April 23, 1957 C. S. SIMPELAAR 2,789,797

HEAT EXCHANGER FIN STRUCTURE

Filed Aug. 20, 1953

Fig. 1.

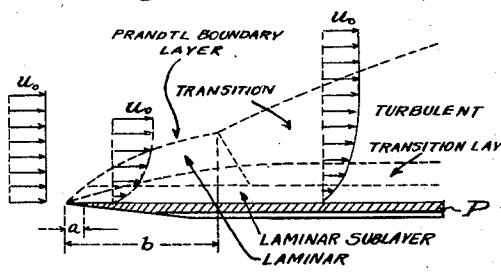


Fig. 2.

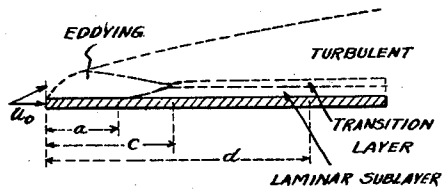


Fig. 3.

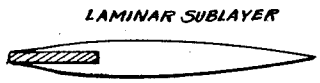


Fig. 4.

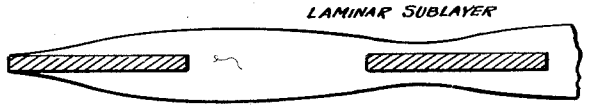


Fig. 5.



Fig. 6.

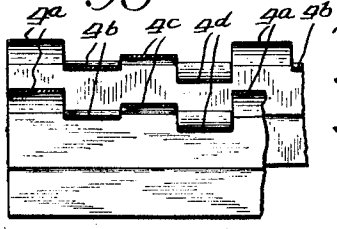


Fig. 8.

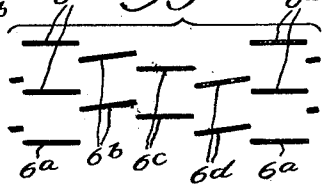


Fig. 9.

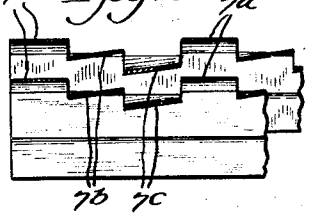


Fig. 7.

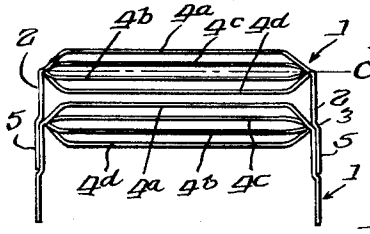


Fig. 10.

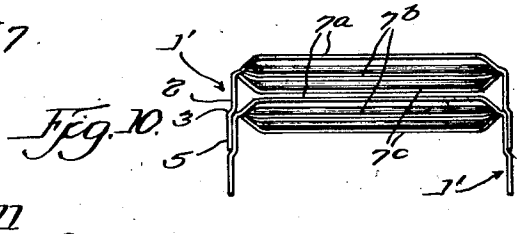
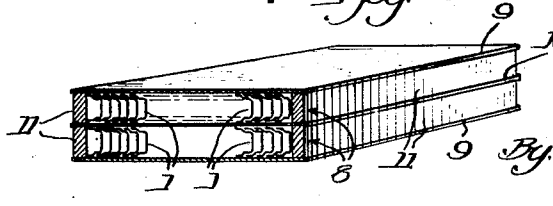


Fig. 11.



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By Lee & Lee Attys.

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2,789,797

HEAT EXCHANGER FIN STRUCTURE

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Application August 20, 1953, Serial No. 375,394

17 Claims. (Cl. 257—245)

The invention relates generally to heat exchange structures and more particularly to a fin construction for use therewith.

The present invention is of particular value in connection with high efficiency heat exchangers, as for example, where the final temperature of fluid being acted upon, either cooled or heated, is within ninety-five to ninety-nine percent of the inlet temperature of the heating or cooling fluid, and where the density of heat exchange surface is in the approximate range of three hundred or more square feet per cubic foot of volume. Expressed in another way, the invention is of particular use in exchangers wherein the accomplished temperature change in one fluid divided by the difference in inlet temperatures of the two fluids exceeds .95. In certain heat exchange applications, exchangers which cannot meet these requirements are commercially impractical, as for example, in low temperature oxygen plant exchangers wherein it is essential that the exchanger volume be at a minimum to reduce exterior heat losses, and where the entire process is commercially feasible only by virtue of the availability of high efficiency heat exchangers.

The advantage of utilizing interrupted heat transfer surfaces such as thin strips or pins has been heretofore recognized and considerable work has been done in connection with the utilization of so-called strip or pin fins. However, past research work has indicated that while generally it is desirable to reduce the width of the fin in the direction of flow, reduction in the width of the fins apparently approached a limiting value beyond which further reduction failed to produce a corresponding improvement in efficiency. Experiments conducted along the above lines have appeared to support such analysis as actual tests of heat exchange surfaces disclosed a gain in efficiency as the fin width was reduced down to what appeared to be a critical or limiting factor, beyond which, additional reduction failed to show a corresponding improvement in efficiency. Normally fin designs applicable to strip or pin fins are of necessity repetitious in pattern, wherein the fins are in line in the direction of flow with other fins, and it has heretofore been expressed that it would appear that all that was necessary with respect to in-line surfaces was that they be separated a few thousandths of an inch.

The present invention is directed to a means of utilizing fins of the strip or pin type which may be constructed in widths in the direction of flow of considerably less than those heretofore deemed practical to achieve extremely high efficiency.

Another object of the invention is the production of heat exchange surface having the desired high efficiency which is capable of being commercially produced with present production techniques and available materials.

Many other objects and advantages of the construction herein shown and described will be obvious to those skilled in the art from the disclosures herein given.

To this end my invention consists in the novel construction, arrangement and combination of parts herein shown and described, and more particularly pointed out in the claims.

In the drawings, wherein like reference characters indicate like or corresponding parts:

Fig. 1 is a diagrammatic figure illustrating the present theory in connection with sharp edged fin surfaces;

Fig. 2 is a similar diagrammatic figure illustrating applicant's theory as applied to fin surfaces having a leading edge of finite thickness;

Fig. 3 is a semi-diagrammatic figure illustrating a cross section of a fin of finite thickness and applicant's theory with respect thereto;

Fig. 4 is a diagrammatic figure illustrating applicant's theory with respect to laminar layer carry-over between in-line fin surfaces;

Fig. 5 is a diagrammatic figure similar to Fig. 4 illustrating the application of the present invention thereto;

Fig. 6 is a cross section through a fin structure embodying the present invention taken on a line extending substantially in the direction of flow along such structure;

Fig. 7 is an end elevational view of the fin structure illustrated in Fig. 6;

Fig. 8 is a semi-diagrammatic figure illustrating a modified fin pattern similar to that embodied in the construction illustrated in Figs. 6 and 7;

Fig. 9 is a sectional figure similar to Fig. 6 illustrating a modified form of construction; and

Fig. 10 is an end elevational view of a pair of the fin structures illustrated in Fig. 9.

The boundary layer theory with respect to immersed bodies, first formulated by Prandtl, briefly is that the fluid surrounding a body may be divided into two portions: (1) a thin layer close to the surface of the body in which the velocity gradient is large enough to produce viscous forces of appreciable magnitude; and

(2) the remaining portions of the fluid outside this boundary layer in which the viscous forces may be neglected in comparison with the inertia forces, or in other words where the Reynolds' number may be assumed to be infinitely large.

The characteristics of "laminar flow" and "turbulent flow" were demonstrated by Reynolds and the "Reynolds number" of course is a dimensionless term involving flow area, and the velocity, density and viscosity of the fluid, which defines the limits of laminar and turbulent flow. It, in effect, thus involves the characteristics of the fluid and the operating conditions under which it is employed.

The present theory with respect to the boundary layer formed by the flow of a fluid over an immersed surface is generally illustrated in Fig. 1, wherein a thin laminar sub-layer adjacent the surface of the object such as the plate P extends along the area of the object. The laminar boundary layer is adjacent the leading edge of the plate and a turbulent boundary layer may be produced following a zone of transition from laminar to turbulent conditions. The laminar sub-layer of the particular fluid being of relatively low velocity compared with the normal fluid flow, offers a high resistance to heat flow or transfer, and in effect acts as an insulating layer on the surface of the fin element as does the laminar layer. The turbulent boundary layer, likewise, offers similar resistance but, of course, not to as great an extent as the laminar layer and may be considered as having a transition or buffer layer interposed between it and the laminar sub-layer, offering intermediate resistance. It is believed that the general theory involving laminar layers and the Prandtl boundary is of sufficiently general knowledge in the heat transfer art that the above is sufficient for the purposes of the present application. It will be appreciated, however, that as the laminar layer acts as an insulating medium if the

theoretical approximation of Fig. 1 is correct, a theoretical fin of the length *a* would have minimum resistance to heat flow and thus, theoretically, would be the most effective width, but its minute physical proportions would substantially preclude its use in a practical commercial structure. Likewise in such case a theoretical fin of length *b* would have an average maximum resistance and thus would be the most ineffective width. Furthermore, as there is a transition from the laminar layer to a zone of turbulence or eddying, with proportionately greater efficiency, a fin having a length greater than *b* would have greater intermediate values of resistance and thus efficiency.

It will be particularly noted that the above analysis involves the utilization of a fin member wherein a leading edge thereof tapers to a line edge and therefore theoretically has no thickness, whereas practical applications require a fin having a thickness of finite order, which from a practical standpoint would approach, or probably be as great as the thickness of the laminar sub-layer. Obviously, where a finite thickness is involved a considerably different action may be produced. Figure 2 illustrates a possible theoretical analysis with respect to the boundary layers in connection with a fin of finite thickness, in which case it is believed that as a result of the fin thickness, strong eddying or turbulence would be produced adjacent the leading edge of the fin member, thus delaying somewhat the formation of the laminar sub-layer as illustrated, and on such theoretical basis a fin having the dimension *a* would have a minimum resistance and maximum efficiency. The eddying action adjacent the leading edge of the fin probably would also delay the formation of the laminar layer and may even eliminate the formation of such layer as indicated in Fig. 2, in which case the distance, equivalent to the distance *b* of Fig. 1, would be for practical purposes eliminated, and the efficiency theoretically would continuously increase as the fin width is decreased.

From the above theoretical discussion with respect to the laminar layer it will be appreciated that in connection with fins having a finite thickness, a fin having a width or dimension in the direction of flow which is less than the dimension *c* illustrated in Fig. 2, theoretically, should have exceptionally satisfactory performance, and as a result of experimentation and tests it is believed that the distance approximating dimension *c*, at normal flowing rates would be equal to approximately one-tenth of an inch to one-eighth of an inch, assuming a fin thickness of approximately three thousandths of an inch to .012 inch. In other words, on the basis of the above theoretical analysis it would appear that the heat transfer efficiency of the fin would increase as the dimension of the fin in the direction of flow, heretofore referred to as the width, is successively decreased below one-eighth to one-tenth of one inch.

However, as previously mentioned, research on heat exchange surfaces has indicated that the practical results apparently do not conform to this theory, as corresponding reductions in the fin width have apparently not achieved a corresponding increase in efficiency of the heat exchange structure.

Strip fins have normally been formed from sheet material by severing the sheet material along spaced parallel lines equal to the fin width, with alternate portions between the lines of severance being offset out of the original plane of the sheet, thus forming two series of fins each of which are connected at their ends to the sheet, the fins of each series lying in a common plane with the trailing edges of a preceding fin spaced from the leading edge of the next in-line fin by approximately the same distance as the width of the respective fins. Consequently, as the width of the fin is reduced the spacing between in-line fins is correspondingly reduced. Studies and considerations have apparently not evaluated the in-line spacing as a factor to be considered in connection with the overall efficiency of the heat exchange structure and, as previously mentioned, the conclusions of some people in this field have been that such spacing is of relatively little importance and even a few thousandths of an inch would be sufficient to achieve satisfactory results. However, I am of the belief that the in-line spacing of the fins is an important factor which must be considered and that by properly spacing the in-line fins highly efficient results may be obtained and the full advantages of the use of narrow fins more fully realized. This theoretical conclusion has been supported by actual tests on heat exchange structures constructed in accordance with the present invention and compared with tests on structures embodying prior concepts on the subject. For example, in one test a considerable increase in efficiency was obtained merely by removing certain in-line fins to increase the spacing between the remaining in-line fins, the increase showing a gain of from six to fourteen percent.

Figs. 3, 4, and 5 roughly illustrate the concept involved in connection with the spacing of in-line fins. Fig. 3 generally illustrates the boundary layer flow of fluid along the fin surface which, for the purposes of explanation may be compared with a generally sticky or viscous material which is frictionally retarded at the fin surface and thus has a tendency to build up into a low velocity "mass" which is increasing in thickness toward the trailing edge of the fin. However, as illustrated in Fig. 4, it is believed that the flow following the trailing edge would tend to revert into its original state prior to engagement with the first fin surface, so that the "mass" tends to taper off as illustrated in Fig. 3, which will hereafter be termed the boundary layer carryover. If, however, before the same can be completely dissipated the next in-line fin is reached, the result is an additional build-up of a relatively low velocity, high resistance "mass," the latter probably increasing in thickness over that formed on the first fin. This action is continued with each succeeding in-line fin, and as a consequence thereof the fins are in effect enveloped in a high resistance boundary layer or "mass," resulting in a reduction in the heat transfer efficiency of the structure.

I am therefore of the belief that if the distance between the trailing edge of a preceding fin and the leading edge of the next following in-line fin is suitably spaced as illustrated in Fig. 5, substantially complete dissipation of the high resistance fluid "mass" may be achieved before the following in-line fin is reached, eliminating a carryover and possible additional build-up on such following fin and resulting in substantially uniform heat transfer between the fluid and each fin of the exchanger structure. It is my conclusion that by properly correlating the spacing between in-line fins with the fin width, the width of the fins may be reduced to any desired practical value and at the same time fully utilize the increase in efficiency resulting from the decrease in fin width, whereby an exchanger of high efficiency and large heat transfer surface area per cubic foot of volume may be produced.

Figs. 6 to 10 illustrate typical fin structures employing the present invention, and while I have shown fin structures of the nested channel type, these structures are merely by way of example and it is believed that the present invention may be readily applied by those skilled in the art to other forms of fin structures, as for example, serpentine structures and the like.

Referring to Figs. 6 and 7, the reference numeral **1** indicates generally a channel shaped fin structure, two of which are illustrated in the drawings, which are constructed to be positioned in nested relation with a sufficient number of channel members being employed to extend across the fluid pass in which they are assembled, the channels extending parallel to the direction of flow through the pass. Each channel member **1** comprises a pair of side walls or portions **2**, each of which are offset outwardly as indicated at **3**. The walls **2** are connected adjacent their upper edges as viewed in Fig. 7

by a plurality of strip fins 4*a*, 4*b*, 4*c* and 4*d*. In normal applications of the invention the thickness of material forming the member 1 is of foil-like thickness, ranging from approximately .003 to .012 inch, the metal employed preferably being copper, aluminum or other suitable material having satisfactory heat transfer characteristics. As clearly illustrated in Fig. 7, the offset 3 is substantially equal to the thickness of the metal employed, whereby the distance between the inner faces of the offset portions 5 is substantially equal to the outer dimension between the portions above the offset, so that the channel members may be nested or interlocked as illustrated in Fig. 7. The strip fins 4 are formed by severing the metal along spaced parallel lines which extend from one side wall to the opposite side wall and deforming or offsetting the material intermediate the respective slits to form the strip fins 4.

In the embodiment illustrated in Figs. 6 and 7, the first strip fin 4*a* is at the highest elevation as viewed in Figs. 6 and 7, the fin 4*c* at the next elevation, the fin 4*b* at the next elevation and the fin 4*d* at the lowest elevation. This staggered pattern then repeats itself, the next fin 4*a* being positioned at the highest elevation and successively followed by fins 4*b*, 4*c* and 4*d*, so that all the fins 4*a* are aligned in the direction of flow and in like manner all corresponding fins 4*b*, 4*c* and 4*d* are respectively in alignment. Thus in the embodiment illustrated each in-line fin is separated from the preceding or following in-line fin by a distance equivalent to the width of three fins. It will be appreciated that when a relatively large number of channel members 1 are nested together the resulting structure contains a plurality of series of fins positioned in sequential arrangement with respect to the direction of flow. Thus the first row of fins 4*a* extending across the fluid pass transversely to the direction of flow forms the first series, the fins 4*b* the second series, the fins 4*c* the third and the fins 4*d* the fourth. As the pattern repeats the second transversely extending row of fins 4*c* form the fourth series and so on throughout the length of the channel member, so that the structure may be considered as comprising a plurality of groups of series, the fins in each series being similarly arranged and the respective series being similarly arranged in their respective groups.

The transverse spacing between the planes of the fins 4*a*, 4*b*, 4*c* and 4*d*, corresponding to the spacing between the respective fins illustrated in Fig. 7, is substantially uniform and the offset 3 in the side walls is so positioned that the fin 4*a* of the adjacent channel member is spaced a like distance from the fins 4*d* of the first or upper channel member, so that all of the respective fins lie in parallel planes which are substantially uniformly spaced. The spacing of in-line fins and the transverse spacing between the respective planes above referred to are determined in accordance with the theoretical explanation heretofore set forth, whereby the spacing between in-line fins is greater than the so-called boundary layer carry-over from the preceding in-line fins, and the transverse spacing is greater than the combined thicknesses of the boundary layers of adjacent fins along any point in the direction of flow, so that each fin functions substantially independently of the other fins and without interference between the boundary layers and boundary layer carry-over of the respective fins.

In the bulk of applications of the present invention the fin spacing will normally range from ten to sixteen per inch, such dimension taken from the center line distance between strips normal to the direction of flow. Likewise in the bulk of the applications of the present invention the transverse distance between the trailing edges and leading edges of adjacent fins or the distance between the planes of respective in-line fins will range from approximately .015 to .04. The width of each individual fin in the direction of flow will normally run from approximately three thirty-seconds to one-quarter of an inch and the distance from the trailing edge of one fin to the leading edge of the next in-line fin will run from approximately three-sixteenths to three-quarters of an inch. As previously mentioned, normal fin thickness corresponding to the thickness of the material forming the channel member will range from approximately .003 to .012 inch.

It will be appreciated that in forming the fin structures in the manner illustrated in Figs. 6 and 7 from thin stock, and offsetting the respective fins 4*a*, 4*b*, 4*c* and 4*d* different amounts, the transverse lengths of the fins between the walls 2 will vary, the fins 4*a* and 4*d* being slightly longer than the fins 4*b* and 4*c*. In this type of fin structure the fins preferably may be formed in a suitable die or the like, the fins being offset above and below a center line *c* which may be considered as passing through the junctures of the respective fins with the side walls 2. Thus the fins 4*a* and 4*d* may be equally offset above and below the center line, and in like manner the fins 4*c* and 4*b* may be respectively offset equal distances above and below such center line. The metal forming the channel members 1 usually is of copper, aluminum or other comparatively soft metal which is capable of flowing a sufficient amount to compensate for the difference in lengths of the respective fins. Thus in forming the fins, the metal comprising the fins 4*a* and 4*d* would flow outwardly, thereby effecting a stretching action and increasing the effective length of the fin to compensate for the difference in length thereof. Likewise, some compressive action may be produced in the other fins, depending on the particular method of production employed.

Fig. 8 illustrates diagrammatically a fin pattern generally similar to that illustrated in Fig. 6 involving a corresponding spacing between in-line surfaces of three times the width of the individual fin so that the fin pattern repeats in series of fours. In the pattern illustrated in Fig. 8 fins 6*a* extend parallel to the direction of flow as do the fins 6*c*, while the fins 6*b* and 6*d* are slightly tilted or twisted angularly with respect to the direction of flow to increase the transverse distance between the trailing edges of the fins of one series and the leading edges of the fins of the immediate following series. A small twist to the fins as illustrated serves to increase such transverse spacing without materially affecting the efficiency of the structure and thereby enables the transverse center lines of the fins to be positioned closer than in the construction illustrated in Figs. 6 and 7, whereby a greater area of heat transfer surface per cubic foot of heat exchanger volume may be obtained. The construction illustrated in Fig. 8 also illustrates the use of a fin pattern wherein each successive fin is at a lower elevation than the preceding fin before the pattern repeats itself, whereas Fig. 6 illustrates a staggered arrangement.

Fig. 9 illustrates the utilization of a fin pattern wherein the spacing between in-line fins is twice the fin width, whereby the pattern repeats itself in groups of three.

Referring to Figs. 9 and 10, this structure also is illustrated in a channel type of fin structure similar to that illustrated in Figs. 6 and 7, the channel member 1' having side walls 2 provided with offset portions 3 whereby the lower offset portions 5 of the side walls are adapted to receive a similar channel member nested therein. In this construction the fins 7*a* of the first series are positioned parallel to the direction of flow similar to the construction illustrated in Fig. 6, while the second and third fins 7*b* and 7*c* are angled in substantially the same manner as the fins 6*b* and 6*d* illustrated in Fig. 8. Likewise as in the case of the construction illustrated in Fig. 8, the fins 7*a*, 7*b* and 7*c* are arranged in symmetrical order on the channel member with successive fins having less elevation than the preceding fin of the particular pattern group. This construction may be fabricated in substantially the same manner as described in Figs. 6 and 7, the fins 7*b* approximately falling on the center

line connecting the junctures of the fins at the opposite side walls of the channel member, so that in forming the respective fins the fin 7*b* is either merely twisted slightly or may have the metal thereof slightly compressed, while the metal forming the fins 7*a* and 7*c* flows or is slightly stretched to accommodate the difference in lengths.

Fig. 11 illustrates one application of the present invention to a heat exchange structure illustrated in the present instance as including a pair of fluid passes **8** formed by outer plates **9** and an intermediate separated plate **10**, the side edges of the passes being bounded by side wall members **11**, the channel members of each respective pass being nested together to form in effect a fin slab with the respective elements being suitably bonded together to form a unitary structure. Suitable means may be provided at the respective ends of the structure for providing inlet and outlet means for the fluids into their respective fluid passes. This construction is similar to that illustrated in my prior Patent No. 2,606,007 issued August 5, 1952.

It will be appreciated that the present invention is adapted for use in any heat transfer structure utilizing strip fins, pin fins and the like, irrespective of the particular physical construction of the fluid passes, etc., and could readily be employed in structures where the entire heat transfer fin surface is constructed from a single sheet of material which is of corrugated or serpentine shape and from which the individual fins are struck up or otherwise formed.

It will be appreciated from the above description that I have provided a novel heat transfer structure and method of arranging the fins thereof to achieve maximum efficiency together with a high heat transfer surface area per cubic foot of heat exchanger volume and which permits the utilization of narrow fins of high efficiency without interference between in-line fin surfaces.

It might be mentioned that where I have referred to the boundary layer, this term is intended to mean the layer of relatively low velocity fluid adjacent the fin surface, a carryover of which from one fin to another will produce a material decrease in heat transfer efficiency.

Having thus described my invention, it is obvious that various immaterial modifications may be made in the same without departing from the spirit of my invention; hence, I do not wish to be understood as limiting myself to the exact form, construction, arrangement and combination of parts herein shown and described, or uses mentioned.

What I claim as new and desire to secure by Letters Patent is:

1. In a fluid pass for heat exchangers, the combination of an elongated relatively thin fluid pass structure, and a plurality of elongated strip fins having their ends operatively connected to the opposite sides of the fluid pass structure in heat transfer relation therewith, the thickness of the respective fins being less than the width thereof in the direction of fluid flow through the pass structure, said fins being of substantially uniform width and arranged in a plurality of series, each of which extends across the fluid pass transversely to the direction of flow therethrough, and to the individual fins, said series being positioned in repeated sequential arrangement with respect to such direction of flow, the fins of each series being positioned out of line in relation to the direction of flow with respect to the fins of the next following series, the spacing transverse to the direction of flow between the trailing edges of the fins of one series and the leading edges of the next series adjacent thereto being approximately from three to five times the thickness of said fins, and the spacing in the direction of flow between any fins of corresponding series in line in such direction being at least twice the width of said fins in the flow direction.

2. In a fluid pass for heat exchangers, the combination of an elongated relatively thin fluid pass structure, and a plurality of relatively narrow fins having their ends operatively connected to the opposite sides of the fluid pass structure in heat transfer relation therewith, the respective fins extending transversely in thin longitudinal direction with respect to the direction of fluid flow through the pass structure, said fins being arranged in a plurality of series, each of which extends across the fluid pass transversely to the direction of flow therethrough, and to the individual fins, said series being positioned in repeating sequential arrangement with respect to such direction of flow, the fins of each series being positioned out of line in relation to the direction of flow with respect to the fins of the next following series, the spacing transverse to the direction of flow between the fins of one series and the fins of series adjacent thereto being greater than the thickness of the boundary layers along said fins, and the spacing in the direction of flow between any fins of different series which are in line in such direction being greater than the fin width and the boundary layer carryover in the flow direction from the adjacent preceding in line fin, under the particular operation conditions and fluid characteristics involved.

3. A fin structure for heat exchange fluid passes comprising a sheet of thin metal of a thickness of approximately .003" to .012" formed to provide a pair of body portions connected by an intermediate portion, the body portions providing means for securing the fin structure to opposite side walls of a heat exchange fluid pass, the intermediate portion of said fin structure being cut along parallel lines uniformly spaced in the direction of flow to form a plurality of individual substantially flat strip fins which extend transversely between the two body portions and have their ends operatively connected to the respective body portions, the width of said fins in the direction of flow being substantially uniform and from approximately 3/32" to 1/4", the fin structure being adapted to be positioned in a fluid pass with such intermediate portion extending in the same direction as the fluid flow through such a pass, each of said strip fins being laterally offset with respect to the adjacent strip fins, said strip fins being offset in a predetermined pattern and sequence which repeats itself whereby each strip fin is substantially aligned in the direction of flow with other strip fins, the pattern being such that the strip fins substantially in line are spaced apart in the direction of flow a distance of from approximately 5/16" to 3/4", the offset distance between trailing and leading edges of adjacent strip fins being from approximately .015" to .040", with alternate fins being positioned in planes extending substantially parallel to the direction of flow and intermediate fins being positioned in parallel planes extending angularly with respect to the direction of flow.

4. A fin structure for heat exchange fluid passes comprising a sheet of thin metal of a thickness of approximately .003" to .012" formed to provide a pair of body portions connected to an intermediate portion, the body portions providing means for securing the fin structure to opposite side walls of a heat exchange fluid pass, the intermediate portion of said fin structure being cut along parallel lines uniformly spaced in the direction of flow to form a plurality of individual substantially flat strip fins which extend transversely between the two body portions and have their ends operatively connected to the respective body portions, the width of said fins in the direction of flow being substantially uniform and from approximately 3/32" to 1/4", the fin structure being adapted to be positioned in a fluid pass with such intermediate portion extending in the same direction as the fluid flow through such a pass, each of said strip fins being laterally offset with respect to the adjacent strip fins, said strip fins being offset in a predetermined pattern and sequence which repeats itself whereby each strip fin is substan-

tially aligned in the direction of flow with other strip fins, the pattern being such that the strip fins substantially in line are spaced apart in the direction of flow a distance of from approximately 3/16", to 3/4", the offset distance between trailing and leading edges of adjacent strip fins being from approximately .015" to .040", with certain corresponding fins extending substantially parallel to the direction of flow and other corresponding fins extending angularly to the direction of flow.

5. A fin structure for heat exchange fluid passes comprising a sheet of thin metal of a thickness of approximately .003" to .012" formed to provide a pair of body portions connected to an intermediate portion, the body portions providing means for securing the fin structure to opposite side walls of a heat exchange fluid pass, the intermediate portion of said fin structure being cut along parallel lines uniformly spaced in the direction of flow to form a plurality of individual substantially flat strip fins which extend transversely between the two body portions and have their ends operatively connected to the respective body portions, the width of said fins in the direction of flow being substantially uniform and from approximately 3/32" to 1/4", the fin structure being adapted to be positioned in a fluid pass with such intermediate portion extending in the same direction as the fluid flow through such pass, each of said strip fins being laterally offset with respect to the adjacent strip fins, said strip fins being offset in a predetermined pattern and sequence which repeats itself whereby each strip fin is substantially aligned in the direction of flow with other strip fins, the pattern being such that the strip fins substantially in line are spaced apart in the direction of flow a distance of from approximately 3/16" to 3/4", the offset distance between trailing and leading edges of adjacent strip fins being from approximately .015" to .040", with each fin of the structure being similarly positioned with respect to the third fin therefrom in the direction of flow.

6. A fin structure for heat exchange fluid passes comprising a sheet of metal formed to provide a pair of body portions connected by an intermediate portion, the body portions providing means for securing the fin structure to opposite side walls of a heat exchange fluid pass, the intermediate portion of said fin structure being cut to form a plurality of individual fins which extend transversely between the two body portions and have their ends operatively connected to the respective body portions, the fin structure being adapted to be positioned in a fluid pass with such intermediate portion extending generally in the same direction as the fluid flow through such a pass, each of said fins being laterally offset with respect to the adjacent fins, said fins being offset in a predetermined pattern and sequence which repeats itself whereby each fin is substantially aligned in the direction of flow with other fins, the pattern being such that the fins substantially in line are spaced apart in the direction of flow a distance at least twice the width of the fins in such direction, the offset distance between adjacent fins being greater than the corresponding dimensions of the boundary layers along said fins, and the distance between in-line fins being greater than the boundary carryover from a preceding fin in the direction of flow, under the particular operating conditions and fluid characteristics involved in the particular fluid pass, with alternate fins being positioned in planes extending substantially parallel to the direction of flow and intermediate fins being positioned in parallel planes extending angularly with respect to the direction of flow.

7. A fin structure for heat exchange fluid passes comprising a sheet of metal formed to provide a pair of body portions connected by an intermediate portion, the body portions providing means for securing the fin structure to opposite side walls of a heat exchange fluid pass, the intermediate portion of said fin structure being cut to

form a plurality of individual fins which extend transversely between the two body portions and have their ends operatively connected to the respective body portions, the fin structure being adapted to be positioned in a fluid pass with such intermediate portion extending generally in the same direction as the fluid flow through such a pass, each of said fins being laterally offset with respect to the adjacent fins, said fins being offset in a predetermined pattern and sequence which repeats itself whereby each fin is substantially aligned in the direction of flow with other fins, the pattern being such that the fins substantially in line are spaced apart in the direction of flow a distance at least twice the width of the fins in such direction, the offset distance between adjacent fins being greater than the corresponding dimensions of the boundary layers along said fins, and the distance between in-line fins being greater than the boundary carryover from a preceding fin in the direction of flow, under the particular operating conditions and fluid characteristics involved in the particular fluid pass, with certain corresponding fins extending substantially parallel to the direction of flow and other corresponding fins extending angularly to the direction of flow.

8. A fin structure for heat exchange fluid passes comprising a sheet of metal formed to provide a pair of body portions connected by an intermediate portion, the body portions providing means for securing the fin structure to opposite side walls of a heat exchange fluid pass, the intermediate portion of said fin structure being cut to form a plurality of individual fins which extend transversely between the two body portions and have their ends operatively connected to the respective body portions, the fin structure being adapted to be positioned in a fluid pass with such intermediate portion extending generally in the same direction as the fluid flow through such a pass, each of said fins being laterally offset with respect to the adjacent fins, said fins being offset in a predetermined pattern and sequence which repeats itself whereby each fin is substantially aligned in the direction of flow with other fins, the pattern being such that the fins substantially in line are spaced apart in the direction of flow a distance at least twice the width of the fins in such direction, the offset distance between adjacent fins being greater than the corresponding dimensions of the boundary layers along said fins, and the distance between in-line fins being greater than the boundary carryover from a preceding fin in the direction of flow, under the particular operating conditions and fluid characteristics involved in the particular fluid pass, with each fin of the structure being similarly positioned with respect to the third fin therefrom in the direction of flow.

9. In a fluid pass for heat exchangers, the combination of an elongated relatively thin fluid pass structure, of a plurality of relatively narrow fins each having at least one end thereof operatively connected to the fluid pass structure in heat transfer relation therewith, the respective fins extending transversely in their longitudinal direction with respect to the direction of fluid flow through the pass structure, said fins being arranged in a plurality of series, each of which extends across the fluid pass transversely to the direction of flow therethrough, and to the individual fins, said series being positioned in repeating sequential arrangement with respect to such direction of flow, the fins of each series being positioned out of line in relation to the direction of flow with respect to the fins of the next following series, the spacing transverse to the direction of flow between the fins of one series and the fins of series adjacent thereto being greater than the thickness of the boundary layers along said fins, and the spacing in the direction of flow between any fins of different series which are in line in such direction being greater than the fin width and the boundary layer carryover in the flow direction from the adjacent preceding in line fin, under the particular operation conditions and fluid characteristics involved.

10. In a fluid pass for heat exchangers, the combination of an elongated relatively thin fluid pass structure, of a plurality of relatively narrow fins having their ends operatively connected to the opposite sides of the fluid pass structure in heat transfer relation therewith, the respective fins extending in their longitudinal direction transversely with respect to the direction of fluid flow through the pass structure, said fins being arranged in a plurality of series, each of which extends across the fluid pass transversely to the direction of flow therethrough, and to the individual fins, said series being positioned in groups sequentially arranged with respect to such direction of flow, corresponding series of the respective groups being similarly arranged and the fins of each series of a group being positioned out of line in the direction of flow relative to the fins of the other series of such group and in line with respect to the fins of the corresponding series of the next following group, the spacing transverse to the direction of flow between the trailing edges of fins of each series and leading edges of fins of the following adjacent series being greater than the thickness of the boundary layers along said fins, and the spacing in the direction of flow between consecutive in line fins of corresponding series of adjacent groups being greater than the fin width and the boundary layer carryover in the flow direction from the adjacent preceding in line fin, under the particular operation conditions and fluid characteristics involved.

11. A fin structure for heat exchange fluid passes comprising a sheet of thin metal formed to provide a pair of body portions connected by an intermediate portion, the body portions providing means for securing the fin structure to opposite side walls of a heat exchange fluid pass, the intermediate portion of said fin structure being cut along parallel lines spaced in the direction of flow to form a plurality of individual substantially flat strip fins which extend transversely between the two body portions and have their ends operatively connected to the respective body portions, the fin structure being adapted to be positioned in a fluid pass with such intermediate portion extending generally in the same direction as the fluid flow through such a pass, each of said strip fins being laterally offset with respect to the adjacent strip fins, said strip fins being offset in a predetermined pattern and sequence which repeats itself whereby each strip fin is substantially aligned in the direction of flow with other strip fins, the pattern being such that the strip fins substantially in line are spaced apart in the direction of flow a distance at least twice the width of the strip fins in such direction, the offset distance between adjacent strip fins, transverse to the direction of flow being greater than the corresponding dimensions of the boundary layers along said fins, and the distance between immediately adjacent in-line fins being greater than the boundary layer carryover from a preceding fin in the direction of flow under the particular operating conditions and fluid characteristics involved in the particular fluid pass.

12. A fin structure for heat exchange fluid passes comprising a sheet of thin metal of a thickness of approximately .003" to .012" formed to provide a pair of body portions connected by an intermediate portion, the body portions providing means for securing the fin structure to opposite side walls of a heat exchange fluid pass, the intermediate portion of said fin structure being cut along parallel lines uniformly spaced in the direction of flow to form a plurality of individual substantially flat strip fins which extend transversely between the two body portions and have their ends operatively connected to the respective body portions, the width of said fins in the direction of flow being substantially uniform and from approximately $\frac{3}{32}$" to $\frac{1}{4}$", the fin structure being adapted to be positioned in a fluid pass with such intermediate portion extending in the same direction as the fluid flow through such a pass, each of said strip fins being laterally offset with respect to the adjacent strip fins, said strip fins being offset in a predetermined pattern and sequence which repeats itself whereby each strip fin is substantially aligned in the direction of flow with other strip fins, the pattern being such that immediately adjacent strip fins substantially in line are spaced apart in the direction of flow a distance of from approximately $\frac{3}{16}$" to $\frac{3}{4}$", the offset distance between trailing and leading edges of adjacent strip fins being from approximately .015" to .040".

13. A fin structure as defined in claim 12 wherein the fins are positioned in planes extending substantially parallel to the direction of flow.

14. A fin structure as defined in claim 12 wherein each fin of the structure is similarly positioned with respect to the fourth fin therefrom in the direction of flow.

15. A fin structure for heat exchange fluid passes comprising a sheet of metal formed to provide a pair of body portions connected by an intermediate portion, the body portions providing means for securing the fin structure to opposite side walls of a heat exchange fluid pass, the intermediate portion of said fin structure being cut to form a plurality of individual fins which extend transversely between the two body portions and have their ends operatively connected to the respective body portions, the fin structure being adapted to be positioned in a fluid pass with such intermediate portion extending generally in the same direction as the fluid flow through such a pass, each of said fins being laterally offset with respect to the adjacent fins, said fins being offset in a predetermined pattern and sequence which repeats itself whereby each fin is substantially aligned in the direction of flow with other fins, the pattern being such that the fins substantially in line are spaced apart in the direction of flow a distance at least twice the width of the fins in such direction, the offset distance between adjacent fins being greater than the corresponding dimensions of the boundary layers along said fins, and the distance between immediately adjacent in-line fins being greater than the boundary carryover from the immediately preceding fin in the direction of flow, under the particular operating conditions and fluid characteristics involved in the particular fluid pass.

16. A fin structure as defined in claim 15 wherein the fins are positioned in planes extending substantially parallel to the direction of flow.

17. A fin structure as defined in claim 15 wherein each fin of the structure is similarly positioned with respect to the fourth fin therefrom in the direction of flow.

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