

Aug. 25, 1970

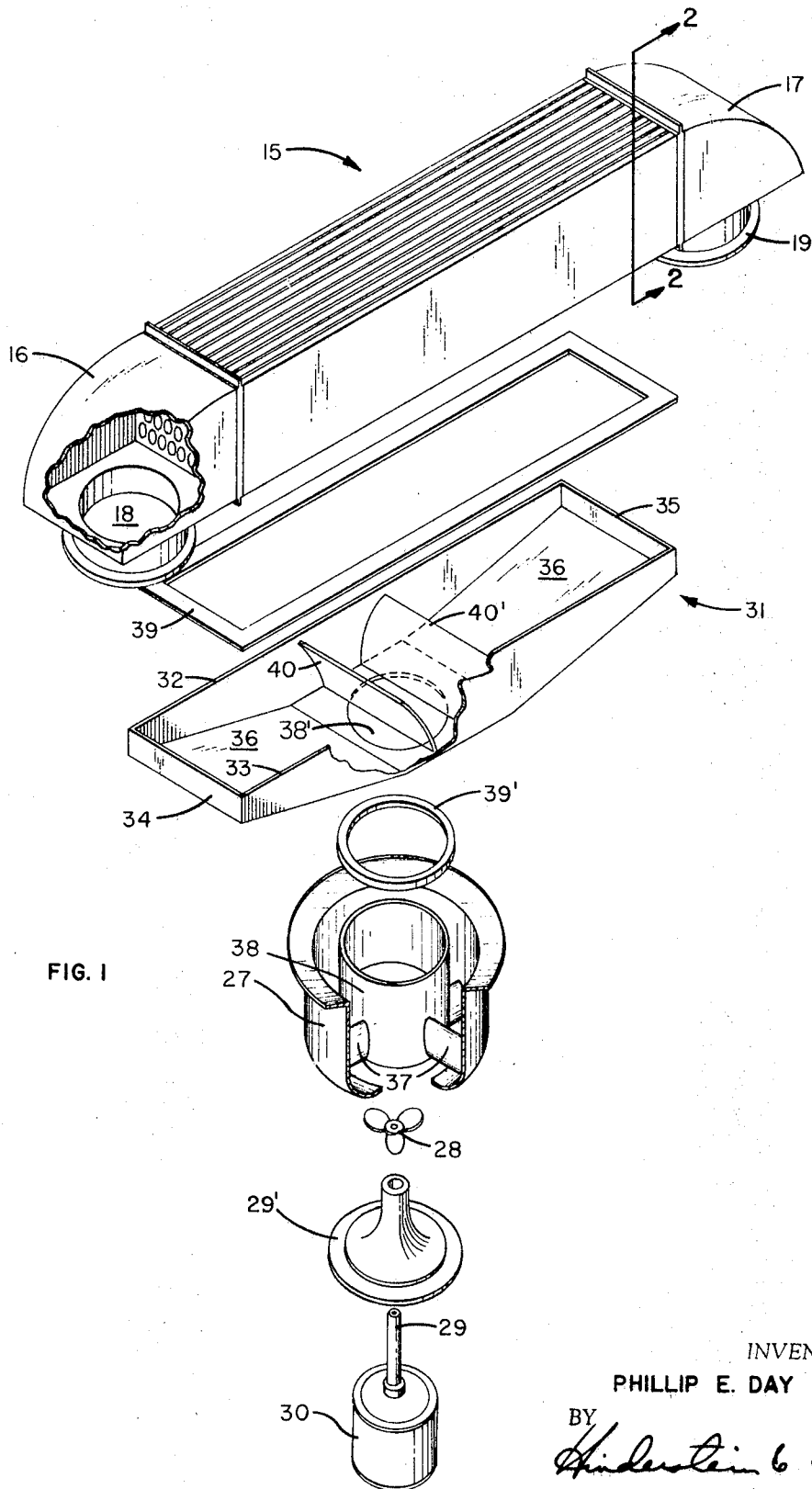
P. E. DAY

3,525,391

HEAT EXCHANGER AND METHOD OF MAKING SAME

Filed Jan. 21, 1969

9 Sheets-Sheet 1



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9 Sheets-Sheet 2

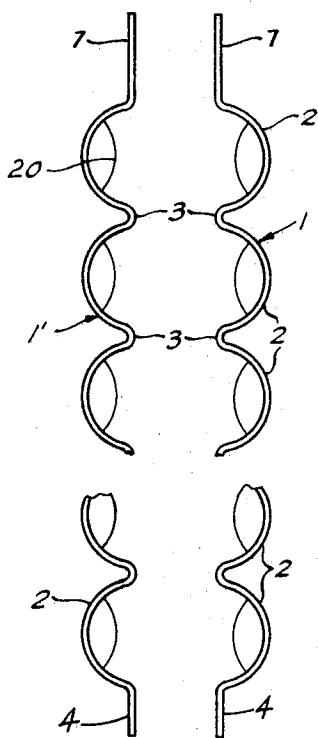


FIG 4

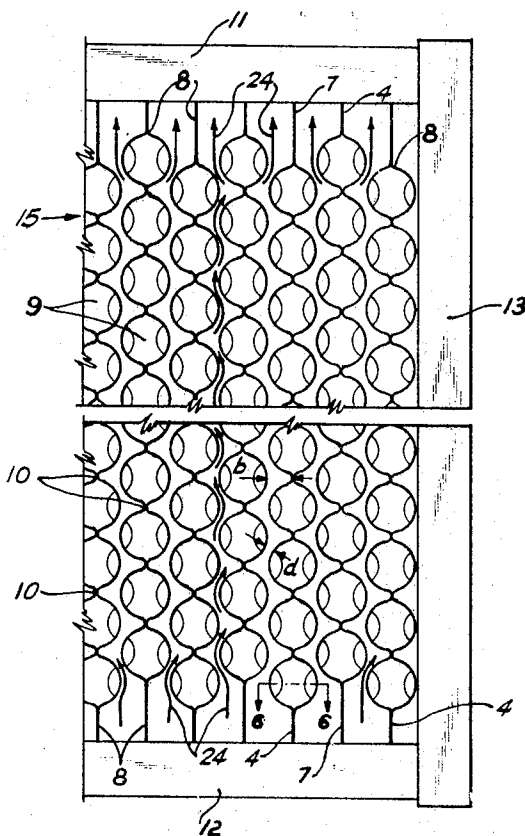


FIG 2

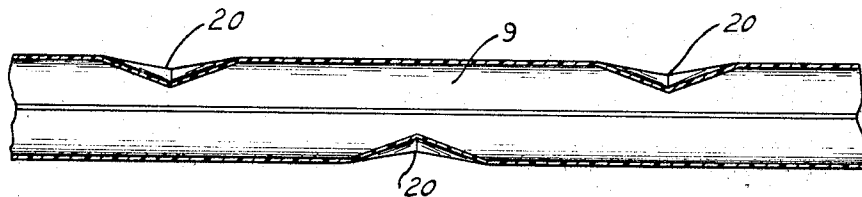


FIG 6

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HEAT EXCHANGER AND METHOD OF MAKING SAME

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9 Sheets-Sheet 3

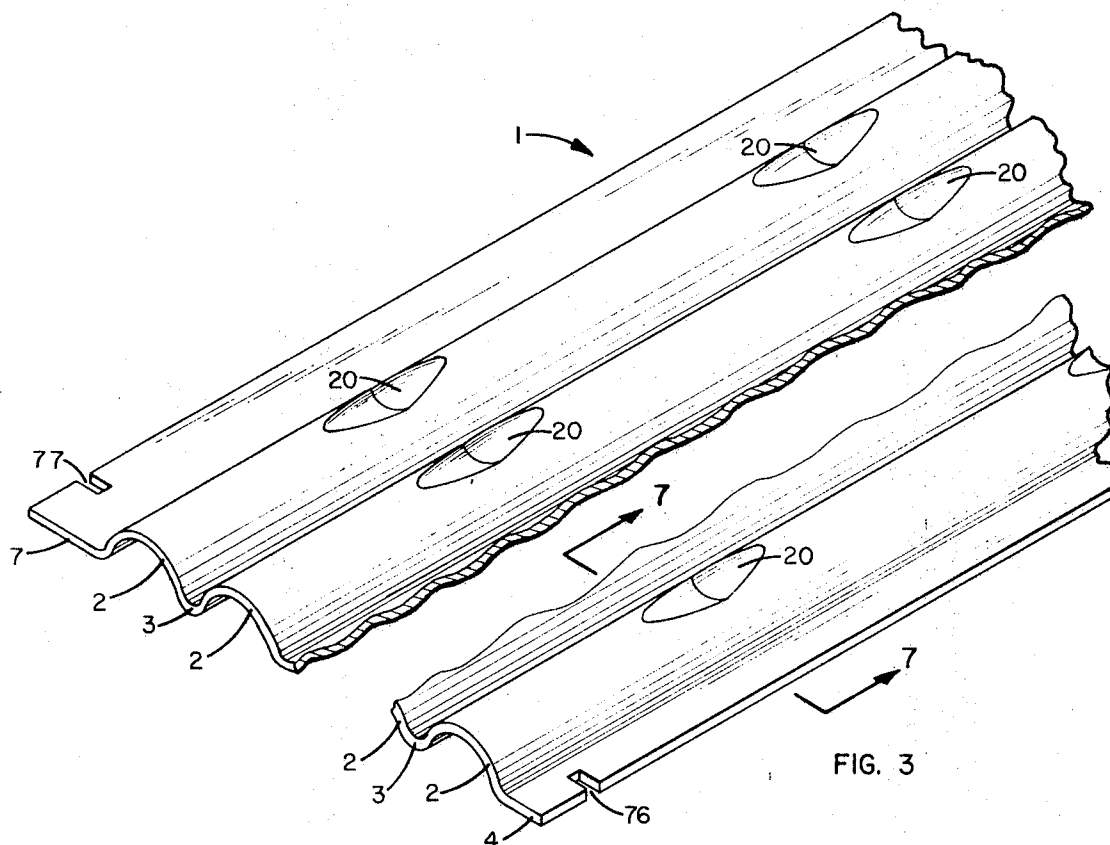


FIG. 3

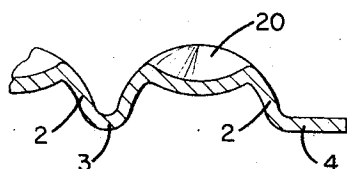


FIG. 7

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HEAT EXCHANGER AND METHOD OF MAKING SAME

Filed Jan. 21, 1969

9 Sheets-Sheet 4

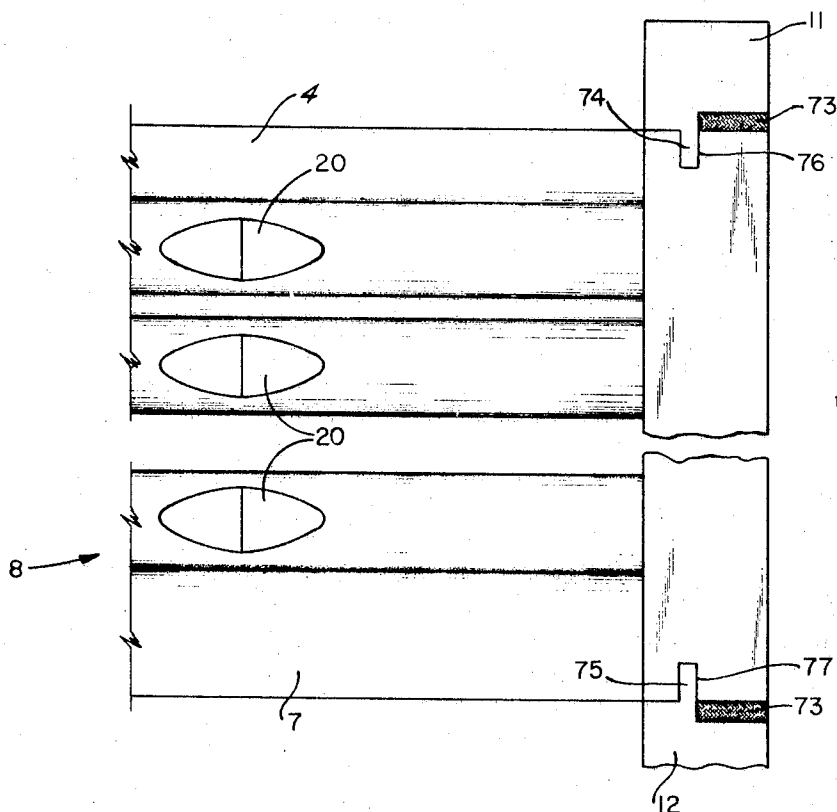


FIG. 23

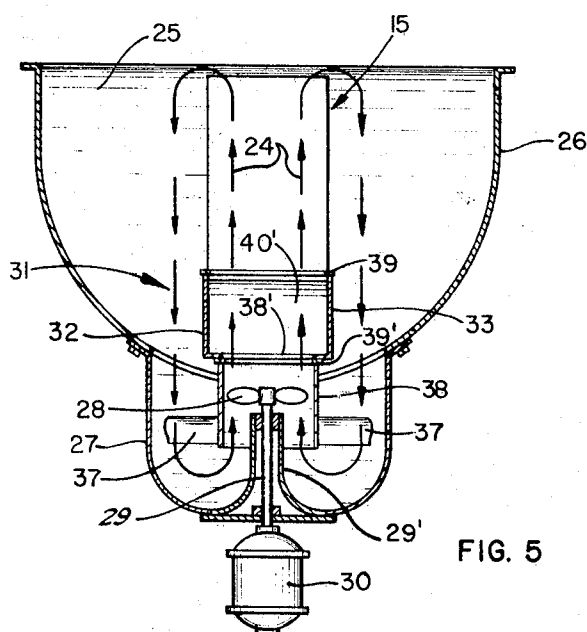


FIG. 5

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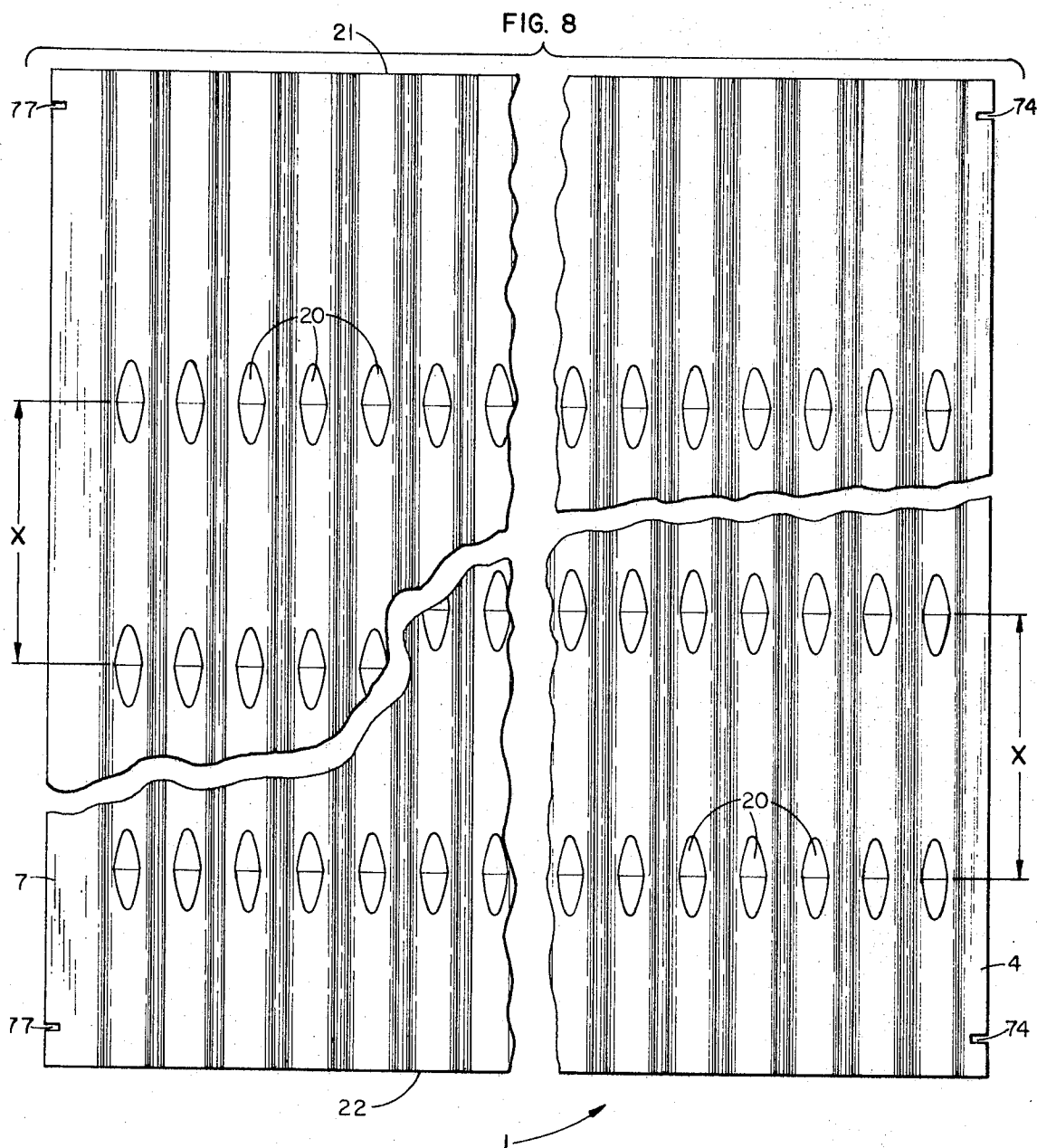
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HEAT EXCHANGER AND METHOD OF MAKING SAME

Filed Jan. 21, 1969

9 Sheets-Sheet 5



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HEAT EXCHANGER AND METHOD OF MAKING SAME

Filed Jan. 21, 1969

9 Sheets-Sheet 6

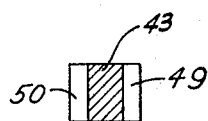
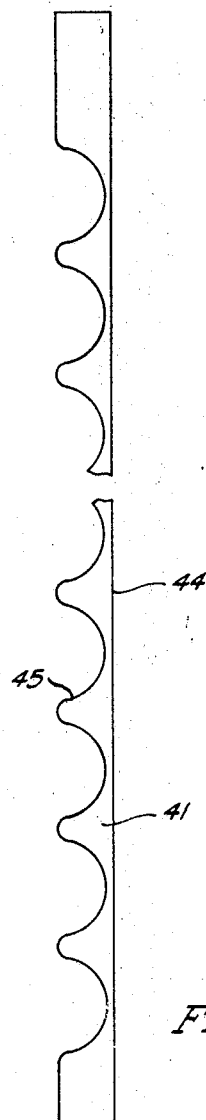
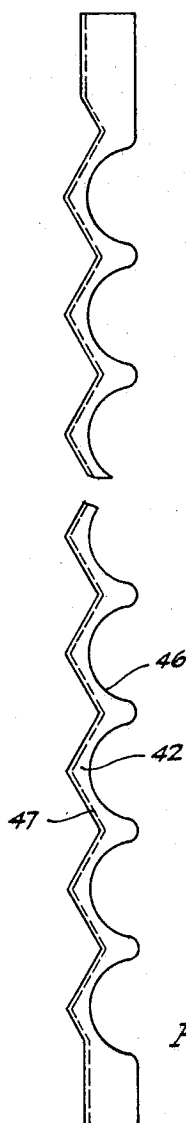
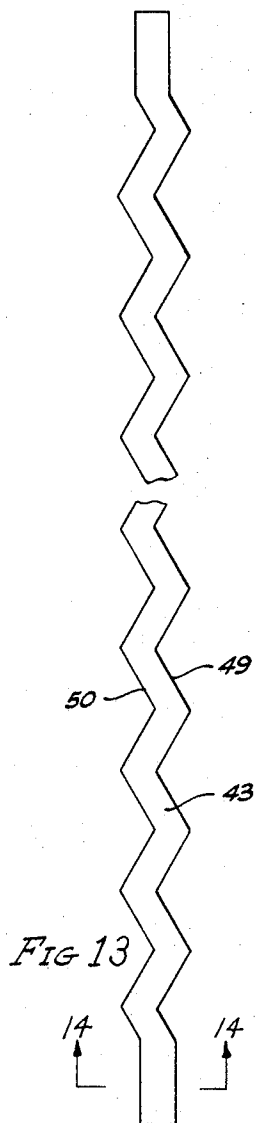


FIG 14

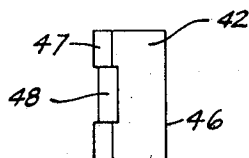


FIG 12

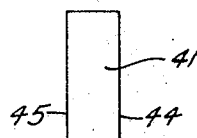


FIG 11

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9 Sheets-Sheet 7

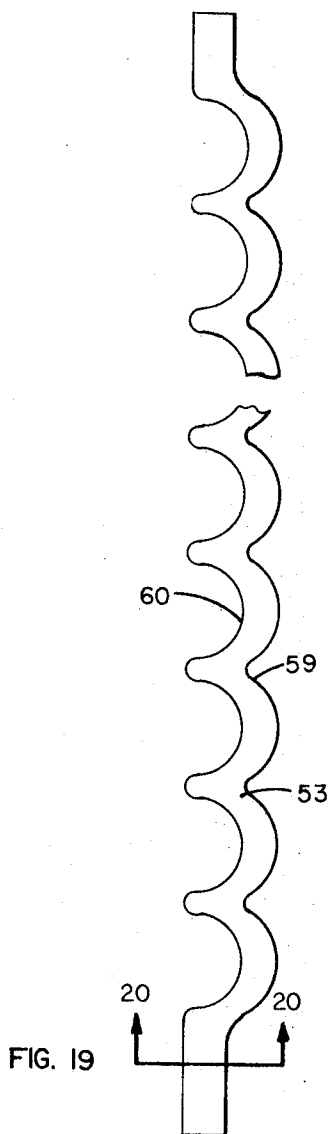


FIG. 19

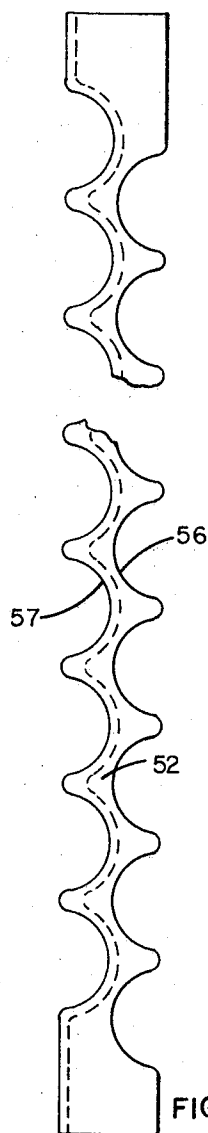


FIG. 16

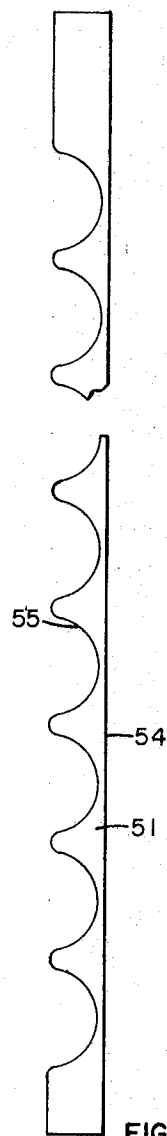


FIG. 15

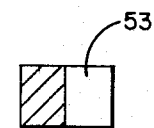


FIG. 20

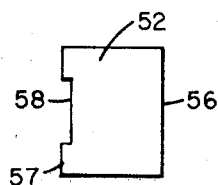


FIG. 18

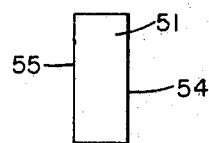


FIG. 17

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HEAT EXCHANGER AND METHOD OF MAKING SAME

Filed Jan. 21, 1969

9 Sheets-Sheet 8

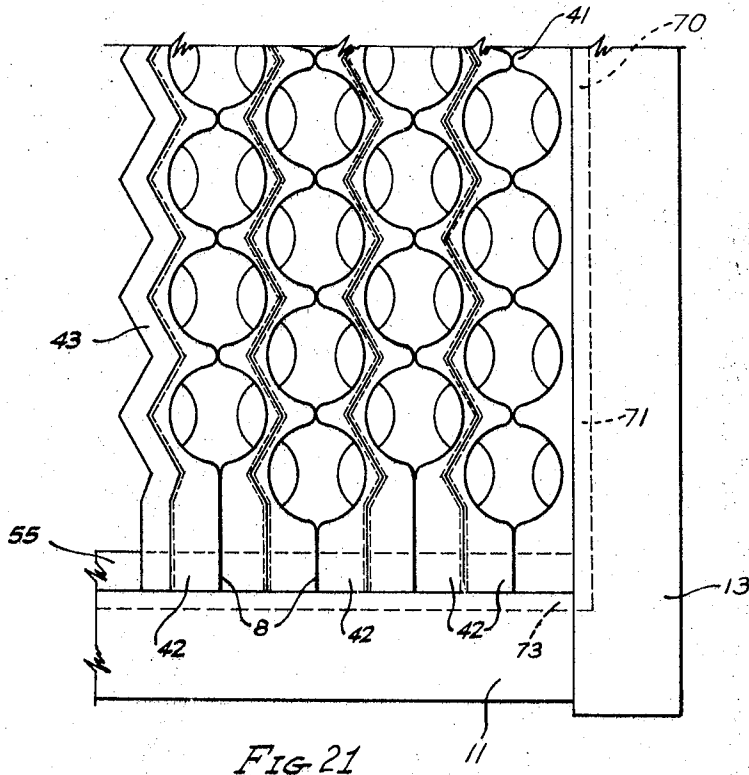


FIG 21

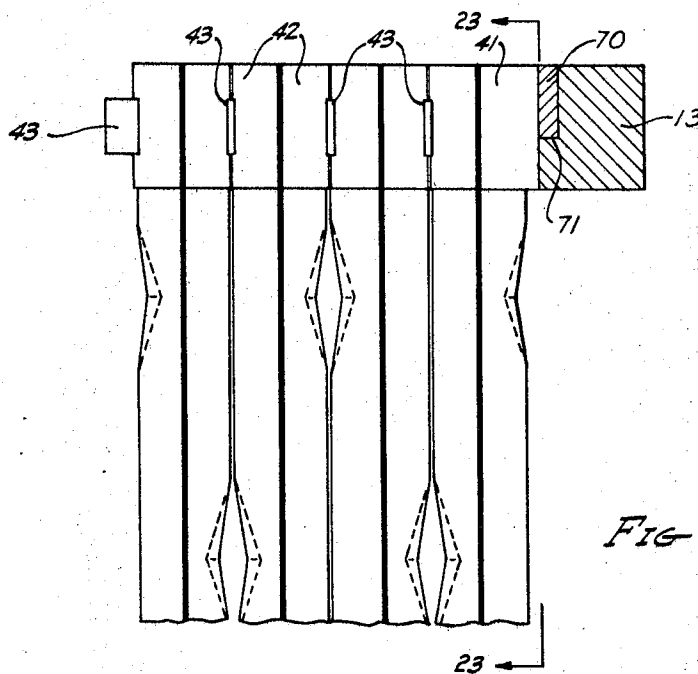


FIG 22

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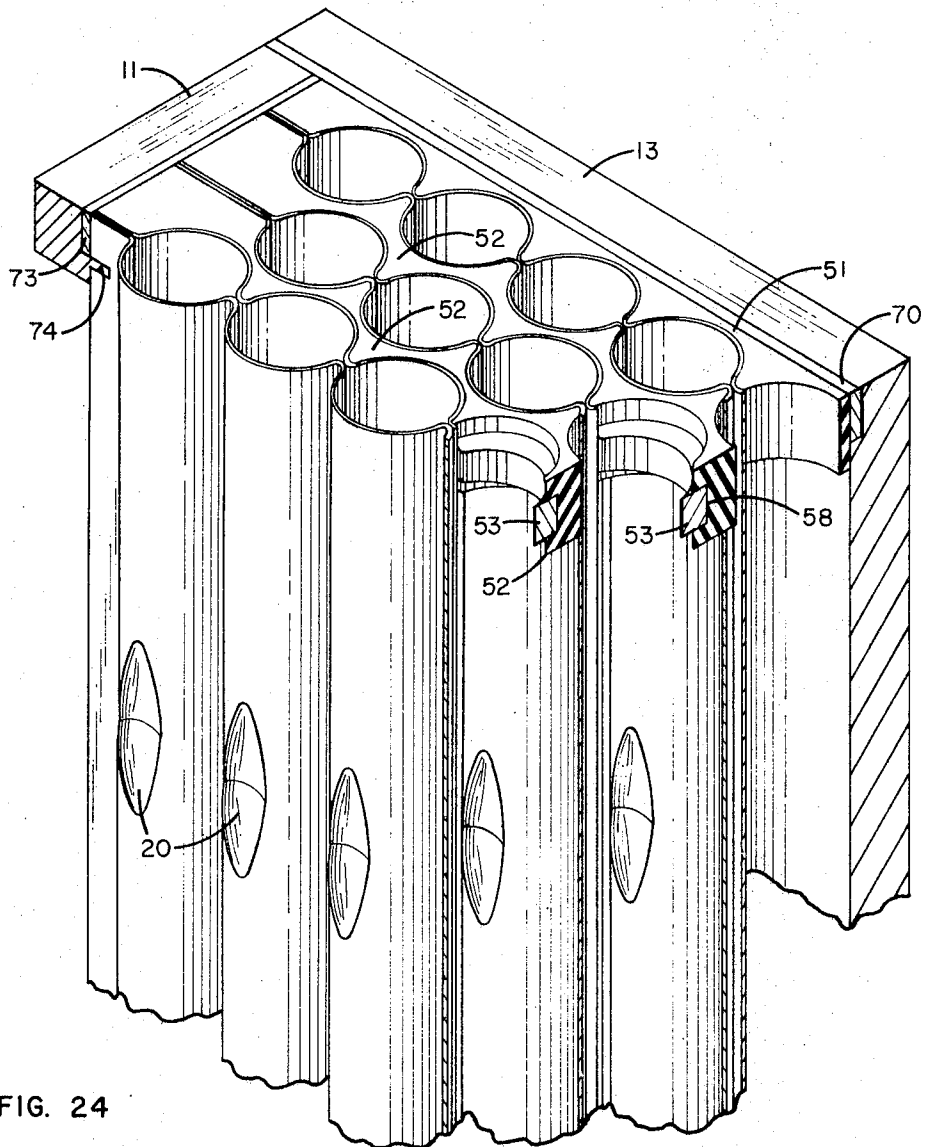
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# HEAT EXCHANGER AND METHOD OF MAKING SAME

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9 Sheets-Sheet 9



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## HEAT EXCHANGER AND METHOD OF MAKING SAME

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U.S. Cl. 165—166

13 Claims

### ABSTRACT OF THE DISCLOSURE

A heat exchanger comprising a plurality of identical corrugated metallic sheets. Tube assemblies comprising a plurality of closely spaced tubes are formed by turning alternate sheets end for end and joining adjacent sheets at the minor corrugations which connect the major corrugations and along the flanges which form the edges of the corrugated sheets. A plurality of ramp-shaped turbulators are positioned on the inside surface of each major corrugation to create turbulence in the tubes. A plurality of tube assemblies are positioned in parallel spaced relation so as to form a heat exchanger core which is the equivalent of the conventional heat exchanger tube bundle. In this heat exchanger core, the tubes form a staggered pattern when viewed from the end. A header at each end of the core conducts a first body of liquid or gas into and out of the tubes. Gaskets at each end of the heat exchanger core separate alternate tube assemblies and seal the space between the tube assemblies themselves and between the tube assemblies and the opening in the header into which the tube assemblies are fitted. Means are provided for circulating a second body of liquid or gas through the spaces between the tube assemblies where it is brought into heat exchange relation with the first body of liquid or gas flowing through the tubes of the heat exchanger core.

### BACKGROUND OF THE INVENTION

#### Field of the invention

The present invention relates to a heat exchanger and a method of making same and, more particularly, to a heat exchanger which significantly increases the rate of heat transfer from a first body of liquid or gas to a second body of liquid or gas and to a method for economically and efficiently manufacturing such a heat exchanger.

#### Description of the prior art

In many situations, it is necessary to transfer the heat energy contained in a first body of liquid or gas to a second, cooler body of liquid or gas. For this purpose, many types of systems have been devised and these systems are generically called heat exchangers. A typical heat exchanger consists of a plurality of smooth tubes which are arranged in parallel bundles and supported at both ends thereof as well as at several intermediate points. The end support members or tube plate plates serve the dual purpose of supporting the tubes and forming one wall of a header which conducts the liquid or gas into and out of the tubes. These tube plates and the intermediate support plates are generally match drilled in a pattern which will bring the tubes in the finished tube bundle into the desired relationship. The holes are usually reamed to a diameter slightly greater than the outside diameter of the tubes so that after the tubes have been carefully hand-fitted, a watertight joint may be formed between the tubes and the tube plates by either expanding the tubes with a tube roller or by welding.

The first body of liquid or gas is conducted through one of the headers into the tubes, and exits from the tubes

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into the header at the other end thereof. The second body of liquid or gas is caused to flow along and around the outside of the tubes. Whether the hotter body is caused to flow through the tubes or around the outside of the tubes, the heat from the hotter body is transferred to the tubes and then subsequently to the cooler body of liquid or gas.

The transfer of heat takes place according to the well known relationship:

$$q=UA\Delta T$$

where

$q$ =the rate of heat transfer in B.t.u./hour,

$U$ =overall coefficient of heat transfer in B.t.u./hour/ft.<sup>2</sup>/° F.,

$A$ =the transfer surface in square feet, and

$\Delta T$ =the mean temperature difference in ° F. between the two fluids exchanging heat.

For a heat exchanger of a given size (area) operating at a given  $\Delta T$ , the amount of heat transferred depends directly on  $U$ . If  $U$  increases or decreases,  $q$  increases or decreases proportionately. The reciprocal of  $U$  is the overall resistance to heat flow which is made up of three resistances in series as expressed by the relationship:

$$\frac{1}{U}=\frac{1}{h_L}+\frac{L}{K}+\frac{1}{h_s}$$

where

$h_L$ =the coefficient of heat transfer through the film on the inside of the tubes,

$L/K$ =the resistance of the tube wall (which is generally negligible, and

$h_s$ =the coefficient of heat transfer through the film on the outside of the tubes.

Although the type of heat exchanger described previously is widely used to transfer heat energy from one body of liquid or gas to another body of liquid or gas, the device is basically inefficient and difficult, time-consuming and expensive to construct. In the first instance, the heat exchanger previously described generally uses smooth tubes through which a liquid is pumped. However, a thin film of liquid tends to adhere to the inside surface of the tubes, thereby acting to insulate the remainder of the liquid in the tubes from the tube's inner surface. The result is a relatively low heat transfer rate between the liquid inside the tubes and the liquid or gas on the outside of the tubes.

The usual approach to solving this problem has been to increase substantially the velocity of the liquid flowing through the tubes. The effect of a high velocity of fluid flow is to create turbulence which tends to break up the film on the inside of the tubes and mix it with the rest of the liquid flowing through the tubes. The result is a significant increase in the heat transfer rate ( $h_L$ ). However, this increase in heat transfer rate is achieved at the expense of greatly increased pumping costs.

It has been shown that the power required to pump a body of liquid through a tube varies as the square of the velocity of the liquid. Therefore, doubling or tripling the velocity of the liquid in the tubes results in increasing the power required for pumping by factors of 4 and 9, respectively. Since pumping costs are directly proportional to power expended, the costs also increase proportionately.

In order to avoid the costly method of circulating the liquid at high velocity, a substantial amount of research has been done to develop other techniques for breaking up the film on the inside of the tubes to thereby increase heat transfer rates. Some experimental tubes have had walls in which helical grooves were formed for the purpose of increasing turbulence in the fluid flowing through

the tube, thereby breaking up the undesirable film on the inner surface of the tube. Other experimental tubes have been corrugated or fluted in various ways. In these experiments, one tube is usually tested rather than a complete section of a heat exchanger, so the test results must be extrapolated. Data obtained in this manner indicates that overall heat transfer rates up to three times as great as would be expected from a conventional heat exchanger containing smooth tubes can be obtained by forming the thin walls of smooth heat exchanger tubes into spiral grooves, corrugations, dimples or other designs which will promote turbulence in the fluid flowing through the tubes. However, the turbulence created by these techniques is usually of a random or incoherent type which creates internal friction in the liquid being pumped. As a result, although it is possible to increase heat transfer rates by using some of these techniques, it has been done at the expense of high pumping costs because of the power required to overcome this internal friction.

Furthermore, two operations have been required in the manufacture of tubes designed to increase the efficiency of heat transfer by changing the configuration of the inner surface thereof to create turbulence. First, the tubes are formed by an extrusion or piercing operation. Second, the walls of the tubes are deformed to create indentations in the outer surface and projections on the inner surface of the tubes. However, the second operation is not only an added expense, but it causes stresses within the metal itself which tend to shorten the life of the tube.

The types of tubes presently being suggested and tested are intended primarily for use in large, multistage, flash evaporator sea water conversion plants in which the cool, incoming seawater flows through the tubes and acts to condense the vapor which flashes off the heated seawater and comes in contact with the surface of the tubes which comprise the tube bundle. However, such a procedure is highly inefficient due to low heat-transfer coefficients. This is so because of the nature of water vapor condensation. On a clean surface that is readily wetted by water, the condensate forms, on the condensing surface, a continuous film of varying thickness depending on various factors. This film tends to blanket the condensing surface with a nonturbulent layer of water that substantially reduces the rate of heat transfer. On a surface not wetted by water, the condensate forms in discrete droplets which quickly run off, continually exposing the metal surface to the vapor and increasing the heat transfer rate.

Under normal conditions, steam condenses filmwise, and special means must be used to make it dropwise. And, although some techniques have been suggested for converting filmwise condensation to dropwise, no technique has shown the ability to provide continuous dropwise condensation for extended periods of time.

In addition to the problems discussed above, conventional types of heat exchangers, consisting of two tube plates, a plurality of support plates, and a large number of tubes, are manufactured in a cumbersome and time-consuming manner. Each tube is individually inserted through a hole in the first tube plate, then through the corresponding hole in each of the support plates, and finally through the corresponding hole in the second tube plate. After each tube is so positioned, it must be individually expanded by rolling, or welded at each of its ends to avoid leakage between the outer surface of the tubes and the inner surface of the holes in the tube plates.

Because such a procedure is a slow one, requiring many hours of skilled labor to complete, the resultant heat exchangers are very expensive. Not only is this a problem at the time of purchasing the heat exchanger, but it is an even greater problem when a leak develops in one or more of the tubes. Because of the expense of the heat exchanger, and because it is usually an integral part of the structure which houses it, it generally is not economically feasible to replace the heat exchanger or the individual tube when a leak occurs. As a result, the standard pro-

cedure is to plug the leaking tube at each end to prevent direct fluid flow between the two bodies of liquid or gas. However, in order to plug a tube, operation of the heat exchanger must be suspended while the leak is found (a difficult procedure). Furthermore, the capacity of the heat exchanger system is permanently reduced by tubes being plugged off.

#### SUMMARY OF THE INVENTION

According to the present invention, there is provided a novel heat exchanger and method of making same which substantially overcomes the problems mentioned above. The present heat exchanger, which is designed primarily to transfer heat from a first body of liquid to a second body of liquid, operates to increase the heat transfer efficiency by simultaneously increasing the heat transfer rate and decreasing pumping costs per unit of heat transferred. By transferring heat from one liquid to another, the difficult problem of maintaining dropwise condensation over long periods of time is avoided. However, due to the compact, efficient design of the present heat exchanger and its low cost of manufacture, the present heat exchanger would be more satisfactory and less expensive than the conventional tube bundle even if it were used as a vapor condenser such as in a multi-stage vacuum flash process.

The present method of manufacturing a heat exchanger permits the formation of a plurality of turbulators or dimples in the tubes simultaneously with the formation of the tube walls. In addition, by shaping the turbulators in a unique way, they can be formed without severely stretching the metal which forms the tubes, and in such a configuration as will cause a coherent type of turbulence in the tubes to further increase the heat transfer efficiency. In addition, by providing a completely unique configuration for a heat exchanger, it becomes possible to manufacture the present heat exchanger in a rapid, efficient and inexpensive manner. As a result, the heat exchanger can be sold and operated at a substantially lower cost than existing heat exchangers. An additional feature is the ability to easily locate leaks and to quickly and inexpensively replace, or repair, the present heat exchanger in the event a leak develops.

According to the present invention, a heat exchanger is constructed by forming a plurality of flat, metallic sheets into a series of identical corrugated sheets. The finished sheets contain corrugations of two different radii of curvature and flanges of unequal width at opposite edges. By turning a second identical sheet end for end so that the corrugations on a first sheet are aligned with the corrugations on the second sheet and by joining the two sheets along the minor corrugations which connect the major corrugations and also along their flanged edges, tube assemblies comprising a plurality of closely spaced tubes which are connected together along their outside edges, are formed. These tube assemblies are strong and rigid and require neither the conventional heavy tube plates on each end nor the intermediate tube support plates used in conventional heat exchangers to prevent sagging of the tubes.

A plurality of ramp shaped turbulators are formed in the tube walls simultaneously with the forming of the corrugations. The shape of these turbulators is such as to create a condition of coherent turbulence in place of the laminar flow that ordinarily occurs in smooth tubes at low velocity. A plurality of these tube assemblies are positioned in parallel spaced relation so as to form a compact, rectangular heat exchanger core in which the tubes form a staggered pattern when viewed from the end. A header at each end of the tube assemblies conducts a first body of liquid into and out of the tubes. The tube plates that form one wall of conventional headers are replaced by a plurality of gaskets which are positioned between the ends of the tube assemblies to properly space the tube assemblies and seal the space between the ends of the tube assemblies themselves and between the

tube assemblies and the opening in the header into which the tube assemblies are fitted.

A third header is provided for circulating a second body of liquid through the spaces between the tube assemblies where it is brought into heat exchange relationship with the first body of liquid flowing through the tubes.

It is, therefore, an object of the present invention to provide a novel heat exchanger.

It is a further object of the present invention to provide a novel heat exchanger and a method of making same.

It is a still further object of the present invention to provide a heat exchanger core fabricated from a plurality of identical corrugated metallic sheets.

It is another object of the present invention to provide a heat exchanger in which the tubes are formed by joining corrugated metallic sheets so that adjacent tubes are interconnected.

It is still another object of the present invention to provide a heat exchanger having a novel tube configuration including a plurality of turbulators for increasing the heat transfer efficiency of the heat exchanger.

Another object of the present invention is the provision of means, in such a heat exchanger, for circulating a body of liquid between the heat exchanger tube assemblies at an angle of 90° thereto, in order to create coherent turbulence in the liquid being circulated.

Still another object of the present invention is the provision of a heat exchanger comprising a plurality of tubes and means for promoting coherent turbulence in the liquid flowing in the tubes.

Still other objects, features and attendant advantages of the present invention will become apparent to those skilled in the art from a reading of the following detailed description of a preferred embodiment constructed in accordance therewith, taken in conjunction with the accompanying drawings wherein like numerals designate like parts in the several figures and wherein:

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an exploded isometric view of a preferred embodiment of the present heat exchanger showing the manner in which a first body of liquid may be pumped through the tubes and the manner in which a second body of liquid may be pumped around the outside of the tubes;

FIG. 2 is a view of a portion of the heat exchanger core of FIG. 1 taken along the line 2—2 thereof;

FIG. 3 is an exploded, perspective view of a single corrugated sheet;

FIG. 4 is an exploded, end elevation view of two adjacent sheets showing the manner in which the present tube assemblies are formed;

FIG. 5 is a cross-sectional view of the assembled heat exchanger of FIG. 1 showing the method of operation thereof;

FIG. 6 is a top sectional view of one of the tubes in the heat exchanger core of FIG. 1 taken along the line 6—6 of FIG. 2 showing the spacing of the turbulators;

FIG. 7 is an exploded cross-sectional view taken along the line 7—7 of FIG. 3 showing the curvature of the turbulators;

FIG. 8 is a top plan view of a single tube assembly showing the placement of the turbulators;

FIGS. 9 and 10 are end elevation views of a first embodiment of tube plate spacers for use in the heat exchanger of FIG. 1;

FIGS. 11 and 12 are top views of the tube plate spacers of FIGS. 9 and 10, respectively;

FIG. 13 is an end elevation view of a first embodiment of gasket used between adjacent tube plate spacers;

FIG. 14 is a view of the gasket of FIG. 13 taken along the line 14—14 thereof;

FIGS. 15 and 16 are end elevation views of a second embodiment of tube plate spacers for use in the heat exchanger of FIG. 1;

FIGS. 17 and 18 are top views of the tube plate spacers of FIGS. 15 and 16, respectively;

FIG. 19 is an end elevation view of a second embodiment of gasket used between adjacent tube plate spacers;

FIG. 20 is a view of the gasket of FIG. 19 taken along the line 20—20 thereof;

FIG. 21 is a partial, end elevation view of the heat exchanger of FIG. 1 showing the use of the tube plate spacers and gaskets of FIGS. 9—14;

FIG. 22 is a partial, top plan view of the heat exchanger of FIG. 1;

FIG. 23 is an exploded, side elevation view of the heat exchanger of FIG. 1 taken along line 23—23 of FIG. 22 showing the technique used to support the tube plates against lateral thrust; and

FIG. 24 is a perspective view of a portion of the heat exchanger of FIG. 1 showing the use of the tube plate spacers and gaskets of FIGS. 15—20.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings and, more particularly, to FIGS. 1—3 thereof, there is shown the heat exchanger of the present invention. According to the present invention, rather than constructing a heat exchanger from a plurality of individual tubes, a heat exchanger core is constructed by forming a plurality of metallic sheets 1 into a series of adjacent, semicylindrical, major corrugated sections 2 which are joined together at the minor corrugations 3 therebetween to form a continuous sheet. FIG. 3 shows an exploded perspective view of a portion of a typical sheet 1 whose length is determined by the desired length of the finished tubes and whose width is determined by the diameter of the tubes and the number of tubes in a given column. Sheet 1 may be formed into the shape shown in FIG. 3 in any convenient manner and also includes flanges 4 and 7 at opposite edges thereof.

Referring now to FIG. 4, in order to form sheets 1 into a plurality of tubes, a second sheet 1' is constructed in exactly the same manner as described hereinbefore for sheet 1 and rotated 180° around a vertical axis so that tube sheets 1 and 1' are facing each other, as shown. After sheets 1 and 1' are so positioned, they are connected together at flanges 4 and 7 and at minor corrugations 3 to form a tube assembly 8 consisting of a plurality of substantially cylindrical, elongated tubes 9 which are connected together at 10 as shown in FIG. 2. Sheets 1 and 1' may be joined by riveting, welding, soldering or any other suitable technique known by those skilled in the art.

After tube assemblies 8 are constructed in the manner indicated above, a plurality of these tube assemblies may be assembled to form a heat exchanger core. If the tubes of the finished heat exchanger core are to be positioned in parallel rows and columns, flanges 4 and 7 of assemblies 8 may be made of equal lengths. However, in order to increase the heat transfer efficiency of the present heat exchanger, the tubes may be staggered as shown in FIG. 2. The reason for this will become clearer hereinafter. According to the present invention, such staggering can be made possible while still retaining the ability to form only one type of sheet 1. This is accomplished by forming each individual sheet 1 and 1' so that flange 7 is longer than flange 4, by an amount equal to one half the width of one major corrugation. Tube assemblies 8 will then be constructed in the manner indicated above but the flanges at opposite sides of each individual tube assembly will be of different lengths. Therefore, in order to provide the configuration shown in FIG. 2, alternate assemblies are rotated through an angle of 180° around a horizontal axis so that the first tube assembly has flange 7 at the top and flange 4 at the bottom, the second tube assembly has flange 4 at the top and flange 7 at the bottom, the third tube assembly has flange 7 at the top and flange 4 at the bottom, etc. In this manner, the present heat exchanger tubes may be constructed in a simple and

efficient manner by forming plain, metallic sheets into a series of corrugated sections and connecting adjacent sheets together in the manner indicated above. This eliminates the requirement for forming individual tubes by extrusion, piercing or other well known, but expensive techniques.

After tube assemblies 8 are formed, they may be arranged into a configuration as shown in FIG. 2 and secured at opposite ends thereof between top and bottom support plates 11 and 12 and side support plates 13 and 14, the latter not being shown in FIG. 2. The manner of supporting tube assemblies 8 in the configuration shown in FIG. 2 will be discussed more fully hereinafter. The finished tube assembly core, generally designated 15, may then be secured to water boxes 16 and 17, as shown in FIG. 1, to conduct the incoming and outgoing liquid or gas to and from tubes 9. Water boxes 16 and 17 have inlet ends 18 and 19, respectively, which may be connected to support means, not shown, of a shape which will be determined by the specific application.

In operation, water, or any other liquid, may be conducted via opening 18 in water box 16 to one end of tubes 9. The liquid will then pass through tubes 9 into water box 17 and exit therefrom through opening 19. The second liquid or gas, which is to come into energy transferring relationship with the liquid or gas in tubes 9, may then be caused to pass around the outside of tubes 9 in any suitable manner. Since the space between adjacent tube assemblies 8 is open, as shown in FIGS. 1 and 2, a liquid or gas may be readily caused to flow between tube assemblies 8 along the outside of tubes 9, as shown by arrows 24 in FIG. 2. A suitable technique for conducting a liquid in this manner is shown, for example, in FIGS. 1 and 5 wherein it is desired to transfer the heat energy in the liquid passing through tubes 9 to a body of liquid 25 positioned in a reservoir 26. To accomplish this, heat exchanger core 15, together with water boxes 16 and 17, may be positioned lengthwise in reservoir 26 so that the liquid will flow through tubes 9 in a direction perpendicular to the paper in FIG. 5. An intake chamber 27, having a saddle-shaped upper end, is attached to the bottom of reservoir 26, where it encloses the propeller 28 of an axial flow pump which is connected via a shaft 29 to a suitable motor 30 which is supported at the bottom of chamber 27 by a housing 29'. A third header or pressure tank, generally designated 31, consisting of spaced, parallel side wall plates 32 and 33, spaced, parallel end wall plates 34 and 35, and a bottom plate 36, may be attached to and suspended from the underside of heat exchanger core 15, at a height above the floor of reservoir 26 that will provide space for the liquid contained in reservoir 26 to flow freely into chamber 27. Chamber 27 supports, via a plurality of struts 37, an annular pump discharge pipe 38 which surrounds propeller 28, pump discharge pipe 38 being positioned directly below an opening 38' in the center of bottom plate 36 of pressure tank 31. The joints between the top of tank 31 and the bottom of heat exchanger core 15, and the bottom of tank 36 and the top of discharge pipe 38 are sealed by means of suitable gaskets 39 and 39', respectively.

In operation, propeller 28, when driven by motor 30, will draw liquid 25 from reservoir 26 into intake chamber 27 and pump such liquid through pump discharge pipe 38 into pressure tank 31. Such liquid is forced out of tank 31 through the spaces between tube assemblies 8 of heat exchanger core 15 as indicated most clearly by arrows 24 in FIGS. 2 and 5. The even distribution of the flow of liquid 25 through the entire length of heat exchanger core 15 may be enhanced by inserting a pair of deflectors 40 and 40' above discharge pipe 38, as shown in FIG. 1. For an example of a situation where such a heat exchange may be used to transfer heat from a first body of water to a second body of water, reference should be had to U.S. Pat. No. 3,390,057 issued June

25, 1968, for "Apparatus for Vapor Compression Distillation of Water."

It should be apparent at this point that the advantages of making a heat exchanger in the manner taught herein are not limited to the fact that the heat exchanger is thereby easier, simpler and less costly to manufacture. In addition, the present heat exchanger has a higher heat transfer efficiency because of the present configuration. With the present heat exchanger, the liquid which flows on the outside of tubes 9 is caused to travel over a fixed path between adjacent tube assemblies 8 in the time that it passes from the bottom of heat exchanger core 15 to the top thereof. In other words, because tubes 9 are connected together at 10, the liquid cannot flow in a random manner at it passes up between tube assemblies 8, but must pass along a fixed path as indicated by arrows 24 in FIGS. 2 and 5. As a result, the liquid travels a certain route that is determined by the outside surfaces of adjacent tube assemblies 8. Furthermore, by staggering tubes 9, the liquid cannot travel in a straight line from the bottom of heat exchanger core 15 to the top, or vice versa. These factors have the effect of increasing the heat transfer rate and efficiency for several reasons.

First of all, because of the staggering of tube assemblies 8, the velocity and direction of the liquid will be continually changing as it passes up between tube assemblies 8 since the cross-sectional area between the tube assemblies is constantly changing. This can be seen most clearly in FIG. 2 where it is seen that the distance  $d$  is much smaller than distance  $b$ . Because the velocity of the water is continually changing as it passes up between tube assemblies 8, there will be a substantial amount of turbulence in the fluid flow. As indicated previously, this turbulence has the desired effect of wiping away the thin film of liquid which tends to accumulate on the outside surfaces of tubes 9. However, in addition to the present configuration creating this turbulence to increase the heat transfer rate, the turbulence is an orderly, coherent turbulence which will tend to minimize the amount of energy needed to pump the liquid between tube assemblies 8 around the outside surfaces of tubes 9. In other words, with conventional heat exchangers, where each tube is individually constructed and there is no connection between the outside surfaces of the tubes, the liquid flowing around the outside of the tubes may pass in a random path which, at any given time, may be going up, down or to the right or left. However, with the present configuration, the liquid can only flow in a single direction, i.e., from the bottom to the top or vice versa. Because of this orderly direction of flow, the turbulence created is coherent and a substantially smaller amount of energy is required to pump the water along the outside of tubes 9. Therefore, even if the heat transfer rate were no greater than with conventional heat exchangers, the heat transfer efficiency would be substantially increased because the required amount of power to pump the liquid is decreased.

Other advantages are achieved with the present configuration. By pumping liquid instead of a gas between tube assemblies 8, large volumes of liquid can be pumped and a high heat transfer rate may be achieved. Furthermore, the length of the path that the liquid travels in passing between tube assemblies 8 is large compared to the vertical dimensions of heat exchanger core 15. The result is to increase the heat transfer which is proportional to the length of the path. Finally, by staggering and closely spacing tube assemblies 8, the heat transfer is increased further because with a given pump, the water velocity is greater resulting in a diminishing of the film of liquid which tends to form on the outside surfaces of tubes 9.

Referring now to FIGS. 3, 6, 7 and 8, there is shown an additional technique for increasing both the heat transfer rate and the heat transfer efficiency of the present heat exchanger. According to the present invention,

tubes 9 are modified to include therein a plurality of turbulators 20. Each turbulator has a generally ramp-type configuration which consists of two equal segments of a cylinder which are connected so that their bases join at an angle, the cylinder from which turbulators 20 are formed having the same diameter as tubes 9. The cross section of each turbulator 20 is circular, as shown in FIG. 7, where the radius of curvature of each turbulator is the same as the radius of curvature of corrugations 2. This fact, together with the present technique for forming sheets 1 into tubes, permits turbulators 20 to be formed in a simple and inexpensive manner. In other words, because conventional types of tubes are made individually by extrusion in other techniques, it is virtually impossible to make anything other than a smooth walled or fluted tube. Any modifications to the tubes must be made separately after the tubes have been formed. Because of the extra cost involved, and the difficulty of making a tight joint between the tubes and the header plates, such modifications are generally unfeasible and are not generally used. Furthermore, even where such modifications are made, they generally involve a stretching and associated weakening of the tube walls.

According to the present invention, these problems are entirely eliminated since turbulators 20 may be made simultaneously with the forming of sheets 1 into corrugations. In other words, suitable apparatus for forming turbulators 20 may be included in the dies used to form sheets 1 into corrugations 2. Therefore, simultaneously with the stamping and forming of corrugations 2, turbulators 20 may be made. In addition, because the radius of curvature of turbulators 20 is the same as the radius of curvatures of corrugations 2, turbulators 20 are formed with no stretching of the material of sheets 1 in the lateral direction and with only very slight stretching of the material of sheets 1 in the longitudinal direction.

FIG. 8 shows the manner in which turbulators 20 are positioned in sheets 1. As shown therein, the turbulators in each row are exactly aligned, with a fixed spacing  $x$  between each adjacent row of turbulators. However, the spacing between one end 21 of tube sheet 1 and the first row of turbulators 20 is  $x/2$  greater than the distance between the other end 22 of sheet 1 and the last row of turbulators 20. The reason for this is so that when a second tube sheet 1' is formed and rotated into the position shown in FIG. 4, the rows of turbulators on tube sheet 1 fall halfway between the rows of turbulators on tube sheet 1' as shown in FIG. 6. Finally, the spacing between turbulators 20 and the slopes thereof are such that liquid flowing through tubes 9 is directed by each ramp-shaped turbulator to the leading edge of the next ramp-shaped turbulator 20 as shown in FIG. 6. The reason for this will appear more fully hereinafter.

As explained previously, with smooth walled tubes, a thin film of liquid tends to adhere to the inside surface of the tubes thereby insulating the remainder of the liquid in the tubes from the tube surfaces. The result is a very low heat transfer rate between the liquid in the tubes and the liquid or gas on the outside of the tubes. Also as indicated above, several solutions have been proposed to create turbulence within the tubes to thereby continually wipe this thin film away and thereby increase the heat transfer rate. However, the previous methods have generally done so by creating eddy currents or other types of random turbulence which has substantially increased pumping costs so that the overall configuration had a low heat transfer efficiency. However, with the present configuration, the flow of liquid passing through tubes 9 is continually directed from side to side by ramp-shaped turbulators 20. By causing the liquid to flow back and forth from side to side within tubes 9, fresh particles of liquid are constantly exposed to the inside surface of tubes 9. In other words, turbula-

tors 20 have the effect of breaking up the laminar flow in tubes 9 and replacing it with a turbulent flow. However, the flow is an orderly one from side to side in tube 9. As was the case with the flow of liquid on the outside of tubes 9, the condition inside of tubes 9 is one of coherent turbulence. In this manner, the energy required to pump the liquid through tubes 9 can be substantially decreased over that required in conventional systems. By substantially decreasing these pumping costs, the heat transfer efficiency is significantly increased.

Referring now to FIGS. 9-14, a method for simply, quickly and efficiently combining the individual tube assemblies 8 into the configuration shown in FIG. 2, may be best understood. Individual tube assemblies 8 may be connected together by means of spacers 41 and 42 and gasket 43. Only four spacers of the configuration shown in FIGS. 9 and 11 are required, since these are only used on the outside edges at both ends of heat exchanger core 15. Spacers 41 and 42 and gasket 43 have lengths equal to the vertical dimension of the individual tube assemblies 8. One side 44 of spacer 41 is flat for reasons which will become clearer hereinafter, whereas the other side 45 is shaped to match the outside surface of individual tube assemblies 8. Spacer 42 has a first side 46 which is shaped in the same manner as side 45 of tube spacer 41 and a second side 47 which is shaped in a substantially zigzag fashion to conform to the path between adjacent tube assemblies 8 as shown in FIG. 21. Side 47 of spacer 42 has a groove 48 cut therein to receive gasket 43 which has opposite sides 49 and 50 which are shaped to conform to groove 48 in side 47 of spacer 42.

Referring now to FIGS. 15-20, there is shown an alternative embodiment for the spacers and gaskets of FIGS. 9-14. More specifically, individual tube assemblies 8 may be connected together by means of spacers 51 and 52 and gasket 53. Only four spacers of the configuration shown in FIGS. 15 and 17 will be required, since these are only used on the outside edges at both ends of heat exchanger core 15. Spacers 51 and 52 and gasket 53 have lengths equal to the vertical dimension of the individual tube assemblies 8. One side 54 of spacer 51 is flat for reasons which will become clearer hereinafter, whereas the other side 55 is shaped to match the outside surface of individual tube assemblies 8. Both sides 56 and 57 of spacer 52 are shaped to match the outside surfaces of individual tube assemblies 8 having alternating corrugations to conform to the path between adjacent tube assemblies 8 as shown in FIG. 2. Side 57 of spacer 52 has a groove 58 cut therein to receive gasket 53 which has opposite sides 59 and 60 which are shaped to conform to groove 58 in side 57 of spacer 52. Spacers 41, 42, 51 and 52 may be molded of any suitable rubber and gaskets 43 and 53 may be made of a compressible, watertight material. Furthermore, as shown in FIGS. 10-14, and 16-20, gaskets 43 and 53 are substantially wider than grooves 48 and 58 which receive them. In this manner, gaskets 43 and 53 are compressed when inserted in grooves 48 and 58 between spacers 42 and 52 and tube assemblies 8 to guarantee a watertight seal.

In order to assemble individual tube assemblies 8 into a configuration shown in FIG. 2, using the spacers and gaskets of FIGS. 9-14, for example, spacers 41 and 42 are first bonded to the ends of tube assemblies 8 with a combination adhesive and sealant as shown in FIGS. 21 and 22. After spacers 41 and 42 are in place, the individual tube assemblies 8 may be stacked together on a suitable frame until the configuration is completed. The assembly procedure would be, for example, as follows: The first tube assembly 8, having a pair of spacers 41 on one side, and a pair of spacers 42 on the other side, may be placed flat on a suitable surface with spacers 41 facing down. Spacers 42 will be facing up with grooves 48 therein exposed. A pair of gaskets 43 may then be positioned in grooves 48 in spacers 42. A second tube

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assembly 8 having a spacer 42 on both sides thereof and at both ends thereof may then be stacked on the first tube assembly 8. The grooves 48 in the bottom two spacers 42 will align with the grooves 48 in the spacers on the first tube assembly so that gasket 43 is compressed within grooves 48 between adjacent tube spacers 42 as shown in FIG. 2. The above procedure may then continue in a rapid and efficient manner, sequentially placing a pair of gaskets 43 on top of the spacers 42 at each end of tube assemblies 8 and stacking the next tube assembly thereon. This procedure may be combined with the technique of supporting the entire configuration between side plates 13 and 14 as shown in FIG. 22. Suitable liquid tight sealing between end spacers 41 and side plates 13 and 14 may be provided by using a suitable gasket 70 positioned in a groove 71 in support plates 13 and 14. As shown in FIG. 23, a similar gasket 73 may be used to provide a watertight seal between the top and bottom surfaces of heat exchanger core 15 and top and bottom support plates 11 and 12.

A similar procedure may be used for assembling tube assemblies 8 using the spacers and gaskets of FIGS. 15-20, the resultant configuration appearing as in FIG. 24. The procedure differs, however, in that a spacer 52 is bonded on only one side of each of tube assemblies 8 at each end thereof, and nothing is bonded to the other side, with the exception of the first tube assembly 8 which has spacer 51 bonded to its other side. The assembly procedure would be, for example, as follows: The first tube assembly 8, having a pair of spacers 51 on one side, and a pair of spacers 52 on the other side, may be placed flat on a suitable surface with spacers 51 facing down. Spacers 52 will be facing up with grooves 58 therein exposed. A pair of gaskets 53 may then be positioned in grooves 58 in spacers 52. A second tube assembly 8 having a pair of spacers 52 bonded to the tops thereof at opposite ends may then be stacked on the first tube assembly 8, gasket 53 being compressed between the second tube assembly 8 and the first spacer 52 thereby forming a watertight seal. This procedure then repeats.

It will be apparent to those skilled in the art that with a flow of liquid through tubes 9 friction between the liquid and the tubes will cause a substantial axial force tending to push tube assemblies 8 in the direction of the flow of liquid. Referring now to FIGS. 3, 8, 23 and 24, there is shown a technique for supporting tube assemblies 8 against this axial thrust. This is accomplished by forming a pair of keys 74 and 75 in top and bottom support plates 11 and 12, respectively. Mating keyways 76 and 77 may then be cut along the top and bottom edges of tube assemblies 8. With keys 74 and 75 positioned in keyways 76 and 77, as shown most clearly in FIGS. 23 and 24, axial thrusts on tube assemblies 8 will be completely supported.

It, therefore, can be appreciated that in accordance with the present invention, there is provided a novel heat exchanger which will have a much higher heat transfer efficiency than any prior configuration. Not only does the present configuration permit superior operation, but it is assemblable in a rapid, efficient and inexpensive manner. As a result, the present heat exchanger cannot only be sold at a substantially lower price than existing heat exchangers, but its operating costs will be substantially less than heretofore possible. Because the present heat exchanger is both inexpensive to buy and inexpensive to operate, it may be readily replaced in the event of a malfunction.

While the invention has been described with respect to a preferred physical embodiment constructed in accordance therewith, it will be apparent to those skilled in the art that various modifications and improvements may be made without departing from the scope and spirit of the invention. Accordingly, it is to be understood that the invention is not to be limited by the spe-

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cific illustrative embodiment but only by the scope of the appended claims.

What is claimed is:

1. In a heat exchanger comprising a plurality of rows and columns of cylindrical tubes, a first body of liquid adapted to be circulated through said tubes and a second body of liquid or gas adapted to be circulated along the outside of said tubes in a direction perpendicular to the longitudinal axis thereof, the improvement comprising:

a plurality of turbulators positioned along the inside surfaces of said tubes on opposite sides thereof in a staggered pattern to deflect said first body of liquid from side to side while flowing through said tubes, each of said turbulators being in the shape of two identical segments of a cylinder which are connected so that their bases join at an angle.

2. In a heat exchanger according to claim 1, the improvement wherein the radius of curvature of each of said cylinder segments is equal to the radius of curvature of said tubes.

3. In a heat exchanger according to claim 1, the improvement wherein the relationship between the spacing of consecutive turbulators and the slope of each turbulator is such that each turbulator directs said liquid approximately to the leading edge of the next turbulator.

4. A heat exchanger core comprising:

a plurality of tube assemblies, each of said tube assemblies comprising:

a first corrugated sheet of heat conducting material having alternate major and minor corrugations of substantially different radii; and

a second identical corrugated sheet of heat conducting material having alternate major and minor corrugations of substantially different radii, said first and second corrugated sheets being arranged in mirror-like relationship and being connected together along said minor corrugations whereby each of said tube assemblies consists of a series of interconnected, substantially cylindrical, straight tubes; and

means positioned between each of said tube assemblies at opposite ends thereof for supporting said tube assemblies in parallel spaced-apart relation throughout the entire length thereof, the area between the adjacent longitudinal side edges of said tube assemblies being open to permit circulation of a liquid or gas between said tube assemblies in a direction perpendicular to the longitudinal axes thereof.

5. A heat exchanger according to claim 4, wherein said heat exchanger core is submerged in a reservoir having an opening in the bottom thereof and further comprising:

means for circulating a first body of liquid through said tubes of said heat exchanger core; and

means for circulating a second body of liquid between said tube assemblies in a direction perpendicular to the longitudinal axes thereof, said means comprising:

an intake chamber, the top of said chamber being secured to the bottom of said reservoir surrounding said opening therein, said chamber being positioned beneath said heat exchanger core and located centrally with respect to the longitudinal and transverse axes of said core, said second body of liquid flowing from said reservoir through said opening into said chamber;

an axial flow pump;

means for supporting said pump in the center of said chamber directly beneath said heat exchanger core;

an annular discharge pipe positioned in said chamber surrounding said axial flow pump, the lower end of said discharge pipe being open and extending into said chamber whereby said pump is operative to draw said second body of

liquid from said chamber into said discharge pipe; and

an elongated pressure tank positioned in said reservoir, said pressure tank enclosing the area from the upper end of said discharge pipe to the bottom of said heat exchanger core, said pump drawing said second body of liquid from said reservoir, into said chamber, through said discharge pipe and directing said liquid into said pressure tank, said tank conducting said liquid to the bottom of said core whereby said liquid flows up through said core between said tube assemblies in a direction perpendicular to the longitudinal axes thereof.

6. A heat exchanger according to claim 5 wherein said discharge pipe is positioned with the axis thereof in a vertical direction and wherein the intake and discharge of said pump are coaxial and aligned with said axis of said discharge pipe.

7. A heat exchanger according to claim 5 wherein said pressure tank has a generally rectangular upper end which is coextensive with the bottom of said heat exchanger core, and a circular lower end having the same diameter as that of the upper end of said discharge pipe.

8. A heat exchanger according to claim 7 further comprising:

means for sealing the joints between the upper and lower ends of said pressure tank and said heat exchanger core and said discharge pipe, respectively.

9. A heat exchanger comprising:

a plurality of tube assemblies, each of said tube assemblies comprising:

a first corrugated sheet of heat conducting material having alternate major and minor corrugations;

a second identical corrugated sheet of heat conducting material having alternate major and minor corrugations, said first and second corrugated sheets being arranged in mirror-like relationship and being connected together along said minor corrugations whereby each of said tube assemblies consists of a series of interconnected, substantially cylindrical, straight tubes;

means positioned between each of said tube assemblies for supporting said tube assemblies in parallel spaced-apart relation throughout the entire length thereof; and

a plurality of turbulators positioned along the inside surfaces of each of said major corrugations in said

first and second sheets, said turbulators being spaced along the longitudinal axis of each of said tubes, each of said turbulators being in the shape of two identical segments of a cylinder which are connected so that their bases join at an angle.

10. A heat exchanger according to claim 9 wherein the radius of curvature of each of said cylinder segments is equal to the radius of curvature of said major corrugations.

11. A heat exchanger according to claim 9 wherein the spacing between the first row of turbulators in each sheet and the adjacent end of said sheet is  $x/2$  greater than the spacing between the last row of turbulators and the adjacent end of said sheet whereby when said first and second sheets are connected together, said turbulators form a staggered pattern with consecutive turbulators being positioned on opposite sides of said tubes.

12. A heat exchanger according to claim 11 wherein the spacing between the first row of turbulators in each sheet and the adjacent end of said sheet is  $x/2$  greater than the spacing between the last row of turbulators and the adjacent end of said sheet whereby when said first and second sheets are connected together, said turbulators form a staggered pattern with consecutive turbulators being positioned on opposite sides of said tubes.

13. A heat exchanger according to claim 12 wherein the relationship between the spacing of consecutive turbulators and the slope of each turbulator is such that each turbulator directs a liquid flowing in said tubes approximately to the leading edge of the next turbulator.

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