

Dec. 30, 1941.

E. R. WALKER ET AL

2,268,361

HEAT EXCHANGE APPARATUS

Filed Aug. 11, 1941

3 Sheets-Sheet 1

Fig. 1

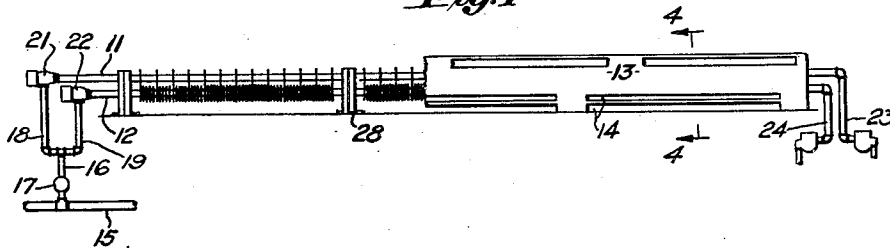


Fig. 2

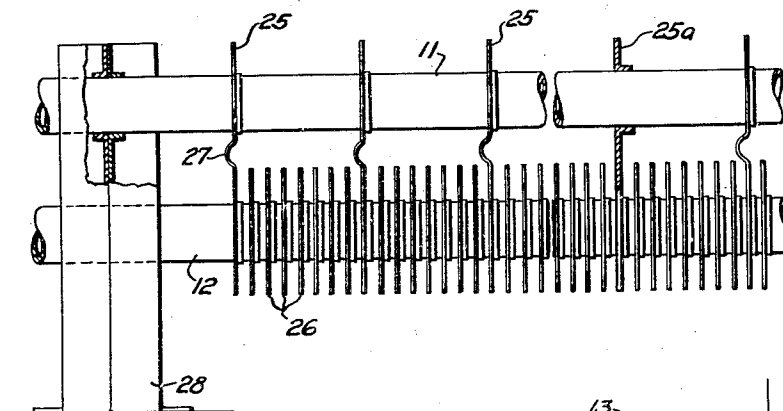


Fig. 3

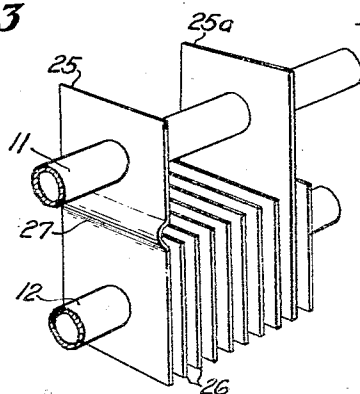
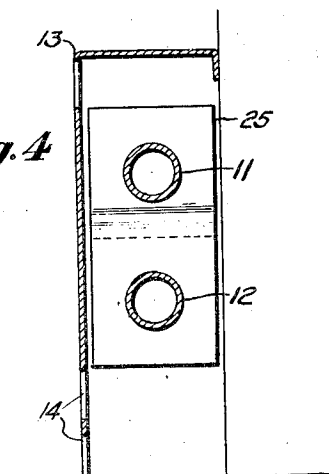


Fig. 4



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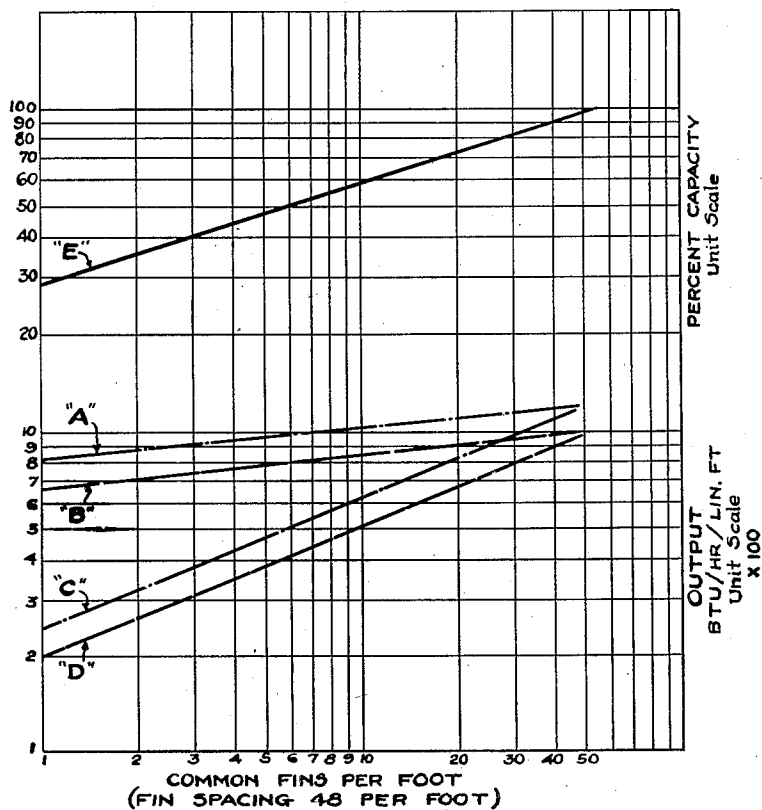
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Fig. 5



A = 10* STEAM } BOTH LINES SUPPLIED
 B = 2* STEAM }
 C = 10* STEAM } STEAM ADMITTED
 D = 2* STEAM } TO UPPER LINE ONLY
 E = { CAPACITY FACTOR WITH FLUID
 { IN LEAST FINNED TUBE

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Fig. 7

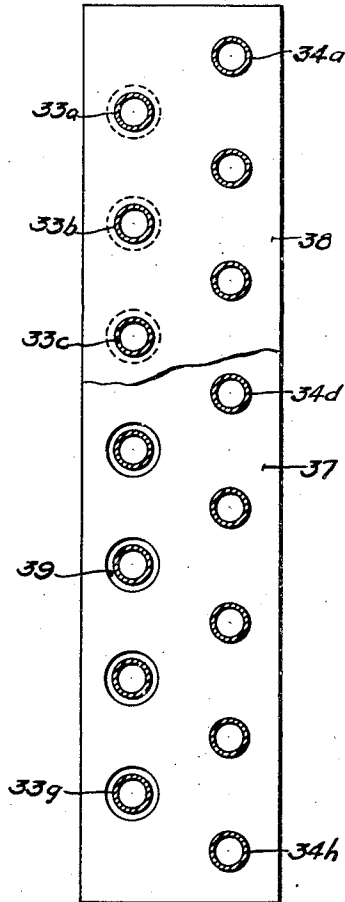
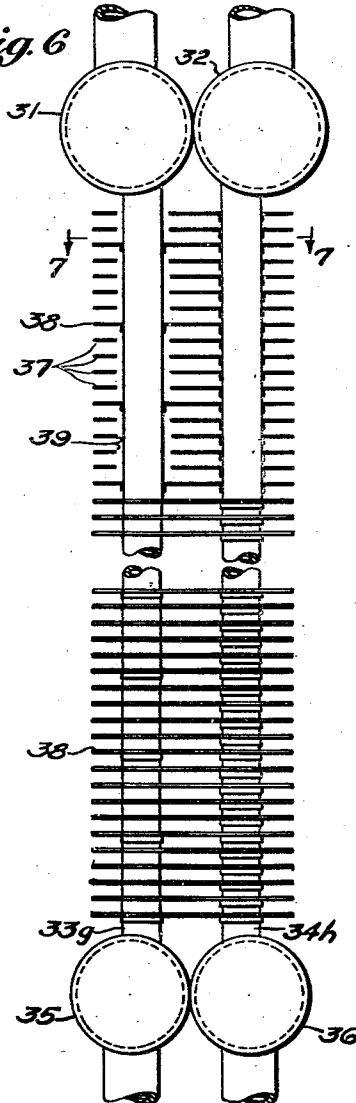


Fig. 6



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HEAT EXCHANGE APPARATUS

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Application August 11, 1941, Serial No. 406,260

8 Claims. (Cl. 257—134)

This invention relates to heat exchange apparatus and systems involving the same, and it is particularly concerned with a system wherein the working fluid may be selectively admitted to one or more rows of a multiple pass heat interchanger, so organized that the heat transfer may be effected at full capacity, or at predetermined fractional values thereof.

A known form of heat interchanger, particularly effective for the heating or cooling of air, is the so-called cross fin coil. In these devices, there are a number of rows of tubing, adapted to be connected in multiple, through which the working fluid may pass, and the tubes are interconnected at spaced intervals by transversely disposed fins providing thermal paths between the several rows, and around which the air may flow. If such a coil is employed for heating, steam is supplied to the various rows of tubing, to give up its heat to the air, while if cooling is intended, the working fluid consists of volatile refrigerant which expands and absorbs heat during its passage from the tube inlets to the outlets. Coils of this general nature, suitably provided with inlet manifolds and valves and suction or discharge connections, are utilized in air conditioning, as unit heaters and coolers, for railway car heating, and similar purposes.

Such coils operate most effectively, however, when the amount of working fluid supplied is such as to provide for substantially the maximum amount of heat transfer for which the coil is designed. There are many instances, however, when it is desirable to reduce the amount of heat transfer below the intended full load rating. The methods heretofore proposed have, nevertheless, been attended with various unsatisfactory complications. For example, in a coil designed to deliver 100,000 B. t. u. per hour with steam at ten pounds pressure, the effort to reduce the output by throttling the steam supply may result in complete condensation of the steam at a region remote from the discharge header—a substantial portion of the coil then becomes inoperative and the air passing through such portion is not heated at all. An analogous condition may prevail with respect to the superheat point, when the problem of refrigeration is considered.

These various conditions may be further illustrated by considering the basic form of equation for heat transfer, frequently written in this manner:

$$Q = A \cdot U \cdot mtd \quad (1)$$

where Q represents the coil capacity in B. t. u. per hour; A is a numerical value, depending on the coil dimensions, and expressible in total external surface in square feet; U is the overall coefficient of heat transfer; and mtd is the mean

temperature difference between the working fluid within the tubes, and the air or other medium flowing around the tubes.

The term U may moreover be evaluated, for a multiple pass coil, by an equation having some similarity to that expressing the resistance, or total impedance, of a branched electric circuit, in this form:

$$1/U = R'/h_i + 1/h_w + 1/h_o \quad (2)$$

wherein R' is the ratio of total external surface to total internal surface, and accordingly is a fairly large and positive value for cross-fin coils; h_i is the partial internal heat transfer coefficient peculiar to the fluid and its film within the tubing; h_w is the partial heat transfer coefficient attributable to the heat exchanger wall and fin structure; and h_o is the partial coefficient primarily chargeable to the fluid flowing around the tubes.

As distinguished from throttling, which basically controls the value of Q through the mean temperature difference, mtd , and as distinguished from variations in the value of Q caused by changes in the quality of the working fluid or changes in the temperature or velocity of the treated air (U as affected by h_i and h_o), and as also distinguished from attempts to block out portions of the coil itself (thereby acting through the factor A), we have discovered that the output of a coil may be effectively controlled by operating through the coefficient h_w . In such a coil, of course, the value of Q may be modified, if desired, by superimposing the effects procured by throttling, etc., but for the present purposes, we shall treat these as being fixed in order to clarify the explanation.

It will also be understood that the factor h_w depends upon the total area of the tubes through which the working fluid passes, and also upon the area of the fins, or indirect surface, which is thermally connected to the tubes. These fins constitute heat transfer paths of relatively high conductivity—if there are a lot of them, more heat can be exchanged in a given length of tubing (up to the saturation point). If there are not so many fins, then more thermal resistance is interposed, and the overall heat transfer coefficient, and the value of Q , is proportionately reduced.

We have now discovered that the tubes and fins may be so related as to provide heat transfer paths which have different values, depending upon the direction of heat flow through the fins and tubes. Our immediate purpose is to describe how that discovery may be utilized, and for that purpose reference may be made to the accompanying drawings, wherein:

Fig. 1 is a side elevation of a cross-fin coil hav-

ing two passes, and utilized for railway car heating;

Fig. 2 is an enlarged fragmentary view, partially in section, of a portion of the coil shown in Fig. 1;

Fig. 3 is a fragmentary perspective view further illustrating the surface shown in Fig. 1;

Fig. 4 is an enlarged section taken on the line 4-4 of Fig. 1;

Fig. 5 is a chart showing the capacity of the coil illustrated in Figs. 1 to 4, in terms of modifications of the heat content of the working fluid and in terms of variations in the availability of indirect heat exchange surface;

Fig. 6 is a side elevation, with a group of fins shown in section, of another coil embodying the invention; and

Fig. 7 is a section on the line 7-7 of Fig. 6.

The heat exchanger shown in Figs. 1 to 4 is a simple form of cross-fin coil, having two relatively long tubes 11 and 12, through which the working fluid may pass in parallel circuit arrangement, it being understood, of course, that coils within this invention may be made with more than two rows, and that more than one tube may be supplied from a common supply point. These tubes, which are adapted in this particular instance to be placed lengthwise of a railway car, are also usually covered by a housing 13 having openings 14 to permit the circulation of the air to be treated.

The tubes are supplied with working fluid—steam in the example taken for illustration—which enters from a main supply line 15 provided with a T connection 16 in which there is a valve 17, which in turn communicates with branches 18 and 19 respectively connected to the tubes 11 and 12. The branches are each provided with a valve, respectively designated by the numerals 21 and 22, so that the steam can be cut off entirely from the coil, or it may be admitted to one, or both of the tubes, as circumstances might dictate. The steam flowing through the coil gives up its heat to the air flowing around the coil, condenses, and is finally eliminated through the discharge lines 23 and 24. Except as is otherwise stated herein, the details of this general circuit are usual, and typical of multiple pass coils, and therefore a further description is deemed unnecessary. It may be noted, however, that the valves 21 and 22 are preferably positive automatic shut-off valves, such as solenoid valves, actuated through suitably located controls in such manner as to be either wide open or tightly closed.

The tubes 11 and 12 are interconnected by metallic fins 25 and 25a, widely spaced along the tubes, while the lower tube 12 only is also provided with an additional number of smaller fins 26 disposed between the fins 25 and 25a, but not in contact with the upper tube 11. The fins 25 are mechanically and thermally bonded to the tubes, and are formed with deformed ribs 27 to permit flexing under temperature changes. The occasional fins 25a, while bonded to the lower tube 12, engage the upper tube 11 with a sliding and somewhat loose fit, and these particular fins are moreover of heavier metal. While this construction detracts slightly from the conductivity through the fins 25a, it also provides a stronger construction, and permits differential lineal movement between the tubes 11 and 12 under forces of expansion and contraction, thus relieving the remaining elements from too much strain. The fin and tube assembly is mounted in aligned

supporting members 28, with a fairly loose fit, so that the entire coil may move bodily, in addition to the relative movement provided by the structure just described.

It will be seen that, in this coil, there is a certain amount of indirect heat exchange surface which is common to both rows, and there is another amount which is specific to one row only.

When it is desired to obtain the maximum amount of heat exchange for which the coil is designed, the valve 17 is opened, and the controls for the valves 21 and 22 are so set as to cause these valves to open. The working fluid then enters all the rows, thereby supplying the greatest possible amount of fluid for heat exchange. If, however, an appreciably less amount of heat is called for, the valve 22 for the lower tube 12 is made to close, as by setting its control thermostat at a higher point than the setting for valve 21. Fluid will then be admitted to the upper row 11 only.

With regard to the above stated proposal to use positive shut-off valves 21 and 22, it may be noted that the valves could be thermostatic throttling valves, whose opening is usually positive, but variable. In such case there could be a small and continuous feed of fluid to the tubes. That can result in an admission rate such that the fluid is expended long before any of it reaches the discharge end of the coil. Thus, the work could be done over a relatively short length of the entire coil, and air passing around the discharge end would not be heated uniformly, or receive its proportionate amount of work. On the other hand, by using intermittently operating shut-off valves, there will be fairly large slugs of fluid admitted when the valves are open. These may then distribute themselves along the entire coil length before their energy is expended, and the coil becomes equally effective at all portions.

Referring again to the use of different amounts of indirect surface assigned to the various tube rows, it will be recalled that we contemplate a coil which can operate effectively at some given full load value, and also operate effectively at fractional values of the full load capacity. In the specific example herein treated, we have laid out the coil for nominal values of 1,000 B. t. u. per hour per lineal foot, with steam supplied at both rows at once, and with a capacity of 50 per cent, or 500 B. t. u. per hour per lineal foot, when the steam is supplied to one row only.

Thus, considering further the coil shown in Figs. 1 to 4, it is apparent that, with steam supplied to both rows, the path of heat flow is from the tube wall and along radial lines through both the large and small fins. This indirect surface, from Equation 2 above, therefore, provides some value for the coefficient h_w . On the other hand, if the steam be admitted to the upper tube 11 only, then while the thermal path is the same as to the upper portions of the large fins 25, the thermal path is different as to the other portions of the fins. Still considering the case of heating, the high potential path is then from the surface of tube 11, down to tube 12 through fins 25, thence along the tube 12 and then laterally through the fins 26. Under these conditions, as we have discovered, the output capacity of the entire coil becomes modified in a relationship to the change introduced by modification of the thermal path, and thus, as we view the principle, by change in the factor h_w .

While a further analysis of this subject may

be attempted by the methods of thermodynamic equations, it appears to be more expeditious to determine the coil output by simple laboratory check test, since, as we find, the rather involved exponential equations found in the mathematical treatment can be readily resolved by graphical analysis. Thus, in Fig. 5, we show the performance data pertinent to the coil illustrated in Figs. 1 to 4, the cover or housing 13 being removed during the test period. Applying the invention to the problem of having a coil which would operate effectively at full or fractional output capacity values, we selected as typical a copper cross-fin coil having two spaced rows, in which four fins to the inch could be tolerated. We then laid out the balance of the design, particularly with respect to the ratio of common to specific fins, to meet an operating condition of fifty per cent capacity, with the results shown in Fig. 5.

In this graph, it will first be noted that a log-log scale has been adopted. This has the advantage of producing curves which plot as substantially straight lines—the many factors entering into the exponential equations simply operating to modify the slope or intercept, but otherwise being eliminated so that the graphical method of performance prediction is simplified. On the abscissa has been plotted the ratio of indirect surface common to all tubes to the indirect surface specific to one row, this being expressed here as number of large fins per foot of a coil provided with 48 specific fins per foot. The lower ordinate shows the output in B. t. u. per hour per lineal foot of such coil, when treating air to 70° Fahr. under convection velocity.

Curves A and C show the capacity ratings when using steam at ten pounds gauge pressure, and these curves are respectively for admission to both tubes 11 and 12 simultaneously, and to the upper tube 11 alone. Curves B and D are similar curves, using two pounds steam pressure. Curve E shows the fractional capacities effected by modifying the available fin ratios, and thus the heat transfer coefficient, and this curve, it will be noted, is not dependent upon steam pressure, or like variable conditions.

From curve A, it will be seen that, as more and more common fin surface is introduced into the coil, and with steam admitted to all lines, the capacity in B. t. u. increases—a naturally expected result, as increase in the indirect surface directly affects the factors A and h_w of Equations 1 and 2. In curve B, with steam at a lower pressure, a similar effect obtains, but, as the steam has less heat content, then curve B is below curve A at all times, and generally is parallel to it. These two curves show the effect of throttling within limits which the coil can readily tolerate, and they also show that throttling in itself may be inadequate to curtail the capacity to any great extent.

In curve C, the steam at high pressure has been shut off from the lower tube 12, which is in thermal contact with the greatest amount of indirect surface, and it will be seen that, as the surface ratio is increased (fewer fins on the dry pipe), the capacity becomes much less, while as the ratio is brought toward unity, the output of the coil is nearly as much when steam is supplied to one line, as to both lines, because curves A and C converge to a saturation point. A similar relation exists between curves B and D. Thus, it appears that in a coil having cross-fins common to all the rows, even when designed along

accepted lines for optimum efficiency, the curtailment of the capacity cannot be effected merely by shutting down a portion of the multiple rows, because there are still so many heat transfer paths that the less amount of working fluid is expended too quickly.

On the other hand, if the thermal transfer paths are differentiated, as by providing more indirect surface for some lines than is provided for others, then the entire surface may be employed in a directional manner, and in such way as to be independent of such factors as relate to the working fluid and the medium with which it exchanges heat.

This effect is best shown in curve E, which shows the relation between the coil capacity when all rows are supplied, and when only one is supplied, again in terms of the indirect surface ratio. It will be seen that, as the number of large fins is curtailed, then the capacity, with fluid supplied to one row, decreases regularly in comparison with the capacity with fluid supplied to both rows. In our illustrative example, we proposed to lay out the coil in such manner that it could be operated at fifty per cent capacity—a result which obviously cannot be obtained by mere throttling over the range indicated. Taking then, the ordinate at 50 per cent capacity, it will be seen that this corresponds to a fin ratio of 6 : 48, or 12.5 per cent. Accordingly, as the lower row 12 had been provided with four fins per inch, the upper row 11 was connected thereto with one fin every two inches, to produce the coil of Figs. 1 to 4. On the other hand, if a seventy per cent capacity value were required, the ratio would have been selected at about 1 : 3, while for a forty per cent capacity value, a ratio of 1 : 16 would be more effective. These values, of course, are slightly diminished in service by including the strengthening fins 25a and the housing 13, but nevertheless represent reliable working figures for the system under consideration.

While the foregoing description of a coil embodying the invention, and of a simplified method of determining the fractional capacity, has been made with reference to one application, it will, of course, be understood that the invention may be utilized in other sizes of coils adapted for different applications. Thus, in Figs. 6 and 7, we show a coil useful in unit heaters or coolers, wherein the working fluid flows from an upper header to a lower header, and the air is generally circulated by means of a fan.

This coil consists of two upper headers, 31 and 32, to each of which is connected a plurality of dependent tubes 33a, 33b, . . . 33g, and 34a, 34h, respectively. The lower ends of the various tubes are also connected to lower headers 35 and 36, and it will be understood that admission of the working fluid to the upper headers, and removal of spent fluid from the lower headers, is effected by suitable valves and pipe connections, not illustrated.

The tubes are transversely intercepted by a plurality of fins 37 and 38, all of which are thermally connected to the tubes 34. All of these fins are moreover of the same size, which provides some advantages in manufacturing procedure, and also increases the total amount of indirect surface. The fins 37 are not, however, thermally or physically connected to the tubes 33, being spaced therefrom by clearance openings 39.

It will be seen that, in common with the embodiment shown in Figs. 1 to 4, there are a number of parallel passes in the coil, to which the working fluid may be supplied selectively, and there are a number of fins, or an amount of indirect surface, common to all the rows, and another and numerically different amount of indirect surface which is specific to less than all the tubes. Thus, depending upon the ratios of these values of indirect surface, and the tubes to which the working fluid is supplied, there can be obtained different, but related, values for the factor h_w , and through it the output of the coil. Other types of coils will be readily recalled by those skilled in the art, while the practical specification of actual sizes or areas for the various surfaces can be readily made by the graphical method outlined, to meet the particular problems that are constantly arising in the industry.

It is, therefore, intended that the invention should be considered as comprehending the various specific embodiments and applications in which its principles may be incorporated, and that it should moreover be considered as commensurate with the scope of the following claims.

We claim:

1. A heat exchange coil comprising a plurality of rows of tubing adapted to receive working fluid, said rows being provided with inlet and outlet ends, means for selectively admitting the working fluid to all, or to less than all, of said rows, common indirect heat exchange surface thermally connected to all of said rows, and an additional amount of indirect heating surface thermally connected to less than all of said rows, whereby, upon admission of working fluid to less than all of said rows, heat exchange may be effected through all of said indirect surface by transfer from the common surface to the additional surface, and the coil may be operated at a fractional value of its full rated capacity.

2. In a heat exchange system having a source of supply of working fluid, a supply pipe leading from said source, branches connected to the supply pipe, a heat interchanger having a plurality of rows of tubing, said branches being connected to said rows, admission means interposed in said branches whereby flow of fluid from the supply pipe to the rows of tubing may be selectively established and interrupted, a plurality of fins forming part of said heat interchanger, certain of said fins being mechanically and thermally connected to all of said rows, other of said fins being mechanically and thermally connected to less than all of said rows, and control means for the admission means effective to admit working fluid to the row having the least number of fins after working fluid supply to the row having the most fins has been interrupted.

3. In a heat exchanger of the type adapted to receive working fluid within a tube and to exchange heat by transfer through the tube wall and indirect surface thermally connected thereto, a coil comprising a plurality of rows of tubing, means for admitting fluid to said rows for parallel flow therethrough, means for interrupting the flow through the several rows selectively, and means for varying the heat transfer coefficient of the coil in response to the row through which the fluid passes, said last named means comprising indirect heating surface thermally connected to all of said rows of tubing and other indirect heating surface thermally connected to certain rows only.

4. A heat exchange coil comprising a plurali-

ty of tubes through which working fluid may pass in parallel circuit arrangement, means at the inlet ends of said tubes for selectively admitting the working fluid to the tubes, a plurality of spaced fins transversely disposed along one of said tubes and thermally bonded thereto, other spaced fins disposed transversely of said tubes and being thermally bonded to all of said tubes, the number of the last named fins being less than the number of first named fins, the relative effective areas of said fins being such that, when working fluid is admitted to the tube carrying the least number of fins, the capacity of the coil is substantially between thirty and seventy per cent of its capacity when the fluid is admitted to the plurality of tubes.

5. A heat exchange coil comprising tubes mounted in parallel relation, said tubes being of relatively great length compared to the spacing between the tubes, means at the inlet ends of the tubes to admit working fluid selectively thereto, a plurality of cross fins spaced along and thermally connected to said tubes, other cross fins disposed intermediate said first named fins and being thermally connected to one tube only, means for supporting said tubes and fins for lineal movement under temperature changes, and other means included in said first named fins for permitting relative movement of the tubes.

6. A cross fin coil comprising a plurality of rows of tubes disposed in parallel relationship, cross fins thermally connected to one of said rows but thermally spaced from the other of said rows, additional cross fins thermally connected to both of said rows and being interspaced with the first named fins, said additional fins being formed with deformed expansion portions, and occasional cross fins disposed transversely of all said tubes and thermally bonded to one of the rows, and having a sliding fit with the tube in the other of said rows.

7. A cross fin coil comprising a plurality of inlet and outlet headers, a plurality of tubes interconnecting pairs of said headers, cross fins disposed along said rows and transversely of the tubes, said fins being of substantially the same size, some of said fins being mechanically and thermally connected to the tubes connecting said header pairs, other of said fins being thermally spaced from some of said tubes.

8. Heat exchange apparatus including, in combination with a source of supply of working fluid, a heat exchange coil having a plurality of rows of tubes through which the fluid may pass, means for selectively admitting to each of said rows the working fluid from the source both concurrently and independently of admission to other of said rows, said admission means alternately admitting no fluid and quantities sufficiently large to be distributed substantially along the tube length, fins mechanically and thermally connecting said rows and spaced along said tubes, other fins mechanically and thermally connected to less than all of said rows, said last named fins being of greater number and area than the first named fins, whereby, upon admission of the working fluid to the row including the first named fins only, the capacity of the coil will be a fraction of its capacity when working fluid is admitted to all of the rows, and the energy of the fluid will be available through all of said fins throughout the length of the coil.

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