Feb. 26, 1935. O. G. WENDEL 1,992,561

METHOD OF HEAT TRANSFER

Original Filed Feb. 12, 1934 4 Sheets-Sheet 1

Fig. 1.

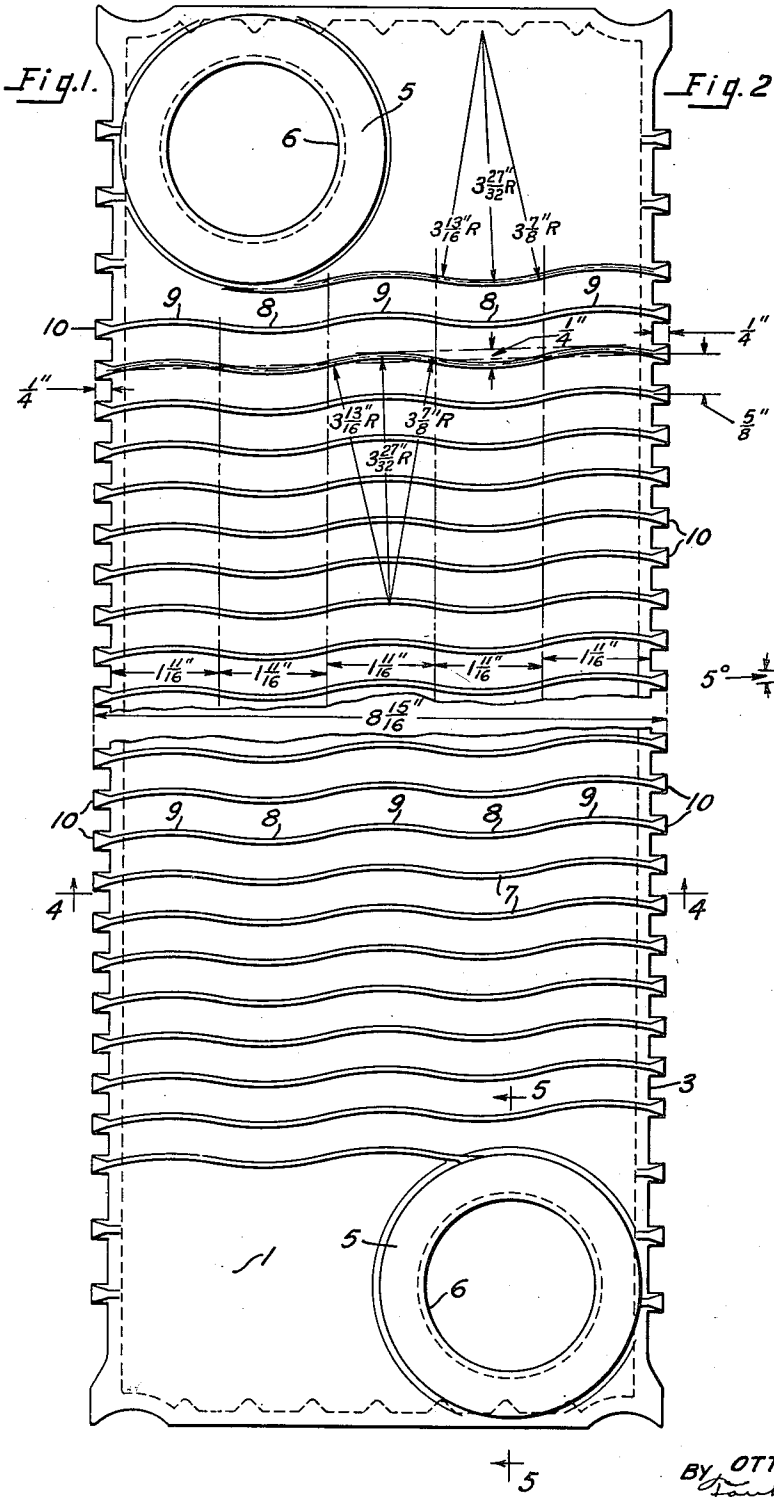
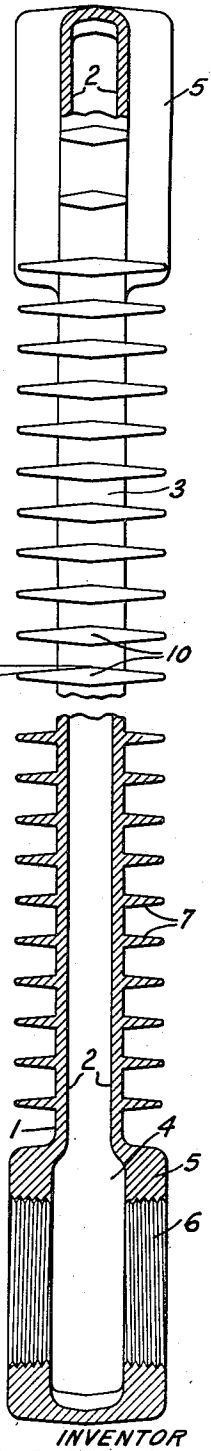


Fig. 2.



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Feb. 26, 1935. O. G. WENDEL 1,992,561

METHOD OF HEAT TRANSFER

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Fig. 3.

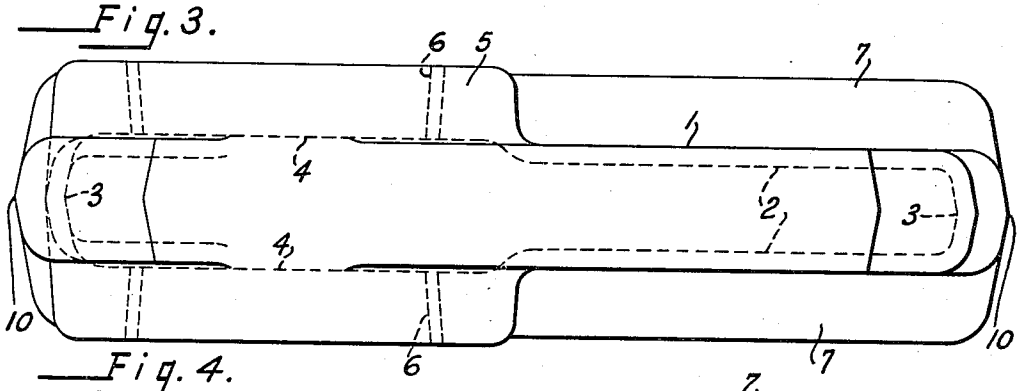


Fig. 4.

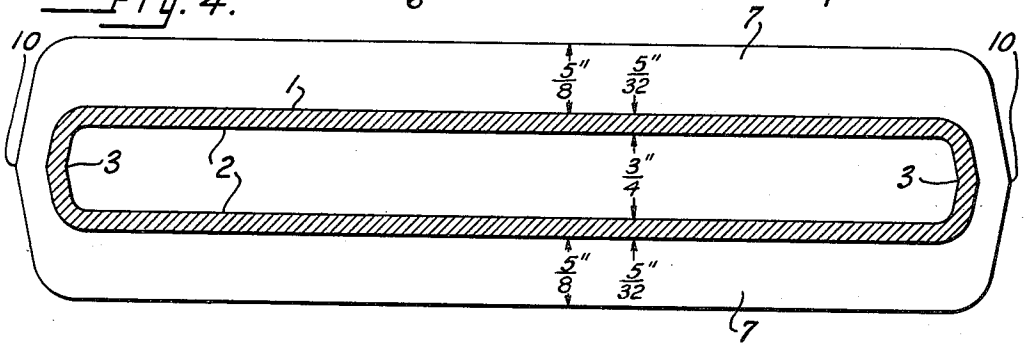


Fig. 5.

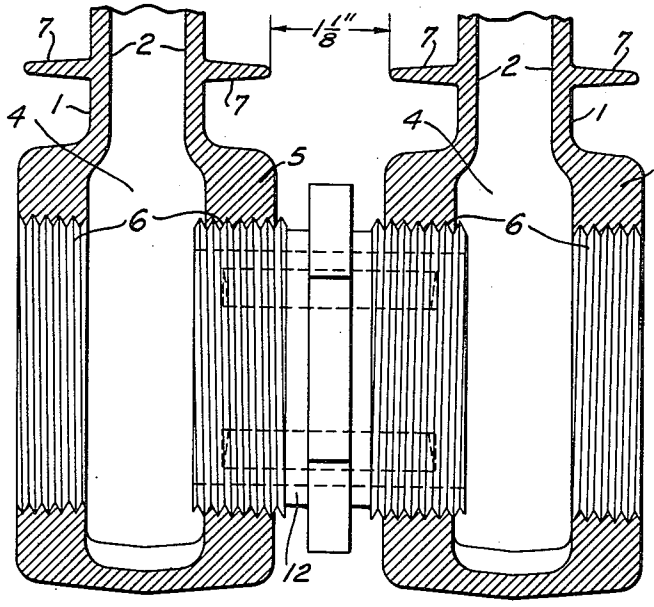
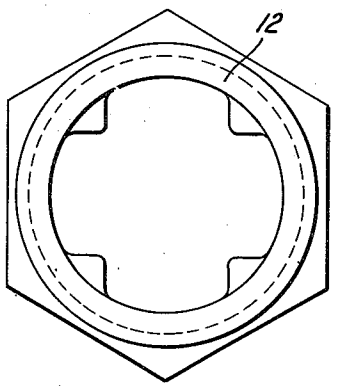


Fig. 6.



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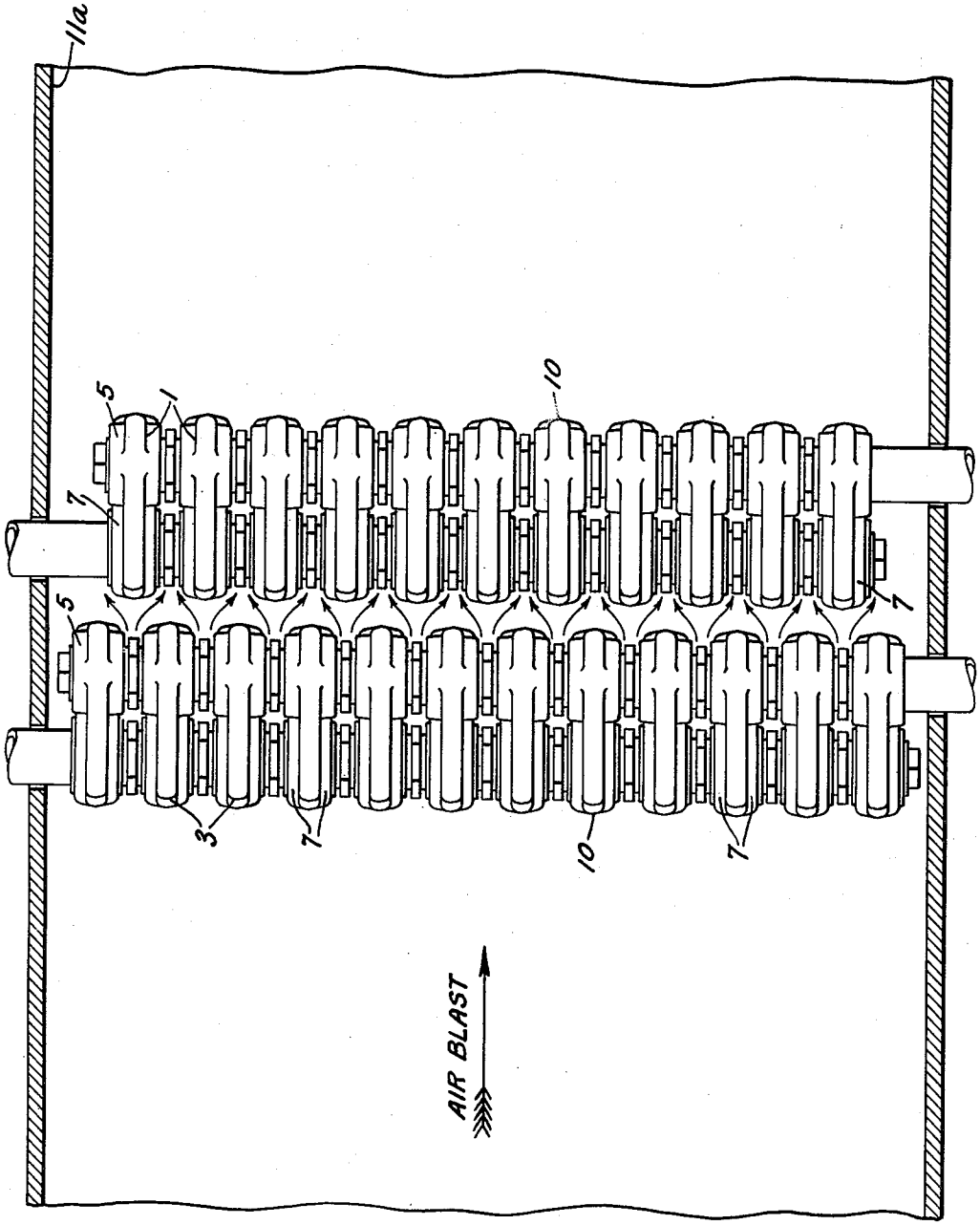


Fig. 7.

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Feb. 26, 1935. O. G. WENDEL 1,992,561

METHOD OF HEAT TRANSFER

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Fig. 8.

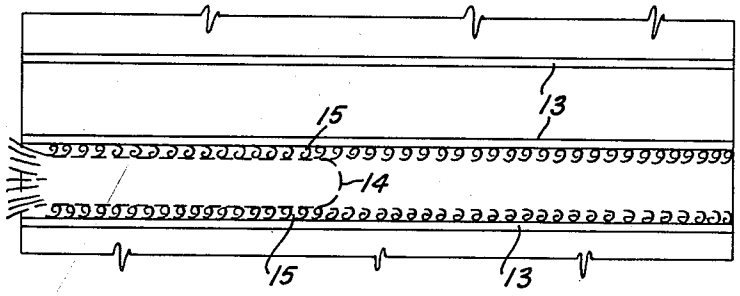


Fig. 9.

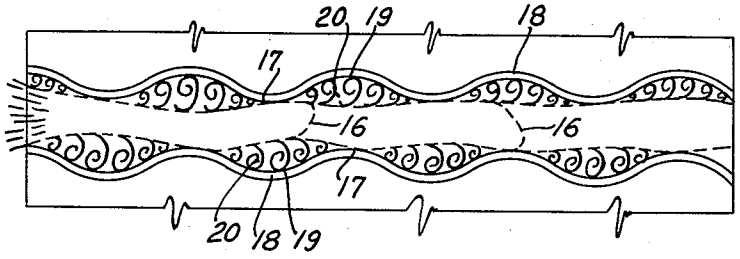
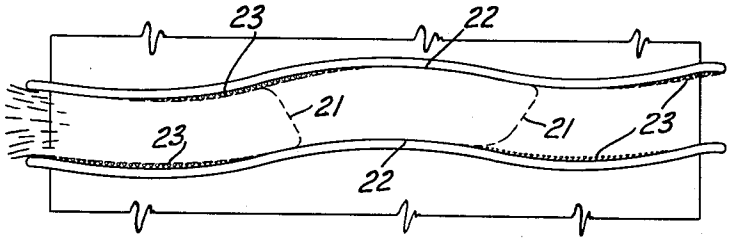


Fig. 10.



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Patented Feb. 26, 1935

1,992,561

UNITED STATES PATENT OFFICE

1,992,561

METHOD OF HEAT TRANSFER

Otto G. Wendel, Buffalo, N. Y., assignor to The American Radiator & Standard Sanitary Mfg. Company, New York, N. Y., a corporation of Delaware

Original application February 12, 1934, Serial No. 710,774. Divided and this application June 6, 1934, Serial No. 729,267

3 Claims. (Cl. 257—1)

My invention relates to a method of heat transfer especially in connection with radiators.

The purpose of my invention is to provide a method and apparatus to practice heat transfer from a fluid having a relatively high specific heat, known as a prime fluid, through containing boundaries, such as cast iron, to a fluid having a relatively low specific heat, denominated as a secondary fluid.

I have been successful in solving the problem of reducing the weight, the amount of space occupied and the friction, and of increasing the rate of heat transfer by the radiator of my invention, which is particularly useful in connection with heat transfer systems where air is blown over the radiators. My invention makes possible high efficiencies, as hereinafter pointed out, while, at the same time, not changing the material, cast iron being employed.

Specifically, the foregoing advantageous results over the prior art have been secured by causing the fluid stream, such as air, to undulate to a point approaching, but never attaining, detached flow, so that, at the upstream point of flow deflection, the pressure and velocity are materially increased while the eddies are consequently reduced in diameter and acceleration, thus permitting more intimate contact at an increased velocity with the more nearly virgin air near the center of the stream and a continual removal of the fluid particles from the center of the stream to the boundary. There is a consequent reduction of velocity on the downstream cavity but, as this decreased velocity is immediately followed by an increased velocity on the same boundary surface by the next undulation, the diameters of the eddies are prevented from increasing to that size heretofore encountered in non-undulating flow as the time element between the alternating high velocity-high pressure and low velocity-low pressure point is insufficient to admit of reformation of an eddy diameter encountered in non-undulating flow.

In my invention, due to the alternate increased and decreased velocities and pressures, the heated boundary particles of the fluid are continually being replaced by cooler inner stream particles, thus producing a greatly increased heating effect on the entire body of the fluid and producing maximum heat transfer from the prime to the secondary fluid, requiring the minimum space, and requiring minimum material in the containing boundaries.

The energy expenditure necessary to produce such undulations is proportional to the angular change in direction added to the increased frictional resistance due to the velocity increase. The loss due to angularity is sufficiently small as to be negligible. A greatly increased rate of heat transfer is, therefore, produced by undetached undulatory flow at an expenditure of a negligible increase in energy.

To secure the foregoing result in my method of heat transfer, I provide a steam-containing body whose sides carry gently undulatory fins which preferably completely encircle the steam containing body. The body itself is longer in a plane at right angles to the direction of the fins than in the direction of the fins and the steam or other heating or cooling fluid or gas is arranged at right angles to the direction of the fluid or gas passing over the outside of the body guided by the undulatory fins. The undulations of the fins or ribs must be of such a character as to preserve the principle of this invention of undetached undulatory flow.

This provides a sufficient body of moving air with the minimum resistance thereto to permit adequate velocity while securing maximum heat transfer.

The smooth interior walls of the body give a free sweep for the transverse flow of fluid or gas therein, such as steam, to reduce the internal film on the interior of the body of the radiator while the undulation of the fins without change of direction of the air body moving on the outside of the radiator between the fins is sufficient to disturb the air film on the outside of the body without back pressure and without detachment so that the undetached undulatory flow principle is practiced which I have discovered is necessary for successful and economical heat transfer. The air flow between the fins is of such a nature that it is continuous with an undetached contact with all surfaces of the metal boundaries comprising the wall of the radiator and the adjacent undulatory fins.

Another object of the invention is the practice of my method of heat transfer which is to so regulate the angularity of the undulations of the fins or ribs as to prevent the air stream leaving the surface of the radiator because the angular rate of undulation must be such as to avoid detachment of the main air stream.

Another object is to provide that the general direction of the fins or ribs shall be at an angle to the general direction of air flow; in other words, one end of the rib will be higher than the other end of the rib.

This application is a division of my application Ser. No. 710,774, filed February 12, 1934.

In the accompanying drawings:

Figure 1 is a side elevation of one section of my radiator;

Figure 2 is an end elevation partially in section;

Figure 3 is a top plan view of the radiator section;

Figure 4 is a section on the line 4—4 of Figure 1;

Figure 5 is a section on the line 5—5 of Figure 1 showing the means of attachment of two adjacent sections;

Figure 6 is an end view of one of the connecting nipples;

Figure 7 is a top plan view of two series of the sections showing the staggered arrangement of one series with respect to the other and showing in section the passageway through which air is forced over the sections;

Figure 8 is a diagrammatic view showing the prior art having parallel fins and the disadvantages thereof;

Figure 9 is a similar view showing the prior art with the conventional sharp undulations and the disadvantages of detached undulatory flow;

Figure 10 is a detailed view of the present invention showing the principles of undetached undulatory flow which characterizes this invention.

Referring to the drawings in detail, 1 designates a radiator body, preferably of cast iron. This body is formed of thin side walls 2 and end walls 3. The side walls 2 are spaced in parallelism with one another adjacent to one another to form with the end walls a relatively narrow rectangular space for the confining of the prime fluid. The upper and lower portions of the body are enlarged at their respective opposite corners forming large chambers 4 having areas in their side walls at such points of increased thickness as in the case of the collars 5 which are internally machined at 6 to receive suitable connecting nipples or inlet or exit pipes or connecting nipples therefor.

It will be noted that the vertical dimension of the radiator body is materially greater than the horizontal dimension and that the horizontal dimension is materially greater than the width from side wall to side wall. The line of flow from inlet to outlet is over a smooth interior surface for the purposes hereinafter described.

On the exterior of the radiator body on opposite sides 2 on the exterior thereof are a series of undulatory fins which are wedge-shaped in section and generally designated 7. In the construction shown there are two valleys and three hill portions on each fin marked respectively 8 and 9. The fins completely encircle the body extending across the ends 3 as at 10.

These end portions of the fins as at 10 are heavier than the side wall fins. Such end wall fins have the dual function of lending strength to the very thin walls of the radiator body and form a continuous fin surface to facilitate the entry and exit of the secondary fluid, that is, the air, into and from the space between the undulatory side fins, thus avoiding the vena contracta which occurs when a sharp cornered wall is used, and thereby I minimize the losses due to changes in velocity and maintain continuous fluid contact with both the entry and parallel walls.

It will be noted that the undulations are very gentle in order to insure the principle of undetached undulatory flow, as more fully explained hereinafter. This is the vital principle governing the construction and method of heat transfer of my invention.

In order to give a typical example of a successful radiator of this character and without intending to limit myself in any manner, the following are the dimensions of a successful radiator which I have constructed and operated. The distance from the entering edge to the exit edge of the end wall fins is $8\frac{1}{8}$ inches. The maximum depth of the end wall fins is $\frac{1}{4}$ inch. The width of the side wall fins is $\frac{5}{8}$ inch, the thickness of the side wall is $\frac{5}{32}$ inch and the distance between the interior of the side walls is $\frac{3}{4}$ inch. The inclination of the ribs in the instance given amounts to a difference in elevation between the ends of the ribs of $\frac{5}{16}$ of an inch.

The taper of the side wall fins is 3 degrees. The distance as indicated on the drawings between the point of departure and the point of return of each undulation of the side wall fins is $1\frac{1}{4}$ inches. I have shown and successfully used five of such undulations on one side of the body in a single fin. The distance between a line drawn from the crest of two adjacent tops of undulations of the side wall fin to the bottom of the intermediate depression of the intermediate portion of the side wall fin between such crests is approximately $\frac{1}{4}$ inch so that it can be seen that the undulation is very gentle and it is this discovery of such a gentle undulation which has made possible the extraordinary results from this invention. The radius of curvature and the dimensions thereof are indicated on Figure 1. I do not, of course, desire to be confined to any of these dimensions, but I recite them in order to show a concrete successful example of the practice of my invention to enable others to practice it and successfully use it.

It will be noted that the fins are relatively thin, the dimensions being as indicated. The end wall ribs which are continuations of the fins are wedge-shaped and thick relative to the side wall fins.

In practice, I can arrange, if desired, the sections either individually or in a series in parallel or in two series with one series staggered or in alignment with respect to the other series. This radiation may be used with convection currents but is preferably used with air delivered under pressure as by a fan and guided by a casing such as indicated at 11*a* in the accompanying drawings.

When the sections are connected together in series they are so connected by a hexagon nipple designated 12. When so connected the space between the marginal edges adjacent the fins of the adjacent sections in the example I have cited is $1\frac{1}{8}$ inches. The design, however, is not limited to this dimension since by use of longer or shorter nipples this dimension can be varied.

In actual test of this radiator of my invention in comparison with the best radiator sections and the most efficient known in the art of cast iron radiators today, I secure the following results:

When comparing the two radiators at equal friction, the radiator of my invention weights 70% of the old radiator, requires 63% of the space of the old radiator, and provides 119% of the heating surface of the old radiator. I further find that the two stacks of the present radiator would do the work of 2.4 stacks of the old radiator.

When comparing the best radiator of the old art with my present invention on the basis of equal velocity of the air passing thereover, I find

that my new radiator of this invention weighs 71% of the old radiator, takes up 68% of the space occupied by the old radiator and has 128% of the heating surface of the old radiator. Two stacks of the new radiator do the work of 2.3 stacks of the old radiator. The radiator of this invention requires 83% of the friction of the old radiator. Furthermore, the new radiator stands a maximum hydraulic pressure of 200 pounds gauge as compared with the maximum pressure of the old radiator of 150 pounds. The new radiator is, therefore, 30% lighter than the old radiator and occupies 35% less space. It is superior whether compared on the basis of equal friction or equal velocity. The significance of these comparisons will be apparent when it is understood that one of the primary uses of this radiation is in forced blast systems where the space occupied, the weight involved, the resistance to air flow and the rate of heat transfer are such vital factors as to constitute the difference between failure and success in the operation of a forced draft system. The radiator of my invention makes it possible to use cast iron with all of its advantages in competition with radiators of other materials. While I do not desire to confine my invention to cast iron, yet its advantages become apparent when cast iron is used as a medium of its embodiment and the basis of its comparison even with other materials in other designs.

While not intending to limit my invention to all or a large part of the following features, nevertheless the following is a summary of the numerous features of operation and construction inherent in the construction and method of operation of the apparatus of my invention:

(1) An oblong, in section, steam body whose flat sides carry undulatory fins; while the sides of the steam-containing body are flat as shown in the drawings, yet they could be made undulatory so long as they preserved the hereinafter mentioned principle of "undetached undulatory flow."

(2) The width of the fins is constant and the edge of each fin is parallel to the flat face of the radiator body.

(3) The fins are undulatory out of a horizontal plane but are not undulatory out of a vertical plane and, therefore, there is no marked lateral change in direction of the air stream by reason of either the fins or of the body of the radiator.

(4) The fins completely encircle the entire radiator body both on the sides and on the ends thereby assisting in the entering of the air and the exit of the air and at the same time improving the radiator qualities of the structure.

(5) Such an arrangement provides a relief of the inlet between sections to reduce the vena contracta loss where the air enters. There is a similar reduction of the loss at the exit in the same manner for the same reason.

(6) The total width of the fins is so proportioned as to constitute substantially the total width of the body.

(7) The undulations of the fins are sufficient to bring about a wiping action of the air on the flat surface of the body to reduce the air film on the surface of the body to increase heat transfer but such undulatory arrangement is not sufficient to set up turbulence or resistance to air flow so that the air movement will be sufficiently rapid to carry away the heat for maximum efficiency. The foregoing statement must be read in the light of the understanding of the principle of undetached undulatory flow hereinafter explained. The fluid stream undulates to a point approaching never attaining detached flow.

(8) The undulations of the rib or fin in this section in this instance have a depth only of one-thirteenth of the distance between the crowns of the undulations. The undulations must be of such a character as to preserve the principle of this invention of undetached undulatory flow, which is a new feature of the invention and from which results the efficiency secured.

(9) The end ribs are heavy, wedge-shaped terminal ribs for reinforcing purposes.

(10) The wall thickness is substantially twice as thick as the rib thickness while the rib or fin surfaces are twice as great as the body surface between the ribs so that the thinner ribs for heat transmission present twice as great a heat radiating surface.

(11) The ribs are progressively thinner the further they are from the heat source so that there will be uniform distribution of heat throughout the rib.

(12) The ribs are spaced on adjacent bodies from one another by a distance approximately the same as the combined width of adjacent ribs in order to provide a sufficient body of moving air to permit a velocity while securing maximum heat transfer. It is not intended, however, to limit the probable application to this ratio.

(13) The straight side walls of the body give a free sweep for the transverse steam flow to reduce the internal film on the interior of the body of the radiator, thus increasing the efficiency of the heat transfer.

(14) The undulation of the fins without change of direction of the air body moving between them is sufficient to disturb the air film on the outside of the body without back pressure and without detachment so that the undetached undulatory flow is secured.

(15) The air flow between the fins is of such a nature that it is continuous with an undetached contact with all surfaces of the metal boundary. The surface must not be deprived of the close and intimate contact with the fluid in order to prevent the loss in efficiency in the transfer of convection heat. The formation and subsequent detachment of large eddies of air due to turbulence without intimate contact results in the expenditure of energy without adequate heat transfer. The present invention has the minimum area of boundary wall with the greatest transfer of heat with the least energy expenditure. This is due to the fact that the fluid stream is caused by the fins to undulate to a point approaching but never attaining detached flow. The eddies are correspondingly reduced in size and the speed thereof accelerated. This secures intimate contact at increased velocities with the continual change of the fluid particles from the center of the air stream to the boundary. Due to the alternate increased and decreased velocity in pressures, the air particles that are heated are continually supplanted by the cooler inner stream particles. So long as the angularity is sufficiently minor, the energy expenditure necessary to produce the undulations, which energy expenditure is proportional to the angular change in direction added to the increased frictional resistance due to the velocity increase will be sufficiently small as to be of no importance. The slightly increased demand for energy due to the undulations has no consequence in view of the greatly improved rate

of heat transfer produced by the undetached undulatory flow secured by this construction.

And, furthermore, the foregoing indicates that my invention and its physical features take into account these important propositions:

(1) The elimination of back pressure and the increase of velocity by using a gentle undulatory flow of the air through channels of metal having substantially equal area on three sides and substantially equal heat distribution throughout the surface of the metal.

(2) The movement of the air through such channels as to break up any air film on the surface of the metal without setting up undue turbulence and back pressure.

(3) The use of straight walls (or undulatory walls without detachment) of a main body so that the maximum velocity of the gas, water or steam wipes the film away on the interior of the wall decreasing its thickness and increasing heat transfer; by having the straight body the film on the interior and the exterior of the wall is reduced by the velocity of the steam and the velocity of the air.

(4) The essence of this invention is the discovery of the principle referred to herein as that of "undetached undulatory flow". This means that the fluid stream undulates to a point approaching, but never attaining, detached flow. Heat transfer is in proportion to the reduction in size of the eddies in diameter and the acceleration of those eddies to secure a more intimate contact and an increased velocity with the cooler air near the center of the stream and a continuous substitution of the fluid particles from the center of the stream to the boundary.

As a basis for a full understanding of the principles of my method of heat transfer and a typical construction by which my method may be practiced, the following premises should be understood as the basis for the practice of my invention.

As my purpose is to effect a heat transfer from the fluid having a relatively high specific heat, such as a prime fluid comprising steam through containing boundaries, such as cast iron, to a fluid having a relatively low specific heat, such as the secondary fluid air, it will be understood that the prime fluid requires more contact area than the secondary fluid. Therefore, I project from the boundaries of the radiator body on the outside where the air is flowing gently undulatory surfaces of such undulation as to effect the practice of this invention. If the fins are made zigzag, in which various parts of the fins are at an abrupt angle to one another, then the object of the invention is completely destroyed. If the fins are made straight, again the object is destroyed.

The side walls may be either flat or undulatory, the latter preferred, but, in any event, with an uninterrupted surface which permits condensation to flow across the surfaces uniformly thus wetting and wiping the surface on the interior of the body with consequent increase in the rate of surface contact and the rate of heat transfer due to the condensation on the walls having a higher specific heat than the container gaseous fluid in the case of steam.

The secondary fluid, such as air, on the outside of the body is confined by the prime surface and the two projecting adjacent undulatory fins are integrally connected to the prime surface and conduct heat therefrom. Those fins are so designed as to provide a comparatively even flow of heat to the boundaries of the secondary fluid, and the spacing is such that the maximum heat, both of convection and radiation, is imparted with the minimum surface friction resistance to fluid flow. The parallel fins are given a slight undulatory effect in direction of the fluid flow and are carried completely around the ends of the radiator body.

The relation of the angularity at any point of these undulations must be such as to conform to the principles of turbulent flow that I observe and such undulations must be such that, at all points on them, there will be uninterrupted surface contact between the air and the cast iron surface.

The importance of this arrangement can best be understood by contrast with the prior art. In the case of parallel fins, without undulations, that is, straight (Fig. 8) the fluid flow will have a velocity higher than the average at a point midway between the fins with a gradual decrease as the fin is approached. The friction of the fin surface on the fluid will cause minute swirls or eddies to form. These eddies revolving on independent axes will be detached and progressed down stream with the fluid flow but at much lower velocity than the true stream, thus retarding the heat transfer which is governed by a function of velocity at the point of contact of approximately the one-half power. These eddies further retard heat transfer in that they act as an insulating media between the surface and the fluid, and prevent the displacement of the film in contact with the surface by fluid in the main stream, the removal of this eddy film from surface contact and the replacement of eddying fluid with less highly heated fluid from the main stream; and the increase of velocity at or near the boundary is, therefore, of prime importance especially as the heat transfer is in the nature of a one-half power. It is apparent that the alternating increased and decreased velocities will materially affect the growth, size and velocity of the eddies interposed between the main fluid stream and the boundary surface.

Turning to the other customary construction in the art of fins having a series of portions at sharp (Fig. 9) angles to one another or having fins that are sharply undulatory giving marked changes in direction, then the angle of undulation will be increased materially and the air flow will be changed in direction a number of times during the passage between the fins. The fluid flow will be deflected sharply with an expenditure of energy relative to the acuteness of angularity of the air path. The main stream will become detached from the boundary forming a low pressure area on the down stream, acute angle region between the stream and the boundary and a swirl or large eddy will be formed having a diameter approaching the maximum distance between the parallel of the fluid stream and the maximum depth of the boundary therefrom. The surface will be thus deprived of intimate contact with the fluid losing its value in the transfer of convected heat, thus materially reducing its effectiveness.

The formation and subsequent detachment of these larger eddies impose greatly increased turbulence without intimate contact with a consequent increase of energy expended in producing flow between these two extremes, i. e., parallel straight flow and alternate detached surface flow, which has characterized the prior art; I have found that there is a principle of construction which, when practiced, will produce the greatest transfer of heat for the least energy

expenditure with the minimum area of boundary wall permitting a marked decrease in the weight of cast iron employed, a decrease in size, a reduction in resistance to air flow and without a decrease in velocity.

The principle I have embodied in my invention, in my construction and method of operation is to so arrange in undulations of the fins as to secure a continuous undetached contact with all surfaces of the boundary which I call undetached undulatory flow (Figs. 1 to 8 and Fig. 10).

To the foregoing as a feature of my invention, I have added means for entry and exit of the air so as to minimize the losses due to changes in velocity and to maintain fluid contact with both entry and parallel walls. At the point of entry, the vena contracta, which occurs with a sharp-cornered wall, is largely avoided.

By the practice of the invention embodying my principles and methods, it is possible to use undulations vertically with respect to the stream line but also horizontal with respect to the main line of the stream.

Referring to Figure 8, it will be seen that it shows a diagram illustrating the use of parallel wall fins, the walls being designated 13. The cone of entering air is designated 14 and two relatively thick streams of turbulent eddies 15 serve to insulate the body 14 of air from the hot walls 13 thereby cutting down heat transfer. This parallel flow type is inefficient for the reasons heretofore pointed out.

Turning to the other form characteristic of the prior art, (Fig. 9) which either consists of sharp undulations as shown, or angular undulations, it will be noted that the cone of air has an even narrower or thinner cone of air designated 16. This cone of air only touches at intervals at 17 the sharply bent walls 18 while the spaces therebetween in the deep valleys 19 are filled with very large areas of turbulent air 20. This illustrates the detached undulatory flow characteristic of the other class of the prior art which is unsuccessful for heat transfer.

Turning to Figure 10, which illustrates the present invention, it will be noted that the body of air 21 passing between the fins 7 engages over a relatively long area indicated at 22 the adjacent areas on the surfaces of the fins 7 and whatever small eddies are set up as at 23 are of very minor character but are sufficient to cause movement of the hot air which is quickly heated due to the diameter of the eddies 23 being small and due to the fact that these eddies move easily into portions of the body of the cooler air 21 and exchange places with other small eddies of cold air, thereby effecting a rapid heat transfer. It will be further apparent upon studying these diagrams, which illustrate graphically the practical tests and laboratory research results that I have secured, that the body of air passing through in Figure 10 is much larger than in Figures 8 and 9. Furthermore, the area of contact of the body 21 of air in Figure 10 is much greater than in Figures 8 and 9. It will be observed that the deep areas of turbulence in Figures 8 and 9 which act as insulation areas between the heated fins and the body of cold air 14 or 16 are absent in Figure 10 of the present invention. These factors are vital in a blast radiator where resistance to air flow must be avoided, and where quantity of air delivered suitably heated with the least expenditure of horsepower to move the air is the primary criterion of success.

By employing a construction which practices the principle of undetached undulatory flow explained herein, the present construction avoids the disadvantages and pitfalls of the prior art and makes possible the use of an economical, forced draft radiator.

It will be understood that I desire to comprehend within my invention such modifications as may be necessary to adapt it to varying conditions and uses.

Having thus fully described my invention, what I claim as new and desire to secure by Letters Patent, is:

1. In a method of heat transfer, passing a heated medium on one side of a heat exchange surface so as to have unobstructed flow and wiping action; and passing a fluid to be heated on the other side of said surface at an angle to the direction of flow of the heating medium in the general direction of a straight line of flow and imparting to said fluid an undulatory motion, the troughs of said undulations extending below the crests to an extent between approximately 11/64 and 13/64 of an inch from a straight line to which the crests of the undulations are tangent, and guiding the fluid passing over the heat exchange surface in a plurality of undulating parallel streams.

2. In a method of heat transfer, passing a heating medium in one direction on one side of a heat exchange surface; and passing a fluid to be heated on the other side of said surface at an angle to the direction of flow of the heating medium in the general direction of a straight line flow, and imparting to the fluid an undulatory motion as said fluid passes over the heat exchange surface, and guiding the fluid as it passes over said surface in a plurality of undulating parallel streams, the troughs of said undulations extending below the crests to an extent between approximately 11/64 and 13/64 of an inch from a horizontal line to which the crests of the undulations are tangent.

3. In a method of heat transfer, passing a heating medium in one direction on one side of a heat exchange surface; and passing a fluid to be heated on the other side of said surface at an angle to the direction of flow of the heating medium in the general direction of a straight line flow, and imparting to the fluid an undulatory motion as said fluid passes over the heat exchange surface, guiding the fluid as it passes over said surface in a plurality of undulating parallel streams, the troughs of said undulations extending below the crests to an extent between approximately 11/64 and 13/64 of an inch from a horizontal line to which the crests of the undulations are tangent, and guiding the streams of fluid at the entry and exit of said streams with respect to the heat exchange surface over which they flow to avoid turbulence.

OTTO G. WENDEL.