Dec. 26, 1967 J. H. AMMON 3,360,037

HEAT EXCHANGER U-BEND TUBE ARRANGEMENT

Filed Aug. 24, 1965

3 Sheets-Sheet 1

FIG.1

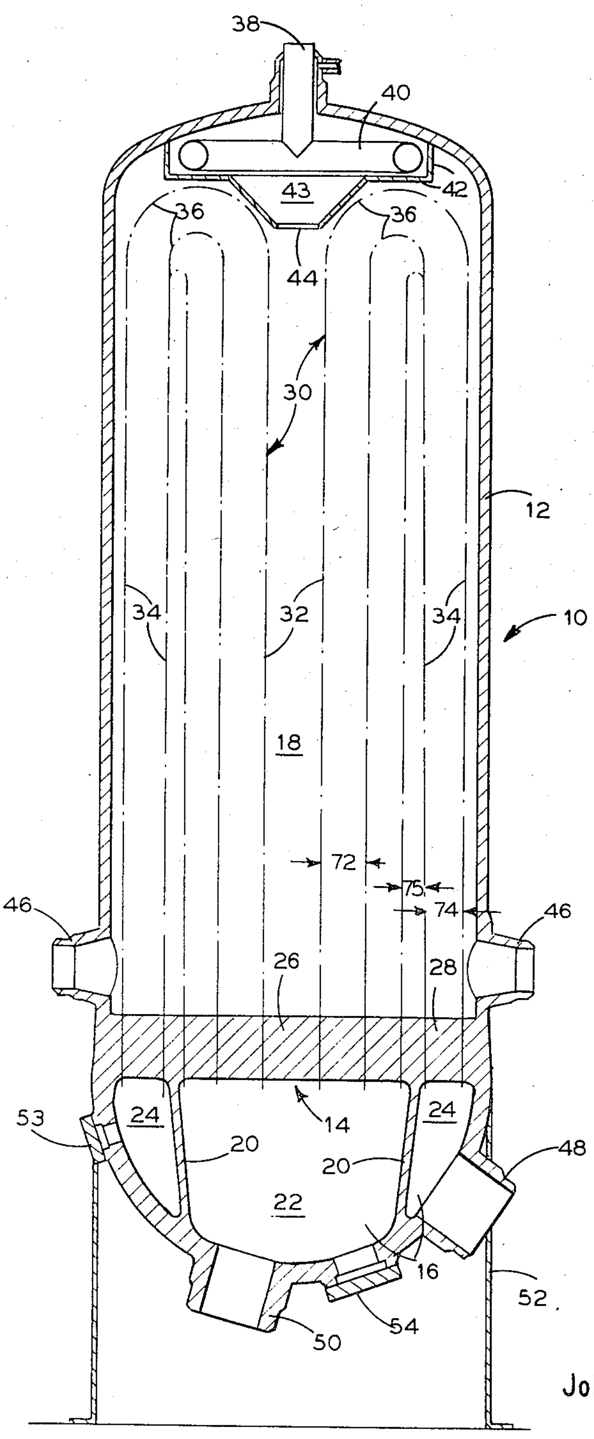

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FIG. 2

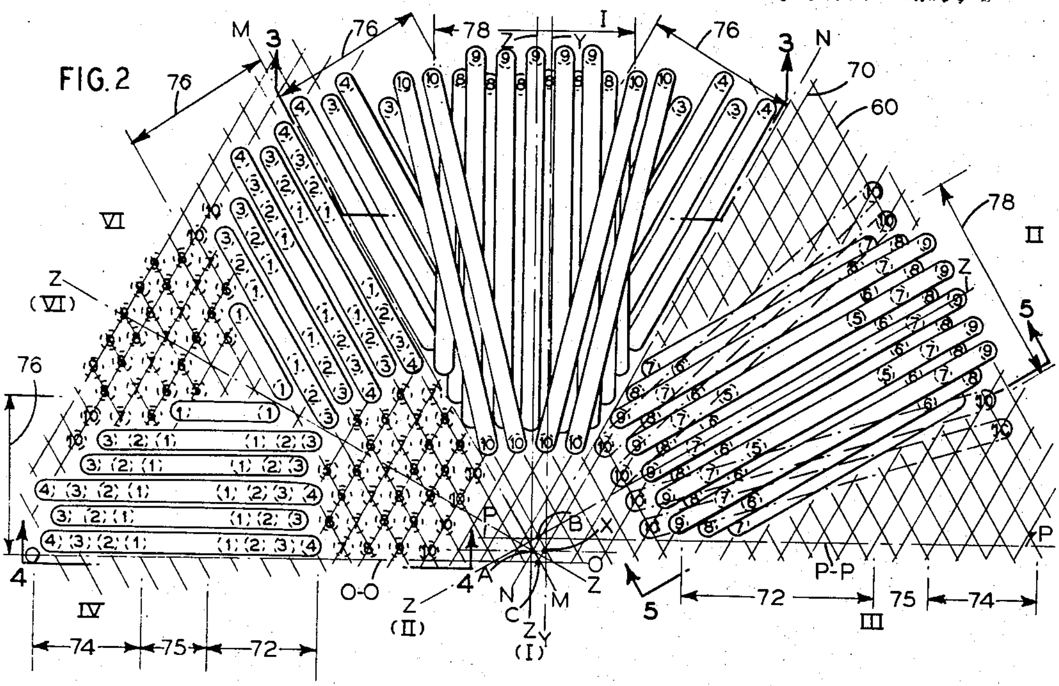

FIG. 3

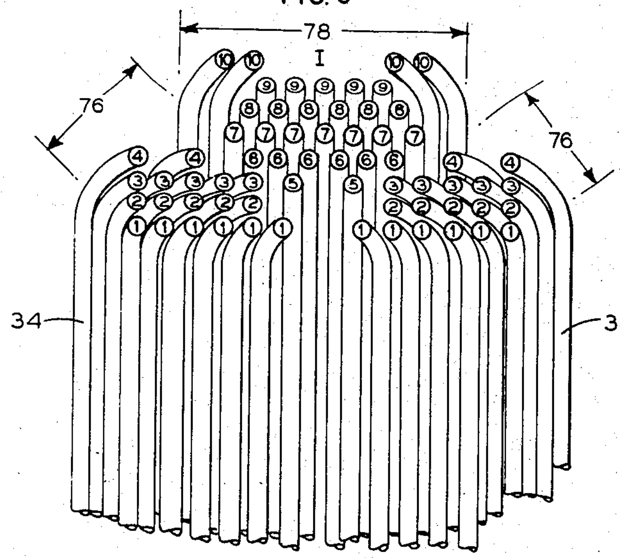

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FIG. 4

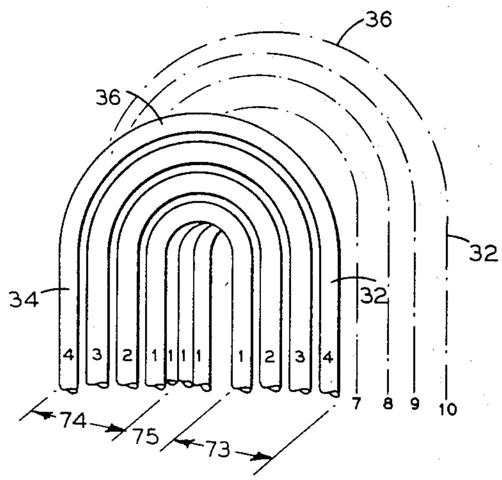


FIG. 5

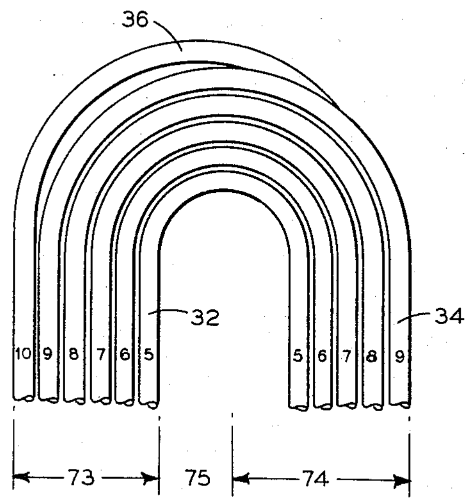
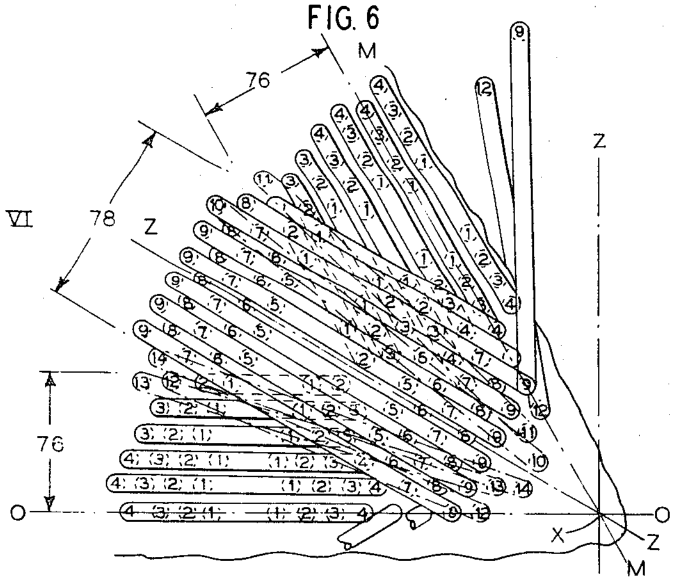


FIG. 6



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HEAT EXCHANGER U-BEND TUBE ARRANGEMENT

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9 Claims. (Cl. 165—158)

ABSTRACT OF THE DISCLOSURE

A U-bend tube arrangement for a heat exchanger having a tube sheet with an inner central portion receiving one end of each tube for communication with one fluid compartment, and an outer annular portion receiving the other end of each tube for communication with another fluid compartment, the U-bend tubes being arranged equidistantly in an annular bank composed of a plurality of equiangular, sector-shaped sub-banks of tubes, with the tubes of each sub-bank being arranged in mutually parallel planes.

This invention relates in general to heat exchangers employing U-bend tubes and more particularly it is directed to the arrangement of the U-bend tubes into an annular bank.

In the heat exchanger art there has been a steady increase in the size of the vessels used and correspondingly an attempt to find tube arrangements which afford the maximum tubular surface within a given heat exchanger volume. Because of the size of such heat exchangers and the large differences in temperature which often exist in them differential thermal expansion is a problem. In heat exchangers, where the vessel and tube sheets are relatively thin, the differential thermal expansion problem is not serious, however, as vessels and tube sheet size increase and temperature differentials widen the problem becomes aggravated.

Originally most heat exchangers were of the the shell and tube type employing straight tubes extending between a pair of spaced tube sheets rigidly connected to the shell. In such constructions thermal stressing became a problem as temperature differentials increased and the differences in thickness of the tubes, tube sheet and vessel became significant. Undue thermal stressing resulted in tube distortion, and leaks between the tube and tube sheet and also in thermal fatigue in the tube sheet and shell. One construction devised to overcome this problem, particularly with regard to tube distortion and leakage, was the U-bend tube bank which utilized a single tube sheet to hold both ends of the tubes, leaving the tubes free to expand without restraint. Chambers were provided for flowing a fluid through the tubes by partitioning the inlet side of the tube sheet. An example of such a U-bend tube heat exchanger can be seen in Patent No. 2,862,479 issued December 2, 1958 to R. U. Blaser et al. In such a unit a great number of different sizes of U-bends are required for the tubes ranging from the small or narrow bight tubes located in the center of the tube bank to the larger or wider bight tubes located at the periphery of the bank.

It has been known that arranging U-bend tubes in an annular shaped bank has certain advantages, for example reduction in the different sizes of U-bends required, reduction in the overall height of the tube chamber, a preferable distribution of the inlet and outlet tubes in the tube sheet, and under certain conditions a more desirable heat transfer arrangement. However, prior to the present invention the problem of disposing an annular bank of U-bend tubes in an identically spaced pattern or lattice had not been solved. In the prior art where annular banks of U-bend tubes have been used the spacing has not been

the same throughout the bank, for example in Patent No. 2,774,575 issued December 18, 1956 to H. Walter the U-bend tubes are arranged in platens extending radially from the center of the heat exchanger vessel. While tubes in a single platen are evenly spaced apart the spacing between adjoining platens increases from the center to the radially outer region of the heat exchanger. When such diverging spacing is employed the effective heat transfer between the fluid flowing through the tubes and that flowing over them is considerably reduced.

It is a primary object of the present invention to provide an annular bank of equidistantly spaced U-bend tubes.

Another primary object of the present invention is to furnish an annular bank of U-bend tubes divisible into a number of equiangular, sector shaped, sub-banks.

A further object of the invention is to provide a method of equidistantly spacing U-bend tubes in an annular bank within a heat exchanger.

Accordingly, the present invention is directed to the arrangement of U-bend tubes into an annularly shaped bank in a heat exchanger. The heat exchanger comprises a longitudinally elongated casing divided interiorly by a tube sheet into an end chamber and a tube chamber. The end chamber is further divided by a partition into an inlet compartment and an outlet compartment and the partition also divides the tube sheet into a centrally disposed inner part and concentrically arranged outer part. In this way the inner part of the tube sheet communicates with one of the compartments in the end chamber while the outer part communicates with the other compartment.

In the tube chamber a bank of U-bend tubes are arranged each having a first tube section connected to the inner part of the tube sheet and in communication with its corresponding compartment and a longitudinally extending second tube section connected to the outer part of the tube sheet and in connection with the other compartment in the end chamber, and the first and second sections connected by a U-bend or bight section. The first and second tube sections of the U-bend tubes are arranged in an equilateral triangular lattice so that each tube is spaced an equal distance from its adjoining tubes in either the inner or outer part of the bank. By a lattice is meant a regular geometrical arrangement of tubes. Generally evenly spaced tubes are arranged in either square or triangular patterns or lattices. In a square lattice the tubes in adjacent rows are in line while in a triangular lattice the tubes in adjacent rows are staggered by half the distance between adjacent tubes in a row. Additionally, the bank is divided into a number of equiangular sectors with the tubes in each sector arranged in planes parallel to either the bisector of the sector or to the planes forming the diverging boundaries of the sector.

The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawing and descriptive matter in which there is illustrated and described a preferred embodiment of the invention.

Of the drawings:

FIG. 1 is a vertical section through a heat exchanger incorporating an annular bank of U-bend tubes;

FIG. 2 is a partial plan view illustrating the arrangement of an annular bank of equidistantly spaced U-bend tubes;

FIG. 3 is a partial vertical section taken along line 3—3 in FIG. 2;

FIG. 4 is a partial elevational view taken along line 4—4 in FIG. 2;

FIG. 5 is a partial elevational view taken along line 5—5 in FIG. 2; and

FIG. 6 is a partial plan view of another arrangement of an annular bank of U-bend tubes.

In FIG. 1 is shown a heat exchanger **10** having a longitudinally elongated vertically arranged, cylindrically shaped vessel or casing **12**. Within the casing a transversely arranged tube sheet **14** divides it into a lower end chamber **16** and an upper tube chamber **18**. Annular shaped partition **20** extending between the tube sheet and the casing divide the end chamber **16** into a centrally located inner compartment **22** and a concentrically disposed outer compartment **24**. Additionally the partition **20** divides the tube sheet into a centrally located inner part **26** and a concentrically arranged outer part **28**, the inner and outer parts **26, 28** of the tube sheet being in communication with the corresponding inner and outer compartments **22, 24**.

Extending upward from the tube sheet **14** within the tube chamber **18** is an annularly arranged bank of U-bend tubes **30**. Each tube comprises a first tube section **32** connected to the inner part **26** of the tube sheet and a second tube section **34** connected to the outer part **28** of the tube sheet. The first and second tube sections **32** and **34** are connected by U-bend sections **36**, the bight or bend of these sections varying in size depending on the location of the tube in the bank. For purposes of illustration the heat exchanger **10** in FIG. 1 is shown vertically arranged with a drainable bank of U-bend tubes, however, the heat exchanger also could be arranged with the tubes depending vertically from its upper end or disposed in a horizontally oriented casing.

At the upper end of the casing an inlet connection **38** and inlet header **40** are provided for introducing fluid into the tube chamber **18**. Plate means **42** form an inlet plenum **43** and an opening **44** for distributing heat transfer fluid into the tube chamber for flow over the U-bend tubes **30**. Oppositely situated outlet nozzles **46** extend outwardly from the casing and are spaced just above the tube sheet for removing the fluid from the tube chamber **18** after its passage over the tubes. In the lower end of the casing **12**, below the tube sheet, nozzle **48** communicates with the outer compartment **24**, and nozzle **50** communicates with the inner compartment **22** for circulating fluid through the U-bend tubes.

Skirt **52**, attached to the lower end of the casing, extends downwardly to provide support for the unit. Closure plates **53, 54** seal access openings in the casing which afford admittance to the inner and outer compartments and the end chamber face of the tube sheet **14**.

One of the primary features of the present invention is the identical spacing of the U-bend tubes throughout the tube bank. This invention is based upon a novel equilateral triangular lattice arrangement which permits the equal spacing of the tubes, and the division of the tube blank into equiangular sectors in which the tubes are arranged in planes parallel either to the bisector of the sector or to one of the planes which form the diverging boundaries of the sector. In the tube bank the radial dimension of the open annular space between the first and second legs of the U-bend tubes is dependent upon the minimum tube bend or bight which can be utilized and also upon the thickness of the partition which divides the tube sheet **14** into its inner and outer part **26, 28**. There is no limitation to the number of tubes which may be used other than the available space in the heat exchanger casing.

In FIG. 2 for purposes of simplicity only a portion of the bank of tubes is shown and the peripheral edge of the tube sheet and the walls of the heat exchanger casing have been omitted.

In FIG. 2 the first step in assembling the U-bend tubes into an annular shaped bank comprises establishing on the tube sheet a reference line extending through the center of the face or in other words providing a diameter across the tube sheet face. The center of the tube sheet face is designated as X and Y—Y represents the reference line used as the starting line for constructing the annular bank of U-bend tubes. A first coordinate line **60** is established passing through the center X and forming a 30 degree angle with the reference line Y—Y. Second coordinate line **70** is also drawn through the center X forming a 30 degree angle with reference line Y—Y and providing an included angle of 60 degrees with the first coordinate line **60**. Additional evenly spaced first and second coordinate lines **60** and **70** are placed on the tube sheet face parallel with the initially established first and second coordinate lines **60** and **70**. The spacing of the coordinate lines is selected based on the size of the tubes and the flow channel required between adjoining tubes. These intersecting coordinate lines form a network of equilateral parallelograms on the tube sheet face, each parallelogram containing two 60 degree and two 120 degree angles. The bisector of the 120 degree angles divides each parallelogram into a pair of equilateral triangles.

Next line Z—Z is established parallel to and spaced from line Y—Y half the distance between adjacent coordinate lines. With line Z—Z as its bisector a 60 degree sector is established with point A as its apex, and lines M—M and N—N as its outwardly diverging boundaries. The remainder of the tube sheet face is divided into five similar sectors starting with line M—M and finishing with line N—N, the sectors shown in FIG. 2 being identified as I, II, and VI. Because the line Z—Z is offset from the reference line Y—Y the apices of the sectors are offset a similar distance from the center X of the tube sheet face, note the location of the apices A, B, and C corresponding to Sectors I, II and VI.

With the coordinate lines and sectors established the U-bend tubes **30** can then be assembled into the tube sheet face. Tube openings as required are provided in the tube sheet at the intersection of the coordinate lines **60** and **70** to receive the ends of the U-bend tubes. Each sector is divided into a radially inner part **72** and a radially outer part **74** separated by an annular open part **75**. The areas of these parts **72, 74** are substantially equal. In addition the outer part of each sector is also divided circumferentially into two side regions **76** each bordering one of the diverging boundaries of the sector, M—M, and N—N for Sector I, and separated by an intermediate section **78** which is equally divided on either side of the bisector Z—Z. The side and intermediate regions are irregular in shape.

In FIG. 2, for the purpose of describing the assembly of the U-bend tubes into the tube sheet, Sector VI illustrates the tubes located in the intermediate region **78**, Sector II shows the tubes in the side region **76**, and Sector I contains the combined arrangement of the tubes in the side and intermediate regions **76, 78**.

Initially as shown in Sector VI the tubes designated as (1) are arranged in planes parallel to the adjacent boundary lines M—M or O—O of the sector. The tubes (1) have their first tube sections located in the inner part **72** of the sector at the intersection of the coordinate lines closest to the inner edge of the open part **75** and their second tube sections in outer part **74** of the sector closest to the outer edge of the open part **75**. Tubes (1) are positioned in spaced parallel side by side relationship from the boundary lines M—M and O—O inwardly until the innermost tube (1) is adjacent the bisector line Z—Z (VI) in the inner part **72**. Successively tubes (2), (3), and (4) are nested with tubes (1) so that they form a plurality of parallel platens **80**. The number of tubes in each platens varies from one to four. None of the tubes in the side regions extend across the bisector Z—Z. The number of tubes per platen is determined by the available locations in the inner part **72** for tubes from the side and intermediate regions **76, 78** and by the need to provide a bank of tubes which is as compact as possible.

In FIG. 4 there is shown the manner in which the tubes in one side region **76** of Sector VI are arranged with the U-bend sections spanning the open part **75**. The size of the bight or loop of the tubes in the side regions increases from tubes (1) to (4). The phantom lines in FIG. 4 show the relative position of the tubes located in the intermediate region 78 with respect to the tubes disposed in the side region 76.

In FIG. 2 Sector II illustrates the assembly of the tubes whose second tube sections 34 are located in the intermediate region 78 while Sector VI shows the location of the tubes in the inner and outer parts of the sector. The tubes marked (5) in the intermediate region are arranged parallel to the bisector Z—Z (II) and loop or cross over the top of the U-bend sections of the tube in the side regions 76. As mentioned previously FIG. 4 shows the relationship between the U-bend sections of the tubes in the side and intermediate regions. Tubes (5) in intermediate region 78 are located along the outer edge of the open part 75, and within the inner part 72 are positioned radially inward of the tubes (1), (2), (3). The tubes in the intermediate region form two groups of parallel platens with tubes (5), (7), (9) forming one group of tubes (6) and (8) forming the other. Tubes (10) are positioned at a 15 degree angle to the tubes in both the side and intermediate regions because they cannot be fitted into the sector parallel to either its boundary or its bisector. The open spaces which remain in the outermost and innermost portions of the sectors may be closed to flow by using baffles to counter any maldistribution in the heat exchange process.

FIG. 3 illustrates manner in which the tubes in the intermediate region 78 loop over the tubes in the side regions 76.

In each of the six sectors three of which are shown in FIG. 2 the arrangement and number of tubes is the same. By utilizing this arrangement the maximum number of tubes are employed in equally spaced relationship in each sector and optimum heat transfer can be achieved. For purpose of supporting the tubes a number of them may be omitted from the bank, i.e., along the bisector or sector boundary, and be replaced by support rods which extend from the tube sheet with the rods in turn forming a part of a tube support assembly.

Earlier it was mentioned that banks of U-bend tubes are well known in the heat exchanger art, however, these prior constructions did not disclose equidistantly spaced U-bend tubes throughout annular shaped banks. In those known constructions the number of different tube bends required was considerably greater than in the present arrangement. In the present invention the tube shapes are repeated in six sectors while in the usual prior art the number of bends would be repeated only twice since the banks are normally formed of two symmetrical halves.

In FIG. 6 there is shown an alternate arrangement in which the tube sheet is divided into sectors without first providing any offset for the starting reference line such as demonstrated in FIG. 2. The component parts of the sector in this figure similar to those shown in FIG. 2 bear the same reference numerals. The tubes in FIG. 6 are arranged in the same parallel relationship to either the bisector or the diverging boundaries of the sector as described for FIG. 2, tubes (1), (2), (3), and (4) are parallel to the adjacent sector boundary and tubes (5), (6), (7), (8), and (9) are parallel to the bisector. Since the apices of the sectors are not offset in relation to the center of the face the U-bend tubes located along the boundary lines are common to the adjoining sectors. However, the inner four tubes on the boundary lines are divided equally between the two adjoining sectors. Two of the tubes, (7) and (8) are disposed parallel to the bisector of one sector and tube (9) is parallel to the other adjoining bisector. Tube (12) is disposed at a 15 degree angle to the bisector and the boundaries as are tubes (10), (11), (13) and (14). This pattern repeats itself in each of the six sectors around the tube sheet.

For purposes of establishing the approximate annular areas required for the legs or U-bend tubes when the number and pitch or spacing of the tubes is known the following formula may be employed:

$$\text{Area}=1.055\sqrt{\text{Number of tubes}}\times\text{pitch}+\text{O.D. of tubes}$$

Basically the present invention resides in establishing a equilateral triangular lattice construction for both legs of the U-bend tubes. In the present arrangement the coordinate lines form an equilateral triangular lattice construction which in combination with the orientation of the tubes in 60 degree sectors permits identical tube spacing though the tubes are arranged in an annular bank.

By achieving equal spacing for all the tubes, in the annular bank, automatic equipment can be used in drilling the tube openings in the tube sheet and as a result a considerable saving made in the cost of the time for assembling the unit. Any other annular disposition of the coordinate lines would not result in equal tube spacing in both the inner and outer parts of the sectors.

What is claimed is:

1. A tubular arrangement in a heat exchanger which comprises a plurality of U-bend tubes, a tube sheet having an inner central area portion receiving one end of each of said tubes to communicate same with one fluid compartment, and an outer annular area portion receiving the other end of each of said tubes to communicate same with another fluid compartment, said U-bend tubes being disposed equidistantly in an annular bank composed of a plurality of equiangular, sector-shaped sub-banks of tubes, the tubes in each sub-bank being disposed in mutually parallel planes.

2. The tubular arrangement according to claim 1 wherein the tubes of at least one sector-shaped sub-bank are parallel to a plane defining one of the boundaries of the sector.

3. The tubular arrangement according to claim 1 wherein the tubes of at least one sector-shaped sub-bank are parallel to the plane defining the bisector of the sector.

4. The tubular arrangement according to claim 1 wherein the tubes of at least one sector-shaped sub-bank are parallel to a plane defining one of the boundaries of that sector, and the tubes of at least one other sector-shaped sub-bank are parallel to the bisector plane of that sector.

5. A heat exchanger comprising:

(A) a longitudinally elongated casing,

(B) a tube sheet arranged within and dividing said casing into an end chamber and a tube chamber,

(C) partition means dividing said end chamber into an inlet compartment and an outlet compartment and said tube sheet into a centrally disposed inner part and a outer part concentrically arranged about said inner part, said inner part of said tube sheet in communication with one of said compartments in said end chamber and the outer part of said tube sheet in communication with the other compartment in said end chamber,

(D) a multiplicity of U-bend tubes disposed within said tube chamber and each comprising a longitudinally extending first tube section connected to the inner part of said tube sheet and in communication with its corresponding said compartment in said end chamber and a longitudinally extending second tube section connected to the outer part of said tube sheet and in communication with its corresponding said compartment in said end chamber, said first and second tube sections connected by a U-bend section,

(E) said first and second tube sections arranged in an equilateral triangular lattice,

(F) said U-bend tubes being divided into similar 60 degree sector shaped banks with each bank having substantially the same number of tubes, and

(G) the tubes in each of said banks divided into two groups, one group being located in planes parallel to the plane bisecting the sector and the tubes in the other group being divided into two subgroups, the tubes in one subgroup located in planes parallel to the one of the two planes forming the diverging boundaries of the 60 degree sector and the tubes in the other subgroup being located in planes parallel to the other plane forming the diverging boundaries of the sector.

6. A heat exchanger comprising:

(A) a longitudinally elongated vertically arranged cylindrically shaped casing,

(B) a tube sheet transversely arranged within and dividing said casing into an end chamber and a tube chamber,

(C) partition means dividing said end chamber into an inlet compartment and an outlet compartment and said tube sheet into a centrally located inner part and a concentrically arranged outer part, said inner part of said tube sheet in communication with one of said compartments in said end chamber and the outer part of said tube sheet in communication with the other compartment in said end chamber,

(D) a multiplicity of U-bend tubes disposed within said tube chamber and each comprising a longitudinally extending first tube section connected to the inner part of said tube sheet and in communication with its corresponding said compartment in said end chamber and a longitudinally extending second tube section connected to the outer part of said tube sheet and in communication with its corresponding said compartment in said end chamber, said first and second tube sections connected by a U-bend section,

(E) said first and second tube sections arranged in an equilateral triangular lattice,

(F) said U-bend tubes being divided into six similar 60 degree sector shaped banks with each having substantially the same number of tubes.

(G) the tubes in each of said banks divided into two groups, one group being located in planes parallel to the plane bisecting the sector and the tubes in the other group being divided into two sub-groups, the tubes in one subgroup located in planes parallel to the one of the two planes forming the diverging boundaries of the 60 degree sector and the tubes in the other subgroup being located in planes parallel to the other plane forming the diverging boundaries of the sector, and

(H) nozzle means in said casing for circulating a fluid through said tube chamber over said tubes and for passing a fluid through said inlet compartment, tube and outlet compartment.

7. A method of assembling an annular arrangement of U-bend tubes into a tube sheet in a heat exchanger comprising:

(A) dividing the tube sheet into a plurality of equiangular sectors,

(B) dividing each sector into a radially inner section and a radially outer section each of substantially equal areas,

(C) establishing two sets of parallel equally spaced cordinate lines on the face of said tube sheets angularly disposed one set to the other and providing on said face a equilateral triangular lattice for said tubes,

(D) drilling tube openings in the tube sheet in the inner and outer sections of said sectors at the intersections of said coordinate lines, and

(E) inserting U-bend tube into said tube sheet with one end fitted into a tube opening in an inner section of one of said sectors and the other end fitted into a tube opening in the outer section of the same sector and positioning said U-bend tubes whereby the one group of tubes in the sector is arranged parallel to a plane bisecting the sector and, said group of tubes divide the remaining tube in the outer section of the sector into subgroups and each subgroup being arranged parallel to the plane of the adjacent boundary of said sector.

8. A method of assembling an annular arrangement of U-bend tubes into a tube sheet in a heat exchanger comprising:

(A) dividing the tube sheet into six 60 degree sectors,

(B) dividing each sector into a radially inner section and a radially outer section each of substantially equal areas,

(C) establishing two sets of parallel, equally spaced coordinate lines on the face of said tube sheets whereby the lines of one set intersect the lines of the other set forming included angles of 60 degrees and dividing the face of the tube sheet into a multiplicity of equilateral parallelograms,

(D) drilling tube openings in the tube sheet within the inner and outer sections of said sectors at the intersection of said coordinate lines, and

(E) inserting U-bend tube into said tube sheet with one end fitted into a tube opening in an inner section of one of said sectors and the other end fitted into a tube opening in the outer section of the same sector and positioning said U-bent tubes whereby the one group of tubes in the sector is arranged parallel to a plane bisecting the sector and, said group of tubes divide the remaining tube in the outer section of the sector into two subgroups and each subgroup being arranged parallel to the plane of the adjacent boundary of said sector.

9. A method of assembling an annular arrangement of U-bend tubes into a tube sheet in a heat exchanger comprising:

(A) establishing a reference line on and passing through the center of one face of said tube sheet,

(B) establishing a first and a second coordinate line on the face of the tube sheet each coordinate line passing through the center of the face and forming an angle of 60 degrees with said reference line and the other coordinate line,

(C) establishing a multiplicity of first uniformly spaced coordinate lines parallel to said first coordinate line,

(D) establishing a multiplicity of uniformly spaced second coordinate lines parallel to said second coordinate line, said first coordinate lines and said second coordinate lines being spaced the same distance apart, whereby the intersectiong first and second coordinate lines divide the face of the tube sheet into a plurality of equilateral parallelograms,

(E) dividing the face of the tube sheet starting with the reference line into six 60 degree sectors,

(F) subdividing the area of each sector into a radially inner part and a radially outer part each having substantially the same area,

(G) providing tube openings in said tube sheet at the intersections of said coordinate lines in said inner and outer parts of said sectors,

(H) inserting said U-bend tubes into the tube openings in said tube sheet with the first leg of the U-bend tube disposed in the inner part of the sector and the second leg of the tube located in the outer part of the sector,

(I) dividing the outer part of each of said sectors into a pair of side regions bordering the diverging boundaries of said sector and separated by an intermediate region,

(J) arranging the plane of U-bend tubes having their second legs located in the sides region of the outer part of the sector parallel to the plane of the adjacent boundary of the sector,

(K) arranging the plane of the U-bent tubes having their second legs disposed in the intermediate region parallel to the plane of the bisector of said sector, whereby all of said U-bent tubes are disposed in a uniformly spaced lattice and the planes of said tubes are disposed either parallel to one of the boundaries of the sector or parallel to the bisector of said sector.

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