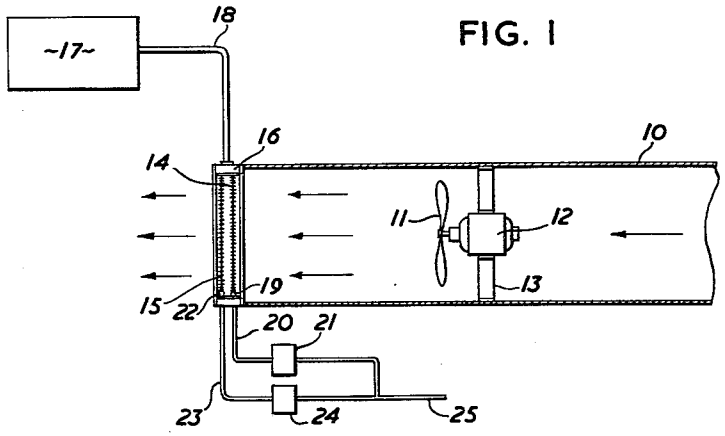
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HEAT EXCHANGE APPARATUS

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FIG. 1



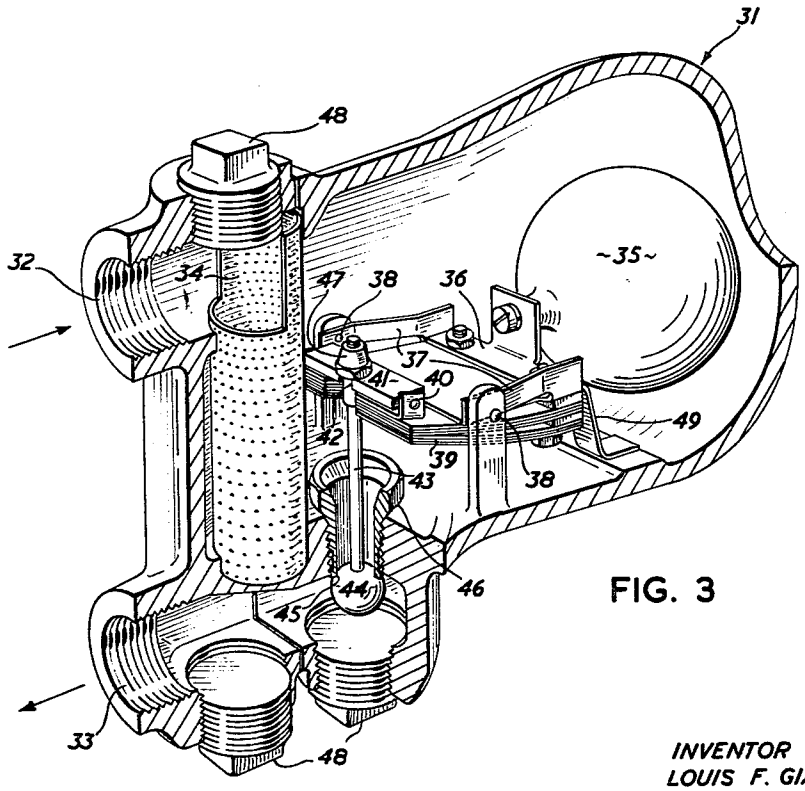


FIG. 3

INVENTOR
LOUIS F. GIAUQUE

BY: Maybee & Legris
ATTORNEYS

Jan. 22, 1963 L. F. GIAUQUE 3,074,479

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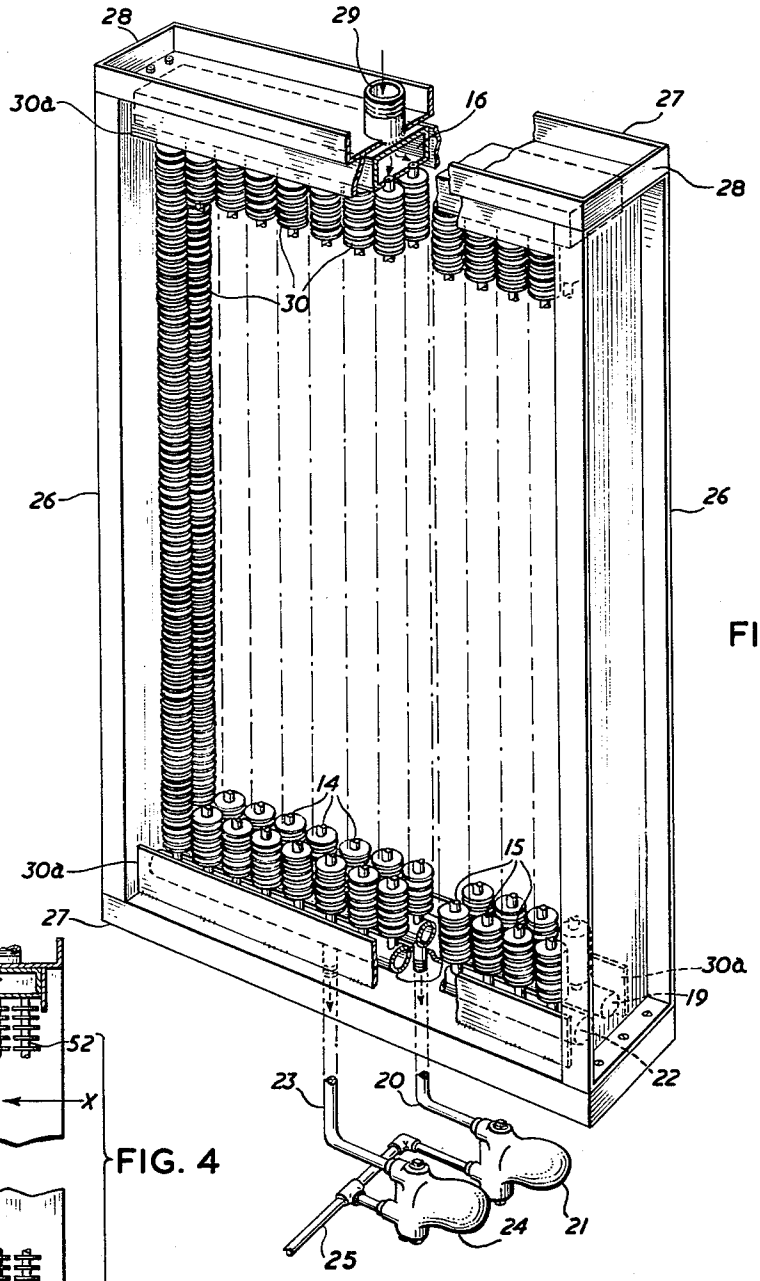


FIG. 2

FIG. 4

INVENTOR
LOUIS F. GIAUQUE

BY: Maybee & Legris
ATTORNEYS

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HEAT EXCHANGE APPARATUS

Louis F. Giauque, 50 Dominion Ave., Kapuskasing, Ontario, Canada

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3 Claims. (Cl. 165—110)

This invention relates to a heat exchange apparatus. The invention is concerned with apparatus for passing steam in heat exchange relation with air having an initial temperature below the freezing point of water; such apparatus is commonly called blast coils or heater coils.

It is known to employ steam to heat air for use in the heating of buildings such as factories, aircraft hangars, etc. One form of apparatus used for heating the air comprises two or more rows of heat exchanger tubes arranged one behind the other; steam is passed through the tubes from a common header, the air is propelled across the exterior of the tubes by means of a fan, and the condensate is collected in a common header. It has been found that, under certain conditions of air flow when the air is initially at a temperature below the freezing point of water, the condensate which forms in the row of tubes with which the air first comes into contact freezes and bursts the tubes. A row of tubes with which the air first comes into contact is hereinafter called a "first row." Air at a sufficiently low temperature to cause bursting of the tubes as described above is commonly encountered in the winter in, for example, the north-westerly parts of the United States and most of Canada and the invention is particularly concerned with providing heat exchange apparatus which may be used in such northerly latitudes and which prevents, or at least minimizes, the freezing of condensate in the tubes.

Although the makers of heat exchanger tubes realize that a freezing problem exists in connection with heating very cold air, they have been unable to provide a satisfactory solution. So called "non-freezing" or "steam distributing" heater tubes which are presently on the market comprise an outer finned tube within which is concentrically arranged an inner tube and a clearance is provided between the outer surface of the inner tube and the inner surface of the outer tube. The wall of the inner tube is perforated all along its length and steam is supplied to the inner tube and passes through the perforations into the clearance between the tubes. This construction is intended to prevent the condensate from freezing in the tubes but it is not effective for this purpose in apparatus having more than one row of tubes connected to a common condensate header. Moreover, such "non-freezing tubes" cost approximately one third more than conventional heat exchanger tubes.

Freezing may be prevented by using excessive amounts of steam, e.g. by passing steam through the tubes without restriction, but this is not practical in the majority of installations where steam is an expensive commodity.

I have now found a solution to the problem of the freezing of condensate in the tubes of the first row in a double or multiple row heat exchanger. My solution does not require the use of excess amounts of steam and is to provide means to eliminate the leg of condensate which I have found normally builds up and freezes in each tube of the first row when this row is connected with a subsequent row or rows to a common condensate header. I achieve this effect by allowing the pressure drop of the steam across the tubes of the first row to be independent of the pressure drop across the tubes of the other row or rows.

I have tested my invention in practice and found that it is operative. For example, when a particular installation of two rows of tubes arranged one behind the

other is used in accordance with my invention, no condensate freezes in the tubes even when the air is initially at —30° F. and passes over the tubes at 750 feet per minute and when the steam pressure applied to the tubes is as low at 7 p.s.i. Previously, when the installation was used in a conventional manner, condensate froze in the tubes when they were used to heat air passing over them at 750 feet per minute at an initial temperature —10° F. and with a steam pressure of 15 p.s.i. across the tubes.

I have developed the following theory which I believe explains the mechanism of my invention. It is apparent that, in a two row heat exchanger with the tube rows arranged one behind the other in the direction of air flow, the air passing across the tubes in the first row is colder than the air passing across the tubes in the second row. It therefore follows that the temperature difference between the steam in the tubes of the first row and the air passing over the tubes of the first row is greater than the temperature difference between the steam in the second row and the air passing over the tubes of the second row. For this reason, the air extracts more heat from the steam flowing through the tubes of the first row than from the steam flowing through the tubes in the second row. It follows that more steam is required to pass through the tubes of the first row than through the tubes of the second row and that therefore the pressure drop across the tubes in the first row is greater than the pressure drop across the tubes in the second row since each pressure drop is proportional to the square of the quantity of steam flowing through the tubes of the row.

When the tubes in both rows are connected to a common condensate header, I believe that it is this difference in pressure drop across the tubes of the various rows that maintains a leg of condensate in a lower portion of each tube of the first row. I have found that by isolating the lower or condensate ends of the tubes of the first row from the corresponding ends of the tubes of the second row and by connecting the tubes of each row to a separate steam trap, I have eliminated the condensate leg which has hitherto built up in each tube of the first row and I have obviated the freezing and bursting of the tubes of the first row. I believe that the reason why this arrangement obviates the condensation leg is that my arrangement allows the pressure drop across each row to be independent of the pressure drop across the other row so that there is no excess pressure at the condensate ends of the tubes of the first row which tends to hold a leg of condensate in the tubes of the first row. On the other hand, when the tubes of both rows are connected between a common steam header and a common condensate header, I believe that the pressure in the common condensate header is determined by the amount of steam flowing through the tubes of the second row, i.e. by the pressure drop across the tubes of the second row, and is sufficient to hold, in the tubes in the first row, legs of condensate which then freeze and burst the tubes.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

FIGURE 1 is a diagram showing the various components of the heat exchange apparatus according to the invention,

FIGURE 2 is a perspective view, partly broken away, of the heat exchanger tubes and traps forming part of the apparatus shown in FIGURE 1,

FIGURE 3 is a broken away perspective view of one of the traps shown in FIGURES 1 and 2, and

FIGURE 4 is a transverse cross section of a heat exchanger coil of the type used heretofore in installations for heating air by steam.

Referring now to the drawings, and particularly to FIGURE 1, there is shown a duct 10 along which cold air is drawn by a fan 11 driven by an electric motor 12 supported within the duct by struts 13. The cold air is propelled by the fan through first and second rows of heat exchanger tubes indicated at 14 and 15 respectively. At their upper ends the tubes of the rows 14 and 15 are connected to a common steam header 16 which is supplied with steam from a source or boiler 17 by means of a steam pipe 18. The bottom ends of the tubes in the first row 14 are connected to a first condensate header 19 which is connected by first conduit means 20 to a first steam trap 21. Similarly, the tubes of the second row 15 are connected to a condensate header 22 which is connected by second conduit means 23 to a second steam trap 24. The traps 21 and 24 discharge the condensate to a hot well or condensate sump (not shown) through a pipe 25.

Referring now to FIGURE 2, the arrangement of the rows of heat exchanger tubes is shown in more detail. The rows of tubes are held in a rectangular frame made up of channel-section side members 26 and channel-section upper and lower cross members 27. The ends of the cross members 27 are closed by ribs 28. Secured to the underside of the upper cross member 27 and parallel thereto is the common steam header 16 which is of box-shaped cross-section and is provided with a steam inlet connection 29 secured to the steam pipe 18. The upper ends of the tubes in the rows 14 and 15 are secured in the lower wall of the steam header 16 and are finned as indicated generally at 30. All the tubes in the row are similar to one another and are provided with re-entrant orifices (not shown) at their upper ends.

The lower ends of the tubes are connected to the condensate headers 19 and 22 which are cylindrical pipes having closed ends and lying parallel to the steam header 16. The first and second conduit means 20, 23 are connected to the condensate headers 19, 22 respectively at condensate connections intermediate the ends of the condensate headers. Upper and lower baffles 30*a* shield the steam header 16 and the condensate headers 19 and 22 so that the air to be heated has to pass through the finned tube section of the apparatus.

Both of the traps 21 and 24 are similar and the trap 24 has been shown in FIGURE 3 as illustrative of both traps. The trap comprises a hollow body 31 having a steam and condensate inlet 32 and a condensate outlet 33; the condensate and steam passes through a strainer 34 after leaving the inlet 32. A float 35 is secured to an angle member 36 having side arms 37 which are pivoted to the body 31 at 38. Also secured to the angle member 36 is a bimetallic element 39 which has secured to one end thereof upstanding lugs 40; pivoted between the lugs 40 is a bar 41 slotted at 42. Received in the slot 42 is a rod 43 having a ball 44 at its lower end and arranged to co-operate with a valve seat 45 at the lower end of an insert 46. The upper end of the rod 43 is provided with an adjusting nut 47 having a sleeve portion which is received in the slot 42. Access plugs 48 are provided in the body and a bracket 49 is secured to the float to control its lowermost position.

The trap is shown in a position it occupies when there is steam in the trap but no condensate. The steam causes the bimetallic element to bend and to lift the rod so that the ball 44 comes into contact with the seat 45 and prevents the escape of steam. When cooler condensate enters the trap, the bimetallic element straightens, and the float 35 rises to discharge the condensate through the insert 46. Once the apparatus is in steady operation the float will operate to maintain a predetermined level of condensate in the trap and will discharge the excess to the hot well. It will be seen that the trap provides means to prevent the escape of steam and to discharge condensate.

The operation of the apparatus is as follows: steam is supplied from the steam supply 17 and passes through the steam pipe 18 to the common steam header 16 so that it is supplied to all the tubes at the same pressure. The steam then passes through the tubes in the rows 14 and 15 and any steam which is condensed in the tubes passes into the headers 19 and 22. The condensate delivered to the condensate header 19 passes along the first conduit means to the trap 21 and is discharged but the trap prevents escape of steam from the condensate header. Similarly, condensate delivered to the header 22 passes along the second conduit 23 to the trap 24 where the condensate is discharged but the steam is prevented from escaping. The fan 11 propels air across the tubes so that the air passes first through the tubes in the first row 14 and then through the tubes in the second row 15. The air extracts heat from the steam in the tubes and leaves the tube assembly at a desired temperature.

The following exemplary calculation will show the temperatures, pressures and pressure drops across the tubes. In a particular example the length of the tubes is 121", they have an inside diameter of 0.527", an inside area of 0.2185 sq. in. and they are provided with an orifice at the tube entrance which is 0.375" in diameter. The steam supplied to the steam header 16 is at a pressure of 15 p.s.i. and at a temperature of 250° F. The steam has a density of 0.0721 lb./ft.^{3}, a specific volume of 13.88 ft.^{3}/lb. and a latent heat of 946 B.t.u./lb. The air is arranged to pass over the tubes at a speed of 700 feet/minute, and has an initial temperature of −40° F., a density of 0.075 lb./ft.^{3} and a specific heat of 0.24 B.t.u./lb./° F. From tables provided by the tube manufacture it may be ascertained that a row of thirty tubes each having a length of 121" has a net face area of 35 sq. ft. and it follows therefore that the face area of a single tube is 1.167 sq. ft. (The face area is the net area of the tube which faces the oncoming air stream and is the same for each tube in each row.)

The manufacturer of the tubes also provides tables whereby the temperature of the air leaving a row of tubes may be calculated given the initial temperature of the entering air and the saturation temperature of the steam. The formula is as follows:

$$K=\frac{T_s-T_e}{T_s-T_f}$$

where T_s is the saturation temperature of the steam, T_e is the temperature of the air entering a row and T_f is the temperature of the air leaving the row. From tables provided by the manufacturer, for this particular example, $K=1.31$ for one row of tubes and is 1.70 for two rows of tubes.

Using the above formula and the given values of K, it follows that the temperature of the air leaving the first row of tubes 14 equals

$$250-\frac{250+40}{1.31}=28° \text{ F.}$$

Following a similar calculation the temperature of the air leaving the second row of tubes equals

$$250-\frac{250+40}{1.70}=79° \text{ F.}$$

The quantity of heat transferred to the air from the steam by one tube of the first row is equal to the face area of a single tube multiplied by the air velocity over the tubes multiplied by the density of the air multiplied by the specific heat of the air multiplied by the rise in temperature of the air. This is

$$1.167\times700\times0.075\times0.24\times(28+40)$$
$$=14.7\times68=999.6 \text{ B.t.u./min.}$$

Similarly, the heat transferred to the air from the steam by one tube of the first row plus the heat transferred to the air from one tube of the second row is

$$14.7\times(79+40)=1749.3 \text{ B.t.u./min.}$$

It follows that the heat transferred to the air from one tube of the second row is 749.7 B.t.u./min.

In order to supply 999.6 B.t.u./min. from each tube of the first row it follows that

$$\frac{999.6}{946}=1.042 \text{ lb./min.}$$

of steam must be passed through each tube of the first row, 946 B.t.u./lb. being the latent heat of the steam. Similarly, the quantity of steam which must pass through each tube of the second row is

$$\frac{749.7}{946}=0.778 \text{ lb./min.}$$

This is assuming that no sensible heat is extracted from the condensate. This is not strictly accurate; obviously it is sensible heat taken from the condensate which causes the latter to freeze, but the amount of sensible heat extracted may be neglected in comparison with the amount of latent heat given up by the steam.

The velocity of the steam as it enters each tube of the first row, neglecting the effect of the orifice, is given by the weight of the steam flowing/min. through the tube multiplied by the specific volume of the steam and divided by the inside area of the tube. This is

$$\frac{1.042\times 13.88\times 144}{60\times 0.2185}=158.4 \text{ ft./sec.}$$

Similarly, the velocity of the steam as it enters each tube of the second row is

$$\frac{0.778\times 13.88\times 144}{60\times 0.2185}=118.2 \text{ ft./sec.}$$

The pressure differential required to force steam through a tube may be stated in terms of the velocity pressure of the steam entering the tube. The velocity pressure may be calculated from the formula $v^2=2gh$ where h is the pressure head due to the velocity. To convert this into inches of water gauge

$$h=\frac{v^2\times 12\times \text{steam density}}{64.4\times \text{water density}}$$

which gives

$$h=\frac{v^2}{4652} \text{ in.}$$

water gauge. It follows that the pressure due to velocity of steam in the first row of tubes equals

$$\frac{158.4^2}{4652}=5.40 \text{ in.}$$

water gauge. Similarly, the pressure due to the velocity of the steam passing through the second row of tubes equals

$$\frac{118.2^2}{4652}=3.02 \text{ in.}$$

water gauge.

I have found that the relationship between the pressure drop in a tube and the tube length will not be linear but will follow some law such as

$$\left(\frac{L}{ND}\right)^x$$

multiplied by the velocity head. This law is due to the fact that as the steam passes through the tubes it continuously diminishes in quantity due to condensation.

On the basis of experiment I believe the pressure drop to be given by a law which is approximate to the form

$$\left(\frac{L}{43D}\right)^{1.85}$$

multiplied by the velocity head, where L and D are the tube lengths and inside diameter respectively. For the figures given above of a tube length of 121" and an inside diameter of 0.527" the law simplifies to 22.0 multiplied by the velocity head. To this I have added a loss due to the steam passing through the orifice at the entrance to the tube. I have calculated that the loss due to the orifice is 0.2 multiplied by the velocity head and therefore the pressure loss coefficient is 22.2. It follows that the pressure drop through a tube in the first row is 22.2 multiplied by the velocity head of the steam in inches of water gauge for that tube $=5.40\times 22.2=120$ in. water gauge. Similarly, the pressure drop in a tube of the second row equals $3.02\times 22.2=67$ in. water gauge.

A pressure of 15 lb./sq. in. is approximately 415 inches water gauge and therefore the pressure in the steam header **16** is 415 in. water gauge whereas the pressure in the first condensate header **19** is 415—120=295 in. water gauge and the pressure in the second condensate header **22** is 415—67=348 in. water gauge. There is therefore a difference in pressure between the two condensate headers **19** and **22** of 53 in. of water gauge. It will be seen that, according to my invention, I permit the pressure drop across each row of tubes to be independent of the pressure drop across the other row and that I maintain the pressure drops at values determined by the quantity of steam condensed in the respective rows. Thus less steam is condensed in the second row than in the first row and therefore the pressure drop across the first row is more than the pressure drop across the second row.

In conventional apparatus a common steam header and a common condensate header are provided so that the condensate ends of the tubes of both rows are in communication. I believe that the column of condensate which I have found is held in the tubes of the first row is due to the differences in the pressure drops in the tubes and to the use of a common condensate header.

Referring now to FIGURE 4 there is shown a conventional construction of heater coil in which freezing readily occurs in the tubes of the first row. The tubes are held within a framework and are connected between a common steam header **50** and a common condensate header **51**. A first row of tubes is indicated at **52** and a second row of tubes at **53** and cold air is passed through the tubes in the direction of the arrow X. Condensate delivered to the common condensate header **51** leaves through a conduit **54** and passes to a trap **55** and thence to a hot well (not shown) through a pipe **56**.

In this arrangement I believe that the pressure difference between the steam header **50** and the condensate header **51** will be determined by the pressure drop across the second row of tubes **53**. For a row of coils of similar size to those discussed above, this pressure drop across the second row will be approximately that calculated above, i.e. 67 inches of water gauge when the entering air has a temperature of —40° F. and is flowing at a velocity of 700 f.p.m. If the pressure in the condensate header were more than 67" water gauge below the steam header pressure, then more steam would pass through the second row of tubes. However, no more steam can pass through the tubes since the above calculations show that the tubes have condensed all they can with a pressure drop of 67 inches of water gauge and any further steam that is unable to pass through the trap **55** would merely increase the pressure in the condensate header **51**.

It follows that the pressure in the common condensate header **51** is, using the figures quoted above, 415—67=348 inches of water gauge above atmospheric pressure. However, due to the higher rate of condensation in the first row of tubes than in the second row, the pressure drop across the first row is 120 inches of water gauge and therefore in order to provide the extra pressure across the first row so that the pressure at the bottoms of the tubes of the first row is 348 inches of water gauge, a leg of condensate forms in the lower part of each tube of the first row. If the first row of tubes were supplied with a separate condensate header, the pressure in the header would be 415—120=295 inches of water gauge above atmospheric pressure. Therefore, when the tubes of the first row are connected to a condensate header having therein

a pressure of 348 inches of water gauge, the height of the leg of condensate in each tube of the first row will be the difference between 348 inches water gauge and 295 inches water gauge, i.e. 53 inches water gauge. There will thus be a condensate leg of 53 inches of water in each tube of the first row. As described above, this condensate leg can be eliminated by ensuring that the first row has a separate steam trap whereby the pressure drop across the first row can be maintained independently of the pressure drop across the second row of tubes.

In practice the water column will be somewhat less than that calculated since it will reduce the effectiveness of heat transfer of the lower sections of the first row of tubes so that the steam required in the first row of tubes will be somewhat less than calculated above. The steam required in the second row of tubes will be somewhat more than calculated above since the water in the bottoms of the first row of tubes will impose a greater load on the bottoms of the second row of tubes. However, it is believed that this does not affect the essential conclusions of the above calculations which is that there will be a difference between the pressure drops in the tubes of the two rows due to the differing amounts of steam condensed and that this difference must be equalized by a leg of condensate which may freeze and burst the tubes.

It will be seen that the invention provides a simple means of obviating a heretofore undesirable and dangerous condition.

An important advantage of the invention is that the tubes of the first and second rows can be connected to a common steam header so that the steam pressure applied to each row of tubes can be the same and no freezing will occur since the pressure drop across each row of tubes is independent of the pressure drop across the other row.

It will be understood that the form of the invention herewith shown and described is a preferred example and that various modifications may be carried out without departing from the spirit of the invention or the scope of the appended claims.

What I claim as my invention is:

1. Apparatus for passing steam in heat exchange relationship with air having an initial temperature below the freezing point of water, said apparatus comprising a plurality of vertically extending heat exchanger tubes arranged in first and second rows, the second row being arranged behind the first row, means to propel a stream of air substantially horizontally across the exterior surfaces of said tubes so that the air passes across the tubes in the first row before passing across the tubes in the second row, means to supply steam to the top end of each of said tubes for flow through the tubes, separate first and second condensate headers, the first header being connected to the bottoms of the tubes of the first row and isolated from the second header which is connected to the bottoms of the tubes of the second row, separate first and second traps to prevent escape of steam but to discharge condensate, first conduit means interconnecting the first header and the first trap and second conduit means isolated from the first conduit means and interconnecting the second header and the second trap.

2. Apparatus for passing steam in heat exchange relationship with air comprising a plurality of heat exchanger tubes arranged in first and second rows, the second row being arranged behind the first row, a common header connected to all said tubes at one end, separate first and second condensate headers, the first condensate header being connected to the other ends of the tubes of the first row and isolated from the second condensate header which is connected to the other ends of the tubes of the second row, separate first and second traps to prevent escape of steam but to discharge condensate, said first and second traps being respectively and separately connected to said first and second condensate headers.

3. Apparatus for passing steam in heat exchange relationship with air having an initial temperature below the freezing point of water, said apparatus comprising a plurality of vertically extending heat exchanger tubes arranged in first and second rows, the second row being arranged behind the first row, means to propel a stream of air substantially horizontally across the exterior surfaces of said tubes so that the air passes across the tubes in the first row before passing across the tubes in the second row, a common header connected to the top ends of all of said tubes, means to supply steam to said common header for flow through the tubes, separate first and second condensate headers, the first condensate header being connected to the bottom ends of the tubes of the first row and isolated from the second condensate header which is connected to the bottom ends of the tubes of the second row, separate first and second steam traps to prevent escape of steam but to discharge condensate, first conduit means interconnecting the first condensate header and the first trap and second conduit means isolated from the first conduit means and interconnecting the second condensate header and the second trap.

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