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FREE-DRAINING FINNED SURFACE ARCHITECTURE FOR A HEAT EXCHANGER

BACKGROUND

5 Aluminum microchannel heat exchangers offer several advantages over the once conventional copper-aluminum or copper-copper round tube plate fin heat exchangers and are used in a variety of applications. However, aluminum microchannel heat exchangers also present new challenges, with effective condensate drainage being one of them. Condensation that forms on heat exchanger surfaces during operation or
10 water collected during an off-cycle can be retained within the fin and tube heat exchanger aluminum core for prolonged periods of time. This problem is compounded when the heat exchanger is used in outdoor industrial, coastal or marine environments, especially where exposure to high humidity levels, frequent rains and winds carrying ocean/sea water can occur. Water retention on the aluminum surfaces of the heat
15 exchangers can lead to accelerated corrosion of the surfaces and, eventually, perforation of critical components, such as heat exchange tubes and manifolds, as well as compromising joints between heat exchange tubes and heat transfer fins.

 Until now, drainage improvements for aluminum microchannel heat exchangers were specifically aimed at evaporators for air conditioning and heat pump
20 applications where fin spacing is relatively wide and only modest amounts of condensate need to be continually removed. These improvements normally did not benefit aluminum microchannel condensers, which generally have closer fin spacing that allows for larger amounts of water to be accumulated within the heat exchanger matrix and impedes condensate drainage. Aluminum microchannel condensers can also become
25 flooded due to the accumulation of environmental water or condensation during off-cycle periods, resulting in extended periods of exposure to water. Thus, these condensers generally have a significantly larger amount of retained water that needs to be removed (and require a corresponding higher rate of condensate or environmental water removal) than evaporators.

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SUMMARY

 A free-draining heat exchanger includes a first heat exchange tube, a second heat exchange tube and a fin structure. The second heat exchange tube is spaced from and generally parallel to the first heat exchange tube. The fin structure includes a

fin contacting the first heat exchange tube and the second heat exchange tube for promoting removal of liquid from external surfaces of the heat exchanger.

A free-draining fin structure includes an array of fins disposed between adjacent heat exchange tubes for providing enhanced water drainage by reducing liquid surface tension. Each fin in the array includes an opening and a louver for directing
5 airflow through the opening and around the fin and the louver.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a front view of a microchannel heat exchanger.

FIG. 2 is a perspective view of one embodiment of a fin.

10 FIG. 3 is a front view of heat exchange tubes and a fin structure.

FIG. 4 is a perspective view of the heat exchange tubes and fin structure of FIG. 3.

FIG. 5 is a cross section view of a fin structure with an overhanging fin.

15 FIG. 5A is a perspective view of a fin structure with notched overhanging fins.

FIG. 6 is a cross section view of a fin structure with an overhanging fin and a lip.

FIG. 6A is a perspective view of a fin structure with overhanging fins and lips.

20 FIG. 7 is a cross section view of a fin structure with an overhanging fin and two lips.

FIG. 8 is a perspective view of a heat exchange tube with a curved fin.

FIG. 9 is a perspective view of a heat exchange tube with an angled fin.

25 FIG. 10A is a partial perspective view of a microchannel heat exchanger with vertical heat exchange tubes and a rotated fin structure.

FIG. 10B is an exploded view of the rotated fin structure of FIG. 10A.

DETAILED DESCRIPTION

The present invention describes fin structures having louvers and drainage enhancement features that provide for improved liquid drainage in heat exchangers. The
30 fin structures allow water to drain more easily and improve the removal of water from heat exchanger external surfaces. The fin structures work with any type of tube-fin heat exchanger and are particularly useful for aluminum microchannel heat exchangers, especially aluminum microchannel condensers. While specific embodiments are described with reference to aluminum microchannel heat exchangers, the invention can

also provide benefits to other tube-fin heat exchangers. Aluminum microchannel heat exchangers typically have a more compact structure than other heat exchangers. Typical fin spacing varies between about 5.5 fins per cm (14 fins per inch) and about 9.1 fins per cm (23 fins per inch) and typical heat exchange tube spacing varies between about 0.5
5 cm (0.19 inches) and about 1.0 cm (0.39 inches). Due to this tight fin and tube spacing combined with the aluminum construction, water removal is critically important for aluminum microchannel heat exchangers.

FIG. 1 illustrates one example of an aluminum microchannel heat exchanger. Heat exchanger 20 can be aluminum or an aluminum alloy and includes first
10 manifold 22 having inlet 24 for receiving a working fluid, such as coolant or refrigerant, and outlet 26 for discharging the working fluid. First manifold 22 is fluidly connected to each of a plurality of heat exchange tubes 28 that are each fluidly connected on an opposite end with second manifold 30. Second manifold 30 is fluidly connected with
15 each of a plurality of heat exchange tubes 32 that return the working fluid to first manifold 22 for discharge through outlet 26. Heat exchange tubes 28 and 32 each typically include flow channels or passages, so-called microchannels or minichannels (not shown), for conveying the working fluid. The structures of heat exchange tubes 28 and 32 are essentially identical; only the direction of working fluid flow differs. Reference is made in this application generally to heat exchange tubes 28 to demonstrate
20 the concepts of the invention. The same concepts can be equally applied to heat exchange tubes 32. Partition 23 is located within first manifold 22 to separate inlet and outlet sections of first manifold 22. The two-pass working fluid flow configuration described above is only one of many possible design arrangements. Single and other multi-pass fluid flow configurations can be obtained by placing partitions 23, inlet 24 and outlet 26 at specific locations within first manifold 22 and second manifold 30. Various other working fluid flow configurations are possible, but are not critical to understanding the present invention. Fins 34 extend between heat exchange tubes 28 as
25 shown in FIG. 1. Fins 34 support heat exchange tubes 28 and establish open flow channels between the heat exchange tubes 28 (*e.g.*, for airflow). Fins 34 are mechanically and/or chemically and/or thermally joined to heat exchange tubes 28.
30 Multiple fins 34 can be connected together to form one continuous fin structure 36. Fins 34 can have louvers for flow re-direction and heat transfer enhancement.

According to the present invention, fins 34 and fin structures 36 are arranged to improve and optimize water drainage aspects for heat exchanger 20. Fins 34

and fin structures 36 affect the operation of heat exchanger 20 in three primary ways. First, fins 34 and fin structures 36 aid in heat transfer between the working fluid flowing within heat exchange tubes 28 and the air passing over heat exchange tubes 28 and fins 34 through heat exchanger 20 in the spaces between adjacent heat exchange tubes 28.

5 Second, fins 34 and fin structures 36 affect the pressure drop across heat exchanger 20. The pressure drop reduces airflow through and around heat exchanger 20, subsequently having a negative impact on heat transfer. Third, fins 34 and fin structures 36 provide for water drainage. Fins 34 and fin structures 36 are arranged to prevent water from being retained by the aluminum surfaces of heat exchanger 20 and to allow water to

10 effectively drain from the outside surfaces of heat exchanger 20. Therefore, fins 34 and fin structures 36, by providing efficient drainage characteristics, reduce water retention within fin structures 36 and diminish the pressure drop effect on performance of heat exchanger 20. Fins used in prior art heat exchangers were generally optimized only for pressure drop and heat transfer considerations. However, fins 34 and fin structures 36

15 provide improved water drainage for heat exchanger 20 without significantly compromising pressure drop and heat transfer characteristics or the performance of heat exchanger 20.

FIG. 2 illustrates a partial perspective view of one embodiment of fin 34. Fin 34 can be aluminum or an aluminum alloy. Fin 34 includes fin body 38, louvers 40 and louver openings 42. As shown in FIG. 2, fin body 38 is generally planar and rectangular in shape. In other embodiments, fin body 38 can be curved or segmented with different portions being angled. Examples of curved and angled fin bodies 38 are described in further detail below. Fin body 38 extends longitudinally to form first portion 44 and second portion 46 of fin 34.

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As illustrated in FIG. 2, fin 34 includes first louvers 40a associated with first portion 44 and second louvers 40b associated with second portion 46. Louvers 40 create louver openings 42 within fin body 38 to provide drainage paths for directing water away from the aluminum surfaces of fin 34, and heat exchanger 20 in general. As shown in FIG. 2, louvers 40 are angled away from fin body 38, creating louver openings

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30 42. In this illustration, both sets of louvers 40 (40a and 40b) are angled so that they open away from the center of fin body 38. Louvers 40 can also be arranged so that they are angled and open in a single direction, towards the leading edge of fin 34 or away from the leading edge of fin 34, or angled so that they open towards the center of fin body 38. During operation of heat exchanger 20, air typically flows around fins 34 and louvers 40

and through louver openings 42 to enhance heat transfer between fins 34 and the airflow passing through heat exchanger 20. Louvers 40 direct air flowing along the surface of fin body 38 to and through louver openings 42. The flow of air through heat exchanger 20 aids in the removal of environmental water or condensate from the external aluminum surfaces of heat exchanger 20 by directing water through and away from heat exchanger 20. Fins 34 and fin structures 36 also contain at least one drainage enhancement feature to provide improved water drainage with reduced or no airflow through heat exchanger 20. The various drainage enhancement features can include louver angles greater than about 50°, notches, overhanging edges, descending lips, curvatures, angles and combinations thereof and are described in greater detail below.

Louvers 40 can extend outwardly from fin body 38 at relatively large louver angles (measured between the plane of louver 40 and the plane of fin body 38). Louver angles suitable for providing adequate drainage in wet environments can be between about 45° and about 75°, with louver angles of about 50° to about 60° being particularly suitable as a drainage enhancement feature. Fins 34 with relatively large louver angles are suitable for use with heat exchange tubes 28, whether heat exchange tubes 28 are arranged horizontally, vertically or in any position in between vertical and horizontal orientation. Louvers 40, and thereby louver openings 42, generally have a width of about 0.5 mm (0.0197 inches) to about 1.8 mm (0.071 inches) and a height of about 2 mm to about 10 mm (0.0787 inches to 0.394 inches). Consecutive louvers 40 are generally spaced about 0.7 mm (0.0276 inches) to about 2 mm (0.0787 inches) apart on fin 34. The relatively large louver angles and widths of louver openings 42 improve drainage capabilities of fin 34. Because the louver angle is relatively large, condensate and other water present on the surfaces of fin 34 more readily flows away from the fin surface. The flow of water is aided by gravity and any airflow passing around and through louver openings 42. The relatively large louver angle significantly reduces the potential water surface tension interactions along fin 34, thereby discouraging water retention on the fin surface. Due to the lower surface tension, gravity alone provides a force substantial enough to facilitate water drainage from louvers 40 and fin 34. Depending on the orientation of fin 34, water can drain from a first fin 34 to a second, lower fin 34 or to lower heat exchange tube 28 for subsequent removal by gravity and/or airflow. Airflow further increases drainage by directing water along fin body 38 towards downstream louvers 40 and louver openings 42 and onto the external surfaces of heat exchange tubes 28.

Multiple fins 34 can be connected together to form fin structure 36. FIG. 1 illustrates continuous fin structure 36 composed of a plurality of fins 34 connected together in a corrugated fashion. Fins 34 are arranged in a repeating alternating V pattern. Fin structure 36 can be constructed from a single piece of material to have a plurality of fins 34 and shaped to fit between heat exchange tubes 28. Such a continuous fin structure 36 can be constructed and positioned in place between heat exchange tubes 28 and mechanically or chemically attached (*e.g.*, welded, brazed, soldered or glued) to heat exchange tubes 28 at one or more locations. Alternatively, individual fins 34 can be connected to heat exchange tubes 28 or connected to other fins 34 by similar techniques (welding, brazing, soldering, etc.).

FIGS. 3 and 4 illustrate continuous fin structure 36 having surfaces parallel and adjacent to heat exchange tubes 28 between fins 34 and “sharp” edges near heat exchange tubes 28. In general, fin structure 36 can have a curved, oval or sinusoidal wave type shape or the sharp edge type shape. The embodiment illustrated in FIGS. 3 and 4 provides for reduced surface tension along fin structure 36 and increased water drainage potential. FIGS. 3 and 4 illustrate fin structure 36 with a series of corrugated geometries. In this embodiment, fin structure 36 is arranged to form a series of trapezoidal like shapes with fins 34 and parallel fin structure portions 50. Between adjacent fins 34, fin structure 36 includes a series of parallel fin structure portions 50 that run generally parallel to heat exchange tubes 28. Parallel fin structure portions 50 are arranged with fins 34 within fin structure 36 to form sharp edges at corners 52 and eliminate the crevices and small spaces possible between heat exchange tubes 28 and fin structures having curved, oval or sinusoidal shapes. As shown in FIGS. 3 and 4, corners 52 formed by the sharp edges of trapezoidal fin structure 36 have an angle that can approach but does not quite reach 90° (*i.e.* fins 34 are not perpendicular to heat exchange tubes 28). Other geometries, such as rectangular shapes, can also be used to form sharp edges at corners 52 near heat exchange tubes 28. When fin structure 36 forms rectangular shapes, fins 34 are generally perpendicular to heat exchange tubes 28.

With angles that are close to 90°, sharp corners 52 of fin structure 36 eliminate the small spaces present between curved edges (not shown) of, for instance, sinusoidal fin structures and heat exchange tubes 28. Those small spaces formed by curved fin structures allow water surface tension to draw water into the small spaces where it can accumulate and become difficult to remove by gravity alone or even with airflow passing through heat exchanger 20. Sharp corners 52 minimize water entrapment

between fin structure 36 and heat exchange tubes 28. For example, sharp corner 52a does not allow water to become trapped between fin 34 or parallel fin structure portion 50 and heat exchange tube 28. The angle of sharp corner 52a is large enough that any water in the vicinity of sharp corner 52a will run down fin 34 due to gravity instead of being trapped between fin 34 and heat exchange tube 28. Since water moves away from sharp corner 52a, it is more easily removed by airflow directed over heat exchange tubes 28 and through fin structure 36. Thus, sharp corner 52a provides reduced surface tension potential that might allow water to not become entrapped. On the other hand, a curved fin structure provides small spaces between the top surface of the fin structure and heat exchange tube 28 where water surface tension can entrap water between the top surface of the fin structure and heat exchange tube 28.

Similar to sharp corner 52a, sharp corner 52b provides a large enough angle so that water does not become easily trapped between fin structure 36 and heat exchange tube 28. Instead of gravity aiding the removal of water from sharp corner 52b here (for horizontally aligned heat exchange tubes 28), however, the large angle between fin 34 and heat exchange tube 28 at sharp corner 52b allows airflow to direct any water that accumulates in sharp corner 52b along the surface of heat exchange tube 28 until it reaches the downstream edge (with respect to the airflow) where the water is removed from heat exchange tube 28. The large angle between fin 34 and heat exchange tube 28 at sharp corner 52b does not restrict the airflow along sharp corner 52b like smaller spaces would.

FIG. 4 illustrates a perspective view of heat exchange tubes 28 and fin structure 36 of FIG. 3. FIG. 4 offers a different view of fin structure 36 with louvers 40 and louver openings 42. In the embodiment shown, fins 34 and parallel fin structure portions 50 of fin structure 36 have widths equal to widths of heat exchange tubes 28. In other embodiments, described below in additional detail, the widths of fins 34 and parallel fin structure portions 50 differ from the width of heat exchange tubes 28.

FIG. 4 also illustrates notches 54 incorporated into fin structure 36. Notches 54 represent areas of fin structure 36 where a portion of the structure material has been cut out or otherwise removed from fin structure 36 or a gap, slit or apertures in fin structure 36 has been created. Notches 54 can be located on fins 34 (as shown in FIG. 4), parallel fin structure portions 50 (as shown in FIG. 5A) or a combination of the two. When located on fins 34 arranged on horizontal heat exchange tubes 28, notches 54 are preferably located on bottom portions of fins 34 (to allow water to move along the

surface of heat exchange tubes 28 more freely). Other heat exchange tube 28 orientations with respect to gravity (as well as above mentioned horizontal orientation) also permit positioning notches 54 to be adjacent to both sides of the heat exchange tube 28. As shown in FIG. 4, notches 54 create openings in fins 34 where they join heat exchange tube 28. Notches 54a and 54c are located on lateral edges of fin structure 36. In this case, notches 54a and 54c are located on fin 34 at first portion 44 and second portion 46 of fin body 38, respectively. Notch 54b is located near the center of fin 34. One notch 54 or a combination of notches 54 can be present to improve water or condensate movement, and hence, airflow along the surface of heat exchange tube 28. The exact location of each notch 54, dimensions and numbers of notches 54 depend on a particular fin configuration and size. For typical microchannel heat exchangers currently employed in the air conditioning and refrigeration industry, the number of notches 54 could be between 1 and 5. Furthermore, the length of notches 54 can range between about 3 mm (0.118 inches) and about 32 mm (1.26 inches) and the height of notches 54 can range between about 1 mm (0.039 inches) and about 5 mm (0.197 inches). Although only rectangular notch configurations are depicted in FIG. 4, other notch shapes, such as oval, elliptical, racetrack, trapezoidal and triangular, are also feasible and within the scope of the invention.

Notches 54 further reduce surface tension within fin structure 36 and improve water drainage. Water is even less likely to accumulate in sharp corners 52 where notches 54 are located. In areas where fin 34 has an opening, water does not easily accumulate as it is in contact with only two surfaces (heat exchange tube 28 and parallel fin structure portion 50) rather than three surfaces of the prior art configurations (heat exchange tube 28, fin 34, and parallel fin structure portion 50). Furthermore, notches 54 provide additional flow paths for airflow passing through fin structure 36 and over heat exchange tubes 28. The additional flow paths allow the airflow to better direct water away from heat exchange tubes 28 and fin structure 36, thereby improving water drainage.

FIG. 5 illustrates a cross section of fin structures 36 with overhanging lateral edges. Fin structure 36 includes fins 34, louvers 40, louver openings 42, first overhanging edge 60 and second overhanging edge 62. Fin structure 36 can be a single continuous piece with parallel fin structure portions 50 or a series of unconnected fins 34 as described above. Louvers 40, louver openings 42 and parallel fin structure surfaces 50 function as described above. Unlike fin structure 36 shown in FIG. 4, however, fin

structure 36 shown in FIG. 5 includes first and second overhanging edges 60 and 62, respectively, which extend laterally past the lateral edges of heat exchange tubes 28. By extending the lateral edges of fin 34 (overhanging edges 60 and 62) past the lateral edges of heat exchange tubes 28, water drainage from the fin structure 36 and heat exchange tubes 28 is improved. For example, water present within fin structure 36 can be directed away from fin structure 36 without contacting heat exchange tubes 28 by the airflow passing between heat exchange tubes 28 and fin structures 36. Water can travel along fins 34 and lower parallel fin structure portion 50b. By extending past the lateral edges of heat exchange tubes 28, first and second overhanging edges 60 and 62 allow water to travel along the edge of fin structure 36 without ever contacting heat exchange tube 28. Once water reaches first or second overhanging edges 60 or 62 or the lateral edge of lower parallel fin structure portion 50b, gravity and/or airflow cause the water to drain downward and in a direction away from heat exchange tubes 28. This prevents water from collecting along the surfaces of heat exchange tubes 28 and subsequently causing corrosion to the surfaces of heat exchange tubes 28. First and second overhanging edges 60 and 62 can extend beyond lateral edges of heat exchanger tube 28 by different distances, preferably with the downstream overhanging edge, with respect to the airflow, extending a larger distance beyond the lateral edge of heat exchange tubes 28. If the distance by which both first and second overhanging edges 60 and 62 extend past the lateral edges of heat exchange tube 28 is identical, the orientation of heat exchanger 20, with respect to the airflow, is symmetrical, so that any lateral edge of heat exchange tube 28 can be a leading edge (i.e. the airflow can pass through heat exchanger 20 in either direction).

Furthermore, condensate collected on the outside surfaces of heat exchange tubes 28 may be drawn to overhanging edges 60 and 62 by surface tension, assisting in condensate retention reduction. Fin structure 36 may have only one overhanging edge 60, preferably downstream, with respect to the airflow flowing over heat exchange tubes 28 and fin structure 36. For currently used microchannel heat exchangers, the overhand dimension for the fins 34 would typically be between about 3 mm (0.118 inches) and about 10 mm (0.394 inches). Overhanging edges 60 and 62 can be combined with notches 54 of FIG. 4. FIG. 5A illustrates a perspective view of fins 34 with notched overhanging edges 60. Louvers 40 have been omitted from FIG. 5A to better illustrate notched overhanging edges 60. It should be understood that fins 34 with notched overhanging edges 60 can include louvers 40. In one embodiment, notches 54

are located in the middle of parallel fin structure portions 50 of overhanging edges 60. In another embodiment, notch 54a is located at the intersection of fin 34a and parallel fin structure portion 50a of overhanging edges 60a and 60b, respectively. Thus, notches 54 can be located on parallel fin structure portion 50, on fin body 38 of fin 34 (*e.g.*, the side rather than the bottom) or on a combination of the two (*i.e.* part of fin body 38 and part of parallel fin structure portion 50 is cut out to form a notch at the intersection of fin body 38 and parallel fin structure portion 50).

FIG. 6 illustrates a cross-section of fin structure 36 with one overhanging lateral edge and a descending lip. Fin structure 36 includes fins 34, louvers 40, louver openings 42, overhanging edge 60 and descending lip 64. Fin structure 36 can be a single continuous piece with parallel fin structure portions 50 or a series of unconnected fins 34 as described above. Louvers 40, louver openings 42, parallel fin structure portions 50 and overhanging edges 60 are as described above. As shown in FIG. 6, overhanging edge 60 extends laterally past the right lateral edge of heat exchange tube 28. Additionally, overhanging edge 60 is connected to descending lip 64 that extends downward from overhanging edge 60 and to one side of heat exchange tube 28. Descending lip 64 can extend at the same angle as fin 34 and overhanging edge 60. Alternatively, descending lip 64 can extend from overhanging edge 60 in a downward or other generally downward angle. Overhanging edge 60 and descending lip 64 work cooperatively to improve drainage of water from fin structure 36. Water is directed across fins 34 or parallel fin structure portions 50b of fin structure 36 by airflow passing over heat exchange tubes 28 and fin structure 36. Once the water reaches overhanging edge 60 or the lateral edge of lower parallel fin structure portion 50b, the water travels down descending lip 64, aided by gravity. When little or no airflow is present over heat exchange tubes 28 and fin structure 36, descending lip 64 still improves water drainage. Water near the lateral edge of parallel fin structure portions 50b that might contact heat exchange tube 28 due to water surface tension is directed downward by descending lip 64, away from heat exchange tube 28. Descending lips 64 can overlap one another or have line contact or a gap separating adjacent descending lips 64. Descending lips 64 can be associated with every fin 34 or alternatively be associated with only some fins 34 in a particular pattern (*e.g.*, every third fin, every fifth fin, etc.).

FIG. 6A illustrates a perspective view of fin structure 36 with overhanging edges 60 and descending lips 64a and 64c. Louvers 40 have been omitted from FIG. 6A to better illustrate overhanging edges 60 and descending lips 64a and 64c.

It should be understood that fins 34 with overhanging edges 60 and descending lips 64a and 64c can include louvers 40. Fins 34a and 34c include overhanging edges 60a and 60c, respectively. Overhanging edges 60a and 60c extend laterally beyond the edge of heat exchange tubes 28. Fins 34b and 34d do not have overhanging edges 60 and fin
5 bodies 38 of fins 34b and 34d do not extend laterally beyond the edge of heat exchange tubes 28. Descending lips 64a and 64c are located adjacent to overhanging edges 60a and 60c. Portions of descending lips 64a and 64c extend from overhanging edges 60a and 60c in a direction roughly parallel to parallel fin structure portion 50. Additional portions of descending lips 64a and 64c extend downward. Descending lips 64a and 64c
10 are typically located on the downstream side of heat exchange tubes 28, but can also be located on the upstream side of heat exchange tubes 28. Descending lips 64a and 64c help direct water away from fin structure 36 by encouraging water to flow in a generally downward direction. In one embodiment, descending lips 64a and 64c are formed by cutting fin bodies 38 of fins 34b and 34d and part of parallel fin structure portion 50 and
15 bending the cut fin bodies 38 in a downward direction to form descending lips 64a and 64c.

FIG. 7 illustrates a cross section view of fin structure 36 with two overhanging lateral edges 60a and 60b and two descending lips 64a and 64b. Although descending lips 64, 64a and 64b are shown to have generally rectangular cross-sections,
20 any other cross-sections, such as trapezoidal, triangular or curved are also acceptable and can equally benefit from the invention.

FIG. 8 illustrates a perspective view of fin structure 36 having curved fins 34. Fin structure 36 is shown with the top heat exchange tube 28 in phantom to better show the elements of curved fin structure 36. Fin structure 36 includes fin 34, louvers 40
25 and louver openings 42 as shown in FIG. 8. Fin structure 36 can also include notches 54 (fin 34a includes notches 54; fin 34b does not include notches 54). Louvers 40, louver openings 42 and notches 54 are as described above. Fin structure 36 can be arranged in relation to heat exchange tube 28 as shown in FIG. 8 where the plane formed between each end of fin 34 is generally perpendicular to the longitudinal axis of heat exchange
30 tube 28 (fin structure 36a). Alternatively, fin structure 36 can be rotated to provide better water drainage properties. Fin structure 36 can be rotated to better direct the airflow through heat exchanger 20 to remove water from heat exchange tubes 28 (fin structure 36b). In a vertical tube arrangement, fin structure 36 can be rotated to improve gravitational water drainage. Rotation of curved fin structure 36 can be used to balance

water drainage needs along with thermal performance and pressure drop characteristics of heat exchanger 20. Fin structure 36 may consist of individual fins 34 as shown in FIG. 8 or fins 34 interconnected together by parallel fin structure portions 50, as described above.

5 FIG. 9 illustrates a perspective view of fin structure 36 having an angled fin. Fin structure 36 is shown with the top heat exchange tube 28 in phantom to better show the elements of angled fin structure 36. Fin structure 36 includes two or more fin segments 66, louvers 40 and louver openings 42 as shown in FIG. 8. Fin structure 36 can also include notches 54 (fin structure 36a does not include notches 54; fin structure 10 36b includes notches 54). Louvers 40, louver openings 42 and notches 54 are as described above. Similar to the embodiments illustrated in FIG. 8, angled fin structure 36 can be rotated to improve water drainage. Fin structure 36a includes two fin segments 66a and 66b. Fin segments 66a and 66b are connected to one another at an angle (i.e. fin segments 66a and 66b are not parallel). The angle between fin segments 15 66a and 66b can vary depending on the orientation of heat exchange tubes 28 (i.e. horizontal or vertical, or any position in between) and the desired pressure drop across heat exchanger 20. Suitable angles between fin segments 66a and 66b include angles between about 100° and about 170°. Each fin segment 66a and 66b has louvers 40 and louver openings 42. Fin structure 36b includes three fin segments 66c, 66d and 66e. Fin 20 segment 66d includes notches 54. Rotation of angled fin structure 36 can be used to balance water drainage needs along with thermal performance and pressure drop characteristics of heat exchanger 20. Fin structure 36 may consist of individual fins 34 as shown in FIG. 9 or fins 34 interconnected together by parallel fin structure portions 50, as described above. Also, the curved and angled fin structures 36 depicted in FIGS. 25 8 and 9, although reducing condensate surface tension by themselves, may also include one or both overhanging edges 60 and descending lips 64, as described above.

FIG. 10A is a partial perspective view of a microchannel heat exchanger with vertical tubes. Part of heat exchanger 20 is shown cutaway to better illustrate heat exchange tubes 28 and fin structures 36. FIG. 10B is an exploded view of fin structure 30 36 of FIG. 10A. Fin structure 36 includes fins 34 with louvers 40 and louver openings 42. Louvers 40 and louver openings 42 are as described above. A distinctive feature of fin structure 36 shown in FIGS. 10A and 10B is that fin structure 36 is rotated 90° while being assembled and integrated into heat exchanger 20. Fins 34 of fin structure 36 form a corrugated pattern along a longitudinal axis of heat exchange tubes 28. This naturally

allows gravitational condensate drainage off of fin structure 36. All of the other features described above can also be incorporated in such a design, as well. Louver openings 42 and potentially additional notches 54 can be designed and sized to achieve adequate pressure drop characteristics for heat exchanger 20.

5 While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from
10 the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS:

1. A free-draining heat exchanger comprising:
a first heat exchange tube;
a second heat exchange tube spaced from and generally parallel to the first
5 heat exchange tube; and
a fin contacting the first and second heat exchange tubes, the fin comprising:
a louver;
at least one drainage enhancement feature for promoting removal
10 of liquid from external surfaces of the heat exchanger.
2. The free-draining heat exchanger of claim 1, wherein the at least one drainage enhancement feature is selected from the group consisting of a louver angle greater than 45°, a notch, an overhanging edge, a descending lip, a curvature, an angle, a rotated fin structure and combinations thereof.
- 15 3. The free-draining heat exchanger of claim 1, wherein the louver has a louver angle between 45° and about 75°.
4. The free-draining heat exchanger of claim 1, wherein the first heat exchange tube comprises a first lateral edge, and wherein the fin further comprises:
a first overhanging edge extending beyond the first lateral edge of the first
20 heat exchange tube.
5. The free-draining heat exchanger of claim 4, wherein the first overhanging edge extends beyond the first lateral edge of the first heat exchange tube by a distance between about 3 mm and about 10 mm.
6. The free-draining heat exchanger of claim 4, wherein the fin further
25 comprises:
a first descending lip extending from the first overhanging edge.
7. The free-draining heat exchanger of claim 6, wherein the first descending lip comprises a cross-section selected from the group consisting of rectangular, trapezoidal, triangular, curved and combinations thereof.
- 30 8. The free-draining heat exchanger of claim 6, further comprising:
a third heat exchange tube; and
a second fin contacting the second and third heat exchange tubes, the second fin comprising:

- a second overhanging edge extending beyond the first lateral edge of the first heat exchange tube; and
- a second descending lip extending from the second overhanging edge, wherein a portion of the first descending lip overlaps with a portion of the second descending lip.
- 5 9. The free-draining heat exchanger of claim 6, further comprising:
- a third heat exchange tube; and
- a second fin contacting the second and third heat exchange tubes, the second fin comprising:
- 10 a second overhanging edge extending beyond the first lateral edge of the first heat exchange tube; and
- a second descending lip extending from the second overhanging edge, wherein the second descending lip is spaced from the first descending lip by a gap.
- 15 10. The free-draining heat exchanger of claim 1, wherein the first heat exchange tube comprises a first lateral edge and a second lateral edge on an opposite side of the first heat exchange tube, and wherein the fin further comprises:
- a first overhanging edge extending beyond the first lateral edge of the first heat exchange tube; and
- 20 a second overhanging edge extending beyond the second lateral edge of the first heat exchange tube.
11. The free-draining heat exchanger of claim 10, wherein the first overhanging edge extends beyond the first lateral edge of the first heat exchange tube farther than the second overhanging edge extends beyond the second lateral edge of the first heat exchange tube.
- 25 12. The free-draining heat exchanger of claim 10, wherein the fin further comprises:
- a first descending lip extending from the first overhanging edge; and
- a second descending lip extending from the second overhanging edge.
- 30 13. The free-draining heat exchanger of claim 1, further comprising:
- a second fin contacting the first and second heat exchange tubes; and
- a parallel portion connecting the fin and the second fin and substantially parallel to and contacting one of the first or second heat exchange tubes.

14. The free-draining heat exchanger of claim 13, wherein the fin, the second fin and the parallel portion are formed from a continuous piece of material.
15. The free-draining heat exchanger of claim 13, wherein the parallel portion forms a sharp corner with the fin to reduce liquid surface tension.
- 5 16. The free-draining heat exchanger of claim 13, wherein the fin comprises a notch on the fin adjacent the parallel portion.
17. The free-draining heat exchanger of claim 16, wherein the notch spans an edge of the fin.
18. The free-draining heat exchanger of claim 16, wherein the notch spans an
10 area of the fin between but not including edges of the fin.
19. The free-draining heat exchanger of claim 16, wherein the notch comprises a cross-section selected from the group consisting of oval, rectangular, trapezoidal, triangular, elliptical, racetrack and combinations thereof.
20. The free-draining heat exchanger of claim 16, wherein the fin comprises
15 between about one notch and about five notches, and wherein each notch has a length between about 3 mm and about 32 mm and a height between about 1 mm and about 5 mm.
21. The free-draining heat exchanger of claim 14, wherein the fin further comprises a first overhanging edge extending beyond a first lateral edge of the first heat
20 exchange tube, and wherein the second fin comprises a second overhanging edge extending beyond the first lateral edge of the first heat exchange tube, and wherein the parallel portion comprises a third overhanging edge extending beyond the first lateral edge of the first heat exchange tube.
22. The free-draining heat exchanger of claim 21, wherein the third
25 overhanging edge comprises a notch.
23. The free-draining heat exchanger of claim 21, further comprising:
a notch located at an intersection of the first and third overhanging edges.
24. The free-draining heat exchanger of claim 21, wherein the first
overhanging edge is separated from the fin and bent downward to form a descending lip
30 adjacent the second fin.
25. The free-draining heat exchanger of claim 1, wherein the fin has a curvature.
26. The free-draining heat exchanger of claim 25, wherein the fin comprises a notch adjacent the first or second heat exchange tube.

27. The free-draining heat exchanger of claim 1, wherein the fin comprises:
a first fin segment; and
a second fin segment connected to the first fin segment, wherein the first
fin segment and the second fin segment form an angle between
about 100° and about 170°.
28. The free-draining heat exchanger of claim 27, wherein the first fin
segment comprises a notch adjacent the first or second heat exchange tube.
29. The free-draining heat exchanger of claim 1, further comprising:
a plurality of fins contacting the first and second heat exchange tubes,
wherein adjacent fins are connected to form a corrugated pattern
along a longitudinal axis of the first and second heat exchange
tubes.
30. A free-draining fin structure comprising:
an array of fins disposed between adjacent heat exchange tubes for
providing enhanced water drainage by reducing liquid surface
tension, each fin in the array of fins comprising:
an opening;
a louver for directing airflow through the opening and around the
fin; and
at least one drainage enhancement feature.
31. The free-draining fin structure of claim 30, wherein the at least one
drainage enhancement feature is selected from the group consisting of a louver angle
greater than 45°, a notch, a sharp corner, an overhanging edge, a descending lip, a
curvature, an angle, a rotated fin structure and combinations thereof.
32. The free-draining fin structure of claim 30, further comprising:
a parallel portion connecting adjacent fins in the array for engaging with a
heat exchange tube.
33. The free-draining fin structure of claim 30, wherein the louver has a
louver angle greater than 45°.