June 30, 1959 S. HOLM 2,892,618

HEAT EXCHANGERS AND CORES AND EXTENDED SURFACE ELEMENTS THEREFOR

Filed April 12, 1957 2 Sheets-Sheet 1

Fig. 1.

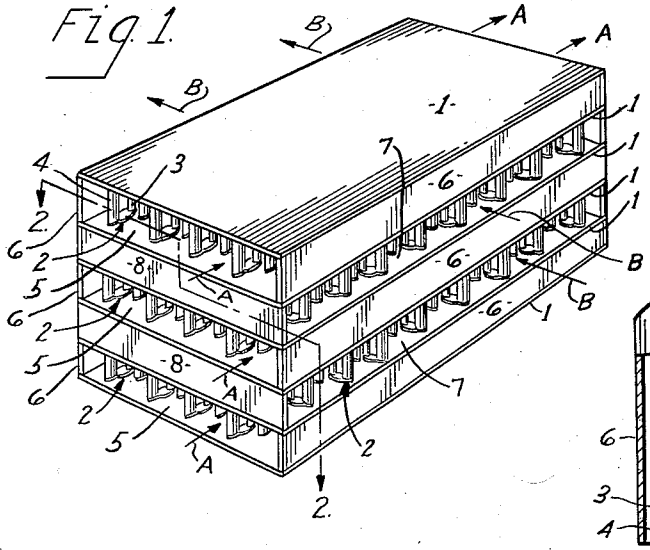
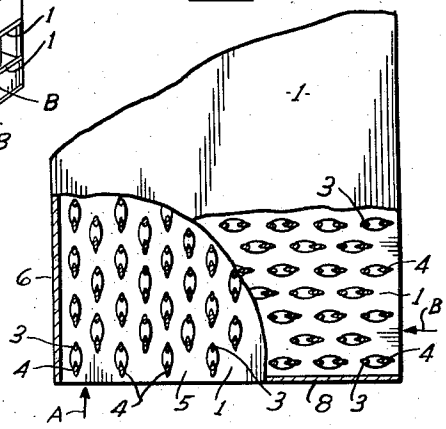


Fig. 2.



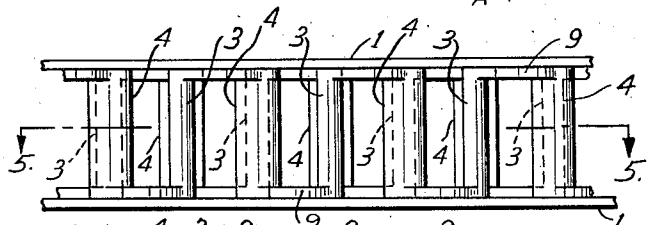


Fig. 3.

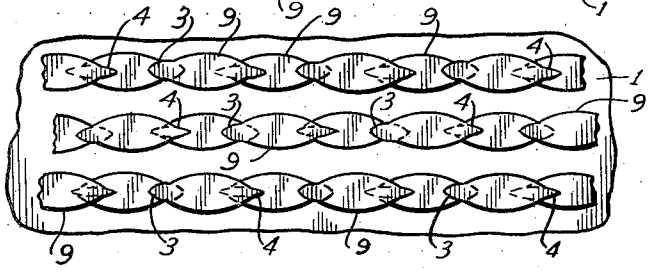


Fig. 4.

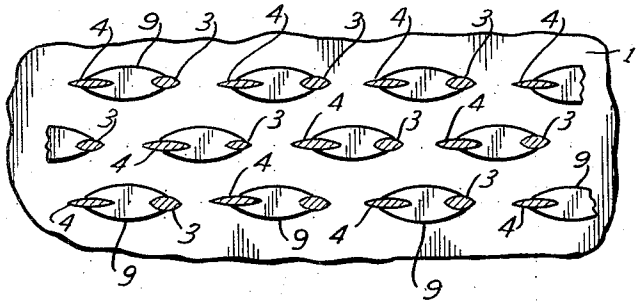


Fig. 5.

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HEAT EXCHANGERS AND CORES AND EXTENDED SURFACE ELEMENTS THEREFOR

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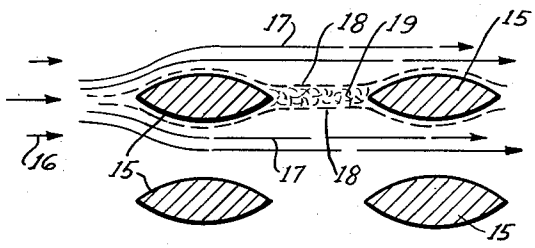


Fig. 6.

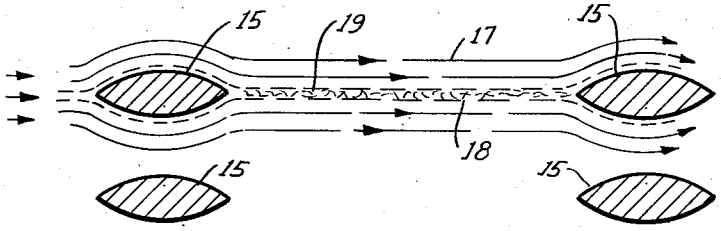


Fig. 7.

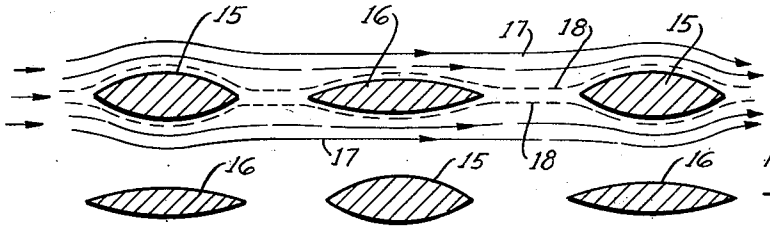


Fig. 8.

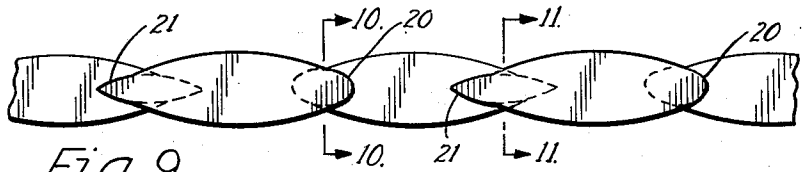


Fig. 9.



Fig. 13.



Fig. 12.

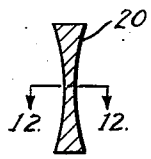


Fig. 10.

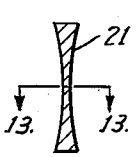


Fig. 11.

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HEAT EXCHANGERS AND CORES AND EXTENDED SURFACE ELEMENTS THEREFOR

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Application April 12, 1957, Serial No. 652,527

6 Claims. (Cl. 257—245)

This invention relates to heat exchangers, and cores and extended surface elements therefor, and is an improvement on the heat exchangers, cores, and pin fin extended surface elements disclosed in U.S. Patent No. 2,678,808, issued May 18, 1954, to J. R. Gier, Jr., and entitled "Sinuous Wire Structural and Heat Exchange Elements and Assemblies."

As more fully described in the above identified patent, relatively efficient heat exchangers can be made by incorporating between suitable metal plates a myriad of metal pins of small diameter arranged in parallel rows and spaced apart from each other a short distance in the rows which, in turn, are spaced apart from each other transversely of the rows about the same distance as a pair of adjacent pins of the same row. The pins of each row are formed of a single length of wire which at portions spaced along its length, is flattened to form ligaments which are very thin and are readily bendable at their junctures with the intermediate portions of the wire, or legs, therebetween, so that the formed wire can be bent into sinusoidal or corrugated form in which the intermediate portions, or legs, are parallel to, and in radially spaced relation from, each other.

The pins may have the normal cross-section of the length of wire from which they are formed or a cross-section modified so that each pin is streamlined in the direction of flow, whether it be along the row of pins or transversely of the rows.

The present heat exchange elements are elements which can be formed of a single length of wire in the manner described in the above identified patent and in the United States application Serial No. 342,823, filed March 17, 1953, now Patent No. 2,778,385 granted January 22, 1957, by J. R. Gier, Jr., and entitled Apparatus and Method for Forming Sinuous Wire Structural and Heat Exchange Elements.

The heat exchanger described in the above identified patent is very efficient in relation to its size and weight. However, the ratio between the amount of heat to be transferred by it and the minimum space and weight of the exchanger can be increased by the present improvements.

In the range of the mass velocities encountered in such installations as gas turbines, pin fin extended surfaces formed of pins of circular cross-section have a lower weight and volume for a given performance than any extended surface heretofore known. Due to the high friction factors characteristic of a surface of this type, a large frontal area exposed to the oncoming gases is combined with a short flow length. Due to these characteristics, a design involving the principles of the above patent, while very effective for the heating or cooling of fluids of high density, is not as effective for fluids of relatively low density. For example, in gas turbine applications, the hot gases of low density flow through the heat exchanger and give up a great part of their heat to cooler high pressure air to be heated and expanded through the turbine. The present invention is particularly applicable to the core passages through which the hot gases pass at low pressure.

A streamlined pin surface, such, for example, as disclosed in the above identified patent, improves to some extent the results obtained under the latter conditions, but it falls considerably short of optimum efficiency. It is true that the friction factors of the pins of streamlined cross-section are considerably reduced relative to that of circular pins—in fact, they may be as little as one-half that of pins of circular cross-section. Also, the frontal area can be reduced in the case of the pins of streamlined cross-section so that they can better lend themselves to the counterflow design. However, these advantages of streamlined pins are offset to some extent by their lower heat transfer coefficient which is due partly to laminar or boundary layer effects caused by the streamlined shape and the resultant carry over of this effect from one pin to the next succeeding pin in the direction of flow. This carry over of the laminar layer can be reduced by spacing the streamlined pins a greater distance apart in the direction of flow. But, then, an increase in spacing defeats the desired reduction in the size of the exchanger.

In accordance with the present invention, a pin arrangement is provided by virtue of which advantages due to a streamlined design of the pins are obtained, and the disadvantages thereof are eliminated by providing streamlined pins of different cross-sectional shape and "aspect ratio," arranged in a row in the direction of flow, so as to destroy or reduce the laminar layer and carry over thereof from pin to pin while eliminating the need for increased spacing of adjacent pins in the direction of flow as a result of their having been streamlined. Further advantages are obtained by an arrangement of the pins of one row relative to those of the next adjacent rows, laterally of the path of flow, so as to take better advantage of the surfaces of all of the pins.

Various objects and advantages of the present invention will become apparent from the following description wherein reference is made to the drawings, in which,

Fig. 1 is a perspective view of a heat exchanger embodying the principles of the present invention;

Fig. 2 is a fragmentary top plan view of the heat exchanger illustrated in Fig. 1, parts thereof being shown in section, as indicated in Fig. 2 by the line 2—2;

Figs. 3 and 4 are enlarged side elevation and top plan views, respectively, of a portion of the heat exchanger illustrated in Fig. 1, showing three adjacent rows of pin fins, and embodying the principles of the present invention;

Fig. 5 is a horizontal cross-sectional view taken on a line 5—5, in Fig. 3;

Figs. 6, 7 and 8 are diagrammatic illustrations showing the manner of flow of gases past a series of pin fins, and illustrating some flow effects on which the present invention is based;

Fig. 9 is a top plan view illustrating a modified form of pins;

Figs. 10 and 11 are vertical cross-sectional views, taken on lines 10—10 and 11—11, respectively, in Fig. 9;

Fig. 12 is a horizontal, cross-sectional view taken on a line 12—12, in Fig. 10; and

Fig. 13 is a horizontal, cross-sectional view taken on a line 13—13 of Fig. 11.

Referring to the drawings, there is illustrated in Fig. 1 a heat exchanger or core of the general character described in the above identified patent, and comprising a plurality of metal sheets 1 which are spaced apart flatwise from each other vertically. Arranged between the sheets are a plurality of rows 2 of heat exchange elements in the form of upright streamlined pins 3 and 4, respectively, the pins 3 and 4 of each row 2 being arranged alter-

nately relative to each other. The pins 3 have a lower "aspect ratio" than the pins 4, "aspect ratio" being the ratio of the major axis of the cross section of a pin to the minor axis of the cross section of the same pin. Also, in the present structure, the cross section of each pin having a higher aspect ratio than the cross section of another pin of lesser aspect ratio has both a longer major axis and a shorter minor axis than the major axis and minor axis, respectively, of the cross section of the pin of lesser "aspect ratio."

In referring to the pins as "streamlined," it is not meant that they be limited to a true streamlined cross-section but that the cross-section is rounded at the leading end and the cross-section is longer than it is wide so as to reduce the resistance to flow as compared to pins of circular cross-section. Thus the cross-section may vary from a true and accurate streamline to oval or elliptical. The rows 2 are offset endwise relative to each other so that each pin 3 of one row lies between two pins 4 of the next adjacent rows between which it is disposed, as more fully set forth hereinafter.

In the heat exchanger illustrated, alternate spaces between the sheets 1 form passages for gases of different characteristics. For example, alternate passages may conduct the heated product from the turbine, and the passages therebetween may conduct the air to be heated to the turbine. In the form illustrated, a group of alternate passages 5 are open at the ends and closed at the sides by walls 6. Passages 7, between the passages 5, are closed at the ends by walls 8 and open at the sides. Thus, in using the present exchanger with gas turbines, the hot low pressure exhaust gases may be discharged through the passages 5 in the direction indicated by the arrows "A" from end to end of the exchanger, and the high pressure air to be heated may pass through the passages 7 transversely of the exchanger, as indicated by the arrows "B."

Referring to Figs. 3 through 5, there are shown three rows of pins embodying the principles of the present in- tion. It is to be noted that the cross-sections of the pins 3 are wide relative to their length and the cross-sections of the pins 4 are narrow relative to their length. As mentioned, the pins 3 and 4 are arranged in a row in alternate relation with respect to each other in the direction of flow and are connected by ligament portions 9 which are relatively thin and readily bendable at their junctures with the pins 3 and 4, as described in the above identified patent.

The rows of pins in a given passage 5 or 7 are preferably arranged so that each pin 3 lies between two pins 4 of the next adjacent rows, respectively, transversely of the direction of flow, and each pin 4 lies between two pins 3 of the next adjacent rows, respectively. The offset preferably is such that the axes of the pins which are in alignment transversely of the direction of flow lie in a common plane and are parallel to each other.

It is to be noted that the pins 3 and 4 all preferably comprise part of a single length of wire of original constant cross-section, and thus the different shapes of cross-sections of the pins 3 as compared with the pins 4 is due to lateral redistribution of the metal of the wire. If different ratios are desired, the wire may be upset at spaced portions along its length prior to forming the pins, so as to provide both longitudinal and lateral redistribution of the metal and a greater total amount of metal in one shape of pin than in another.

Referring next to Figs. 6, 7 and 8, the reason for the shaping of the pins in this manner will be readily understood.

Referring first to Fig. 6, there is illustrated a plurality of pins 15 arranged in rows in a manner hereinbefore described. All of these pins 15 are of the same aspect ratio and all are streamlined or lenticular in cross-section. The direction of flow is indicated by the arrow 16 and the general pattern of the flowing gases is indicated by the lines 17 and 18. As indicated by the dotted lines 18, there is a laminar layer at each side of each pin which tends to carry over from one pin to the next succeeding pin in the row. These laminary layers cause a somewhat turbulent but low velocity area 19 to be formed between the trailing edge of one pin and the leading edge of the next adjacent pin in the direction of flow. This low velocity area 19 lies between and is bounded by the dotted lines 18 and is indicated by the short crisscrossing curved dash lines. This low velocity of flow causes a very low coefficient in the areas 19 and greatly reduces the effectiveness of the frontal areas of succeeding pins at the trailing ends of the areas 19.

Next, referring to Fig. 7, it is to be noted that if the pins 15 are moved farther apart from each other in the row in the direction of flow, then the laminar layers from opposite sides of each pin draw more closely together, thus reducing the size and width of the low velocity areas 19. This allows the continuance of a higher velocity flow of the gases between the trailing edge of one pin to the leading edge of the next adjacent pin in the direction of flow, but due to the greater spacing of the pins from each other in the direction of flow, there is a smaller amount of heat exchange surface for a given volume of heat exchanger or core. The streamlining of the pin fins reduces the friction factor of the flow, the friction factor of the pins 15, for example, being only about half that for corresponding pins of circular cross-section. This permits the reduction of the frontal area of the pins 15 and lends itself to a counter flow design. However, the heat transfer coefficient of the streamlined pin fins is lower than that of the pin fins of circular cross-section, due partly to the laminar boundary layers, indicated at 18, at each side of streamlined pin fins being carried over from the leading pin to the next adjacent trailing pin. As shown, this condition can be improved, in turn, by increasing the spacing of the pins in the flow direction, as shown in Fig. 7. But increasing the spacing in this manner reduces the amount of heating surface too greatly in relation to the volume of the heat exchanger.

Thus, Fig. 6 shows the desired spacing from the point of view of compactness, but in the structure there illustrated, the area at 19 is quite large.

In Fig. 7, the longitudinal spacing has been increased 100% with reduction of the area 19 and some improvement in the conditions and results, but with too great a size and lack of compactness of the resultant core.

Referring next to Fig. 8, it is to be noted that, by alternating, in the direction of flow in a given row, pins 15 of low aspect ratio with pins 16 of high aspect ratio, and spacing the former sufficiently far apart to cause the laminar layers at their opposite sides to approach more closely and thus reduce the areas 19 and maintain a higher velocity of flow between the trailing edge of one pin and the leading edge of another, and introducing in the increased space between the low aspect ratio pins 15, pins 16 of higher aspect ratio, the advantage of greater spacing of the pins 15 is retained without the corresponding increase in size of the core. Also, there is obtained a larger ratio of free air space as compared to a structure in which the aspect ratio of all pins is low, particularly since pins of high aspect ratio are staggered transversely of the rows with pins of smaller aspect ratio.

In Fig. 8, the spacing of pins 15 of lower aspect ratio has been doubled and pins 16, of higher aspect ratio have been introduced midway between the two adjacent lower aspect ratio pins of the same row.

Thus, in Figs. 1 through 5, introduction of pins 4 of high aspect ratio between the adjacent pins 3 of small aspect ratio, in the direction of flow, does not change appreciably the advantageous flow pattern in Fig. 7, but retains it, as illustrated in Fig. 8.

An additional advantage is obtained by offsetting adja-

cent rows in the direction of flow so that each pin 3 is centered between two pins 4 of the adjacent rows and vice versa. The advantage is that the flow stream is given a sine motion over the heating surface. This assists in reducing or breaking up the boundary layers, and in reducing or eliminating their carry over from one pin to the following pin in the direction of flow. It accomplishes this result without creating any high degree of turbulence. The flow resistance, therefore, is not increased appreciably over the rows of pins spaced widely apart, as in Fig. 7.

The ratio of free area to frontal area is also increased and the velocity of flow is substantially constant. Dead pockets are eliminated or reduced so that the heat transfer coefficient is improved without a reduction in the amount of heating surface in a given volume of core.

Referring next to Figs. 9 through 12, there are shown pins 20 of predetermined aspect ratio alternating with pins 21 of larger aspect ratio. Each of the pins is further modified by shaping it so that its cross-section is reduced in size at its axial midportion, that is, midway between its ends. The cross-sectional areas of each pin gradually increase from the midportion outwardly toward each end. This is done preferably by decreasing the width of the pins at the various cross-sections and not the length, thus providing a larger aspect ratio at the axial midportion of each pin than at its ends. This increases the free space area and also the effective surface for heat exchange within a given volume of heat exchanger core.

In summary, therefore, streamlining the pins to improve the effect to be obtained and render the structure efficient for counterflow, introduces the objectionable carry over of laminar layers from one pin to the next pin in the direction of flow and thus greatly enlarges the low velocity space between adjacent pins and decreases the efficiency of heat exchange. This carry over phenomenon can be eliminated by spacing the pins farther apart in the row without changing their cross-sections, but the latter solution too greatly increases the size of the heat exchanger. By alternating pins 4 of high aspect ratio between adjacent pins 3 of lower aspect ratio, the advantages of streamlining are obtained and its disadvantages eliminated, thus decreasing the size of core needed for a given amount of heat transfer while obtaining a more advantageous flow and resultant higher efficiency.

Finally, by alternating the pins transversely of the row so that each pin of higher aspect ratio is between two of lower aspect ratio, and vice versa, transversely of the direction of flow, so as to produce a wave or sine motion to the gases flowing through the exchanger, better flow and heat exchange characteristics are obtained.

Having thus described my invention, I claim:

1. In a heat exchanger, a plurality of rows of pin fins, the rows being spaced apart transversely of the direction of flow through the exchanger and the pin fins in each row being spaced apart from each other in the direction of flow, each pin fin having a different aspect ratio than those pin fins of the same row between which it is disposed, and the cross section of each pin fin which has a higher aspect ratio than other pin fins of lesser aspect ratio has both a longer major axis and a shorter minor axis, respectively, than the major axis and minor axis of the cross section of each pin fin of lesser aspect ratio.

2. A heat exchange structure according to claim 1, wherein alternate pin fins in the same row have substantially the same aspect ratio as each other and the pin fins therebetween have substantially the same aspect ratio as each other and different from the aspect ratio of said alternate pin fins.

3. A heat exchange structure according to claim 1, wherein the rows are arranged so that each one of the pin fins of one row is aligned, transversely of the rows, with a pin fin of each of the adjacent rows between which said one row is disposed, and the said one pin fin has an aspect ratio different from those between which it is disposed transversely of the rows.

4. A heat exchange structure according to claim 1, wherein at least some of said pin fins are streamlined.

5. In a heat exchanger, a plurality of rows of pin fins, the rows being spaced apart transversely of the direction of flow through the exchanger and the pin fins in each row being spaced apart from each other in the direction of flow, some of said pin fins of the same row having aspect ratios different from each other, and the cross section of each pin fin which has a higher aspect ratio than other pin fins of lesser aspect ratio has both a longer major axis and a shorter minor axis, respectively, than the major axis and minor axis of the cross section of each pin fin of lesser aspect ratio.

6. A sinuous wire element for the purposes described and comprising a length of wire having spaced ligament portions which are wide and thin relative to leg portions therebetween and readily bendable at their junctures with the leg portions, said wire being in sinusoidal form with the ligament portions providing the crests of the waves and the leg portions forming the sides of the waves, each leg portion being streamlined in the same direction, and the aspect ratio of each leg portion being different from the aspect ratios of those leg portions between which it is located, respectively, and the cross section of each leg portion which has a higher aspect ratio than other leg portions of lesser aspect ratio has both a longer major axis and a shorter minor axis, respectively, than the major axis and minor axis of the cross section of each leg portion of lesser aspect ratio.

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