 and causes an increased process fluid pressure drop for the heat exchanger 48 compared to the heat exchanger 70. The higher velocity of process fluid in the tubes 50 of the heat exchanger 48 increases the

efficiency of the heat exchange between the process fluid and the tubes 50. The interior surfaces of the tubes 50 may have surface treatments, such as rifling, to further increase the rate of heat transfer between the process fluid and the tubes 50. The increased spacing between the tubes 50 of the heat exchanger 48 may also reduce the rate of build-up of dirt or other debris on the coil 30.

[0037] Regarding FIG. 5, a heat exchanger 150 is provided that may be utilized in the coil 30 instead of the heat exchanger 48. The heat exchanger 150 includes tubes 152 and fins 154. The tubes 154 are arranged in rows 160, 162, 164, 166, 168, 170. The heat exchanger 150 has a spacing row 172 between rows 162 and 164 and a spacing row 174 between rows 166, 168. The spacing rows 172, 174 are blank and lack openings for tubes 154. The heat exchanger 150 has six rows like the heat exchanger 48 and a width 180 of each fin 154 that is the same as the width 100 of fins 51 and the width 82 of the fins 80. The tubes 184, 186 of row 160 have a transverse distance 188 of 1.25 inches between centers of the tubes 184, 186, which is the same as the transverse distances 84, 112 discussed above. The tubes 184, 190 of adjacent rows 160, 162 have a longitudinal distance 192 between centers of the tubes 188, 190 of 1.083 inches, which is the same as the longitudinal distance 86 of the heat exchanger 70. However, the spacer rows 172, 174 create large longitudinal spacings between rows 162 and 164 as well as between row 166 and row 168. In this manner, the tube 200 of row 162 has a transverse distance 202 between centers of the tubes 200, 202 that is the same as the transverse distance 188. But there is a longitudinal distance 204 of, for example, a distance in the range of approximately 2 inches to approximately 2.3 inches such as approximately 2.1 inches to approximately 2.2 inches. The longitudinal distance 204 extends between the centers of the tube 200 and a tube 206 of the row 164 and is larger than the longitudinal distances 86 of the heat exchanger 70 discussed above. The larger longitudinal distance 204 provides spacing for the air flow to recover velocity as the air flows through the heat exchanger 150 in direction 210. In one embodiment, the ratio of the longitudinal distance 204 to the transverse distance 202 may be in the range of, for example, 1.04 to 1.5.

[0038] Regarding FIG. 6, a heat exchanger 220 is shown that is a conventional six-row fin-and-tube heat exchanger and receives air in direction 235. The heat exchanger 220 has fins 222 with a width 224 of 6.499 inches. The heat exchanger 220 has tubes 226

arranged in six rows including rows 228, 230. The row 228 has tubes 232, 234 with a transverse distance 236 of 1.25 inches between centers thereof, which is the same as the transverse distance 84 of the prior art eight-row fin-and-coil heat exchanger 70. Similarly, the heat exchanger 220 has a longitudinal distance 240 that is the same as the longitudinal distance 86 of the eight-row fin-and-tube heat exchanger 70. Thus, the prior art six-row heat exchanger 220 has similar spacing between the tubes 226 as the heat exchanger 70, but the heat exchanger 220 has a reduced number of tubes 226 and a narrowed width 224 of the fin 222 which reduces material used to manufacture the heat exchanger 220.

[0039] Regarding FIG. 7, a table 250 is provided that compares the prime surface area 252, the total surface area 254, and the effective surface area 256 of the prior art eight-row heat exchanger 70 of FIG. 3 (see row 260), the prior art six-row heat exchanger 220 of FIG. 6 (see row 262), and the heat exchanger 48 of FIG. 4 (see row 264). The prime surface area 252 is the surface area of the tubes of the heat exchanger. The total surface area 254 is the sum of the surface areas of the tubes and the fins of the heat exchanger. The effective surface area 256 is a conventional heat transfer calculation that represents the total surface area 254 reduced by heat transfer parameters. The heat transfer parameters include a convection coefficient (h), a perimeter of the fin cross-section (P), the conductivity of the fin material (k), and the surface area of the fin (A).

[0040] As shown in the table 250, the prime surface area 266 of the heat exchanger 48 is 25% less than the prime surface area 252 of the heat exchanger 70 due to the fewer tubes of the heat exchanger 48 as compared to the heat exchanger 70. However, the heat exchanger 48 has a total surface area 268 that is actually larger than a total surface area 269 of the heat exchanger 70. The larger total surface area 268 is due to the increase in the surface area of the fins 51 by having fewer openings formed in the fins 51 since there are six rows of tubes 50 instead of eight rows. The effective surface area 270 of the heat exchanger 48 is marginally less than the effective surface area 272 of the heat exchanger 70 despite having two fewer rows of tubes 50.

[0041] Providing the heat exchanger 48 with six tubes 50 instead of eight tubes as in the heat exchanger 70 results in a higher pressure and velocity of process fluid through the tubes 50 if the flow rate through the heat exchanger 48 is to be similar to the flow

rate through the heat exchanger 70 and the circuiting arrangement of the tubes is held constant. It has been discovered that the combination of increased velocity of process fluid through the tubes 50, the effective surface area 279 being approximately the same as effective surface area 272, and a higher airflow rate enabled by a lower airside pressure drop permits the heat exchanger 48 to have a higher heat transfer efficiency than the heat exchanger 70.

[0042] Regarding FIG. 8, an air pressure map 300 is provided for the heat exchanger 70 of FIG. 3. The air pressure map 300 shows the air pressure as the air travels generally in direction 90 along the fin 80. The fin 80 is shown with openings 302 that correspond to the tubes 74. The air pressure map 300 includes a static pressure key 304 with different visual indications representing different static pressures. The air pressure is highest in a region 310 by the edge 94 where air flow is entering the heat exchanger 70. The air pressure is lowest in region 312 near the edge 94 where the air is exiting the heat exchanger 70. Further, the air pressure decreases as the air travels between the rows 72 of the tubes 74. In FIG. 8, the air pressure map 300 shows that a maximum static air pressure 305 is 0.767987 inches H₂O for the heat exchanger 70.

[0043] Regarding FIG. 9, an air pressure map 320 is provided showing air pressure as air travels along the fin 51 of the heat exchanger 48 of FIG. 4. The air pressure map 320 has openings 322 where the tubes 50 extend. The air pressure map 320 has a key 326 that shows a maximum 328 static air pressure of 0.618 inches H₂O in a region 330 along the fin 51. Thus, the maximum static pressure in the air flow through the heat exchanger 48 is significantly less than the static air pressure flowing through the heat exchanger 70. The heat exchanger 48 therefore has a lower air pressure drop across the heat exchanger 48 and increased air flow velocity than the heat exchanger 70.

[0044] Regarding FIG. 10, an air pressure map 340 is provided showing the static air pressure in air flow across the fin 154 of the heat exchanger 150 of FIG. 5. The air pressure map 340 includes a key 342 showing a maximum 344 static air pressure of 0.653464 inch H₂O in the air flowing through the heat exchanger 150. The maximum 344 static air pressure of the heat exchanger 150 of FIG. 5 is lower than the maximum pressure 305 of the heat exchanger 70 of FIG. 3. Thus, like the heat exchanger 48 of FIG. 9, the heat exchanger 150 of FIG. 5 has a decreased air pressure drop across the

heat exchanger 150 when compared to the eight-row fin-and-tube heat exchanger 70 of FIG. 3.

[0045] Regarding FIG. 11, the heat exchanger 400 is provided that is similar in many respects to the heat exchanger 150 discussed above and may be utilized in the coil 30. One difference between the heat exchangers 150, 400 is that the heat exchanger 400 has fins 402 with empty openings 404 where tubes 406 are not inserted. More specifically, as shown by a key 410 in FIG. 11, an indicator 412 shows where tubes 406 are present and indicator 414 shows where no tubes are present. The fins 402 have openings 416 in rows 424, 426, 428, 430, 432, 434 to receive the tubes 406 but tubes are not inserted into the openings 404 of spacing rows 420, 422. In this manner, the heat exchanger 400 permits a six-row fin configuration while utilizing fins that have been formed with eight rows of openings. Due to the openings 404 in rows 420, 422, the fin 402 has less surface area than the fin 51 but provides increased spacing between the tube rows 426, 428 and tube rows 430, 432.

[0046] Regarding FIG. 12, a cross-section of the heat exchanger 400 is shown including fins 402, 500, 502, 504, 506 that are fixed to tubes 510, 512, 514 via collars 519. The collars 519 include collars 520A-C, 522A-C, 524A-C, 526A-C, 528A-C. The collars 519 are formed in the fins 402, 500, 502, 504, 506 during a stamping operation. The stamping operation also imparts an undulating or sinusoidal shape to the fins 402, 500, 502, 504, 506. The heat exchanger 400 has lengthwise spacings 525A, 525B between the collars 522A, 522B, 522C of the row of tubes 510, 512, 514. In another embodiment, the fins 402, 500, 502, 504, 506 may be flat.

[0047] During manufacture of the heat exchanger 400, the tubes 510, 512, 514 are advanced through the collars 519, the fins 402, 500, 502, 504, 506 are stacked upon one another, and the outer diameters of the tubes 510, 512, 514 are expanded such as using ball bearings or hydrostatic pressure to fix the collars 519 to the tubes 510, 512, 514. The collars 519 maintains spacings 540, 542, 544, 546 between the fins 402, 500, 502, 504, 506.

[0048] Regarding FIG. 13, a cross-section of the heat exchanger 400 is shown of the spacing row 420 where there are no tubes. In the embodiment of FIG. 13, the fins 402, 500, 502, 504, 506 have collars 550A-C, 552A-C, 554A-C, 556A-C, 558A-C. The collars

519 maintain the spacings 540, 542, 544, 546 between the fins 402, 500, 502, 504, 506.

[0049] Regarding FIG. 14, an alternative embodiment of the heat exchanger 400 is provided wherein the fins 402, 500, 502, 504, 506 do not have openings 404 in the spacer row 420. By removing the openings 404 and associated collars 519 of the spacer row 420, the heat exchanger 400 has a less obstructed air flow path through the spacings 540, 542, 544, 546. The less obstructed flow path decreases the pressure drop across the heat exchanger 400.

[0050] Regarding FIGS. 15-17, cross-sectional views of the heat exchangers 70, 220, 48 are provided that show the wavy cross-sectional shapes of the fins of the heat exchangers 70, 220, 48. The cross-sections are each taken along a plane parallel to the direction of airflow through the heat exchanger 70, 220, 48. The following table provides CFD results for the heat exchangers 70, 48, 220, 400 of FIGS. 3, 4, 6, and 11.

Heat Exchanger Ref. No.	Study	Rows	v_sp	h_sp	fin_w	Air	Air Resistance	Predicted Air Velocity
			in	in	in	fpm	%	%
70	8 Row Standard	8	1.25	1.083	8.661	595	100.0%	99.9%
48	6 Row Stretch	6	1.25	1.444	8.661	615	83.2%	104.0%
220	6 Row Standard	6	1.25	1.083	6.496	623	74.2%	106.2%
400	6 Row in 8 Row Fin	6	1.25	1.083	8.661	612	86.9%	103.1%

[0051] The disclosures above describing the similar performance of the heat exchanger 48 with six rows of tubes and the heat exchanger 70 with eight rows of tubes may be used to design fin-and-tube heat exchangers having different numbers of rows of tubes. For example, the longitudinal distance between centers of tubes in adjacent rows of a four-row fin-and-tube heat exchanger to replace a six-row fin-and-

tube heat exchanger can be calculated using the following equation:

$$\textit{Longitudinal Distance}_{4\textit{ Tube}} = \textit{Longitudinal Distance}_{6\textit{ Tube}} * 6/4$$

[0052] Likewise, the longitudinal distance between centers of tubes in adjacent rows of a five-row fin-and-tube heat exchanger to replace an eight-row fin-and-tube heat exchanger can be calculated using the following equation:

$$\textit{Longitudinal Distance}_{5\textit{ Tube}} = \textit{Longitudinal Distance}_{8\textit{ Tube}} * 8/5$$

[0053] Uses of singular terms such as “a,” “an,” are intended to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms. It is intended that the phrase “at least one of” as used herein be interpreted in the disjunctive sense. For example, the phrase “at least one of A and B” is intended to encompass A, B, or both A and B.

[0054] While there have been illustrated and described particular embodiments of the present invention, it will be appreciated that numerous changes and modifications will occur to those skilled in the art, and it is intended for the present invention to cover all those changes and modifications which fall within the scope of the appended claims. For example, it will be appreciated that the coils and heat exchange apparatuses discussed above may be configured to transfer heat from ambient air to process fluid flowing through the coils that has a temperature lower than the ambient air.

Claims

What is claimed is:

1. A heat exchanger comprising:
 - fins each having openings;
 - tubes extending in the openings of the fins for receiving a process fluid;
 - the fins extending from the tubes for transferring heat between the process fluid and air contacting the fins;
 - the fins each having a length, a width perpendicular to the length, and a thickness perpendicular to the length and the width, wherein the length of the fin is larger than the width of the fin and the width of the fin is larger than the thickness of the fin;
 - the tubes and fins arranged to have air directed across the fins in a direction transverse to the length of the fins;
 - a first row of the tubes aligned along the length of the fins and having a first distance between centers of adjacent tubes of the first row, the first distance extending along the length of the fins;
 - a second row of the tubes adjacent the first row and aligned along the length of the fins, the second row of the tubes having a second distance between centers of adjacent tubes of the second row, the second distance extending along the length of the fins;
 - the first row and the second row of tubes having a third distance between centers of adjacent tubes of the first and second rows, the third distance extending along the width of the fins and being larger than the first distance and larger than the second distance; and
 - a widthwise spacing between the adjacent tubes of the first and second rows that is larger than a first lengthwise spacing between the adjacent tubes of the first row and is larger than a second lengthwise spacing between the adjacent tubes of the second row to reduce airflow pressure drop and increase airflow velocity through the heat exchanger.
2. The heat exchanger of claim 1 wherein a ratio of the third distance to at least one of the first distance and the second distance is in a range of approximately 1.04 to approximately 1.5.

3. The heat exchanger of claim 1 wherein the tubes have an outer diameter of 0.5 inches;
wherein the third distance is in a range of approximately 1.3 inches to approximately 1.9 inches; and
the first and second distances are each in a range of approximately 1.0 to approximately 1.5 inches.
4. The heat exchanger of claim 1 wherein the fins each include a first edge and a second edge on opposite sides of the tubes and extending along the length of the fin; and
wherein the first row of tubes is adjacent one of the first and second edges of the fins, the tubes of the first row of tubes have centers spaced along the width of the fins from the one of the first and second edges by an edge distance that is less than the third distance.
5. The heat exchanger of claim 4 wherein the tubes have a tube diameter; and
wherein the edge distance plus half of the tube diameter is approximately half of the third distance.
6. The heat exchanger of claim 1 wherein the tubes include a third row of tubes adjacent to the first row, the first row of tubes intermediate the third and second rows of tubes along the width of the fins; and
wherein the tubes of the third row of tubes have centers that are spaced along the width of the fins from centers of adjacent tubes of the first row by a fourth distance that is less than the third distance.
7. The heat exchanger of claim 6 wherein the tubes of the third row of tubes are offset along the length of the fins from the tubes of the first row.
8. The heat exchanger of claim 7 wherein the tubes of the second row are aligned with the tubes of the first row along the width of the fins.

9. The heat exchanger of claim 6 wherein the fins each include a first edge and a second edge on opposite sides of the tubes and extending along the length of the fin;
wherein the tubes have a tube diameter; and
wherein the third row of tubes is adjacent one of the first and second edges of the fins, the tubes of the third row of tubes have centers spaced along the width of the fins from the one of the first and second edges by an edge distance; and
wherein the edge distance plus half of the tube diameter is approximately half of the fourth distance.
10. The heat exchanger of claim 1 wherein the tubes of the first row are aligned with the tubes of the second row along the width of the fins.
11. The heat exchanger of claim 1 wherein the fins include a row of openings aligned along the length of the fins and intermediate the first and second rows of tubes along the width of the fins.
12. The heat exchanger of claim 1 wherein the rows of tubes include six rows of tubes.
13. The heat exchanger of claim 1 wherein the tubes and fins are configured to have air directed across the fins in a direction perpendicular to the length.
14. The heat exchanger of claim 1 wherein the fins comprise elongated, rectangular plates.
15. The heat exchanger of claim 1 wherein the fins have collars fixed to the tubes.
16. The heat exchanger of claim 1 wherein the fins each have a wavy surface pattern.
17. The heat exchanger of claim 1 wherein the length of each of the fins is at least three times the width of the fin.

18. The heat exchanger of claim 1 wherein the first and second rows of tubes each include at least twelve tubes.

19. The heat exchanger of claim 1 wherein the tubes are elliptical.