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Lazaridis et al.

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[54] **JET IMPINGEMENT RECUPERATOR**

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[51] **Int. Cl.**.......................... **F24c 3/00;** F28d 7/10

[58] **Field of Search**.......... 126/116 R, 91 A, 116 A; 432/222, 223; 165/76, 154, 174, 184; 431/350

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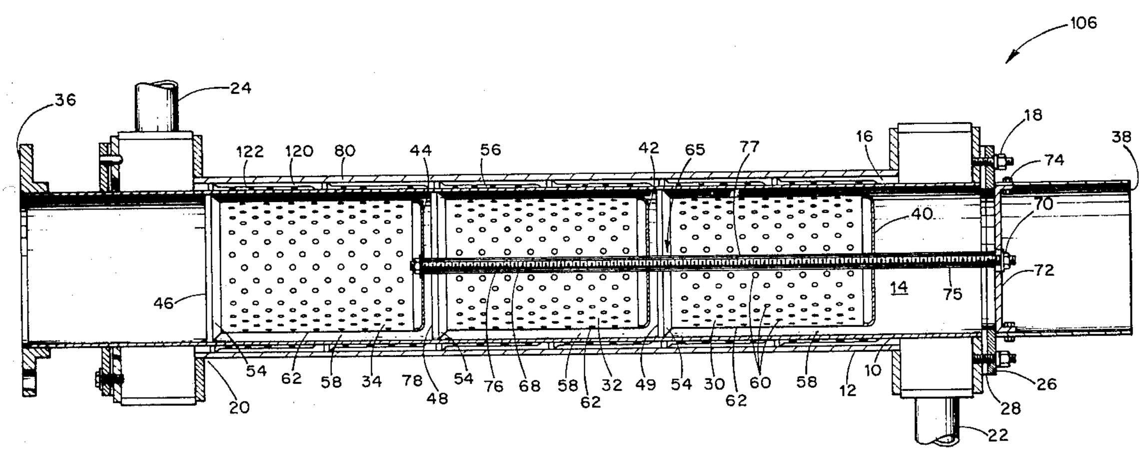
[57] **ABSTRACT**

A recuperative heat exchanger employs a jet impingement technique for transferring heat from hot combustion products to cool combustion air. An interior conduit of the heat exchanger contains baffles for producing this jet impingement effect. The baffles are secured in place during operation of the heat exchanger by a thermally expansible lip on the open end of each baffle. When the heat exchanger is not in operation the baffles may be removed for cleaning or replacement. Certain embodiments of this heat exchanger are specifically suited for use with a radiant tube furnace requiring a low pressure drop through the recuperator.

16 Claims, 3 Drawing Figures



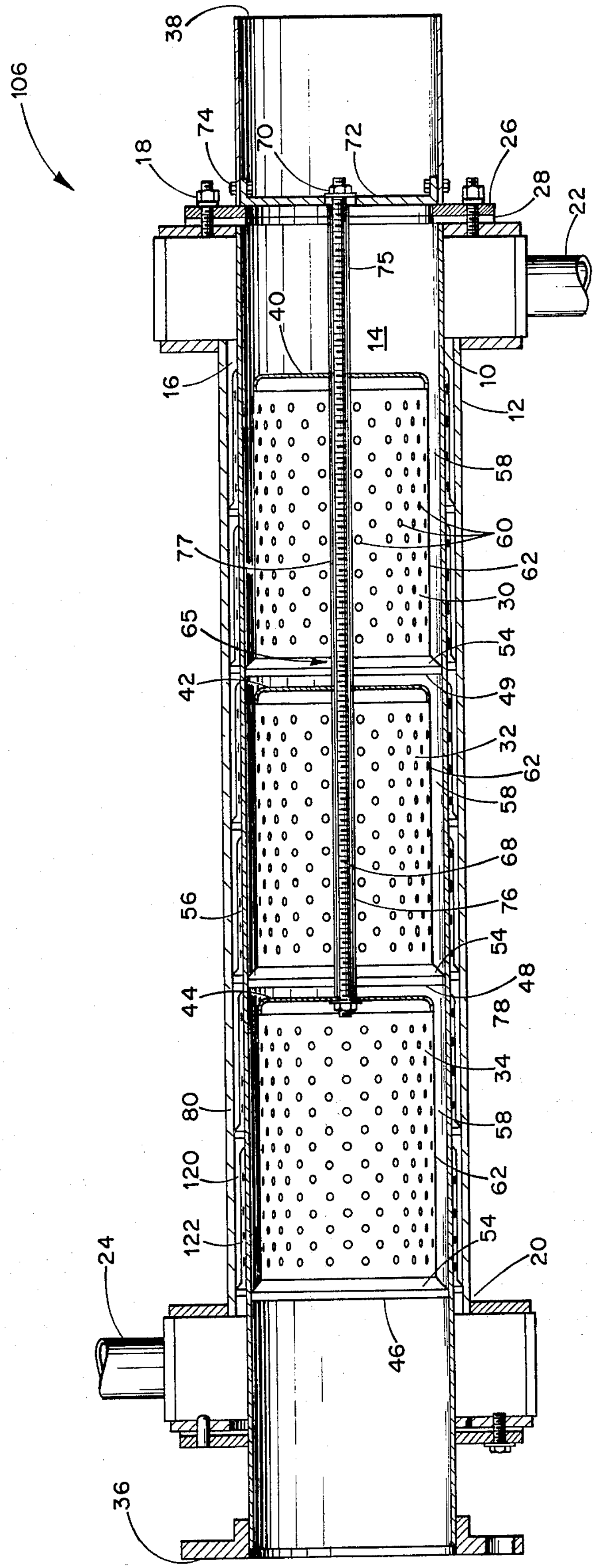

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Fig. 1.

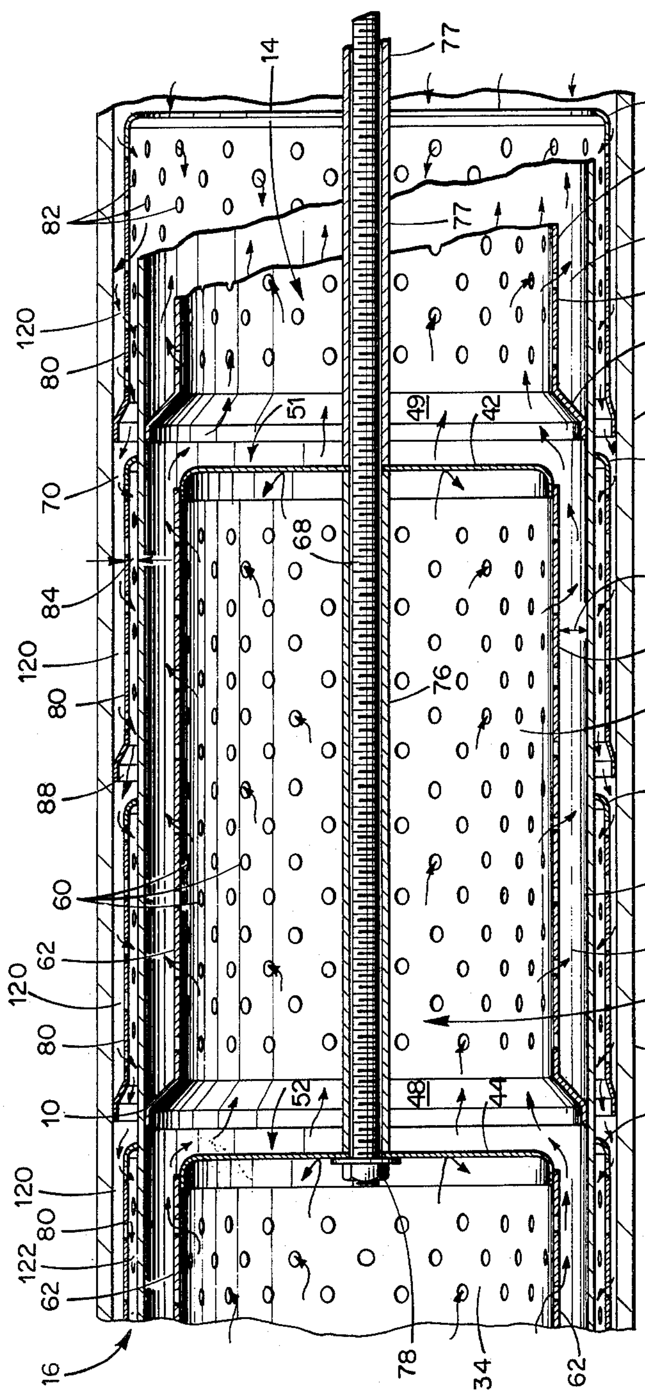

Fig. 2.

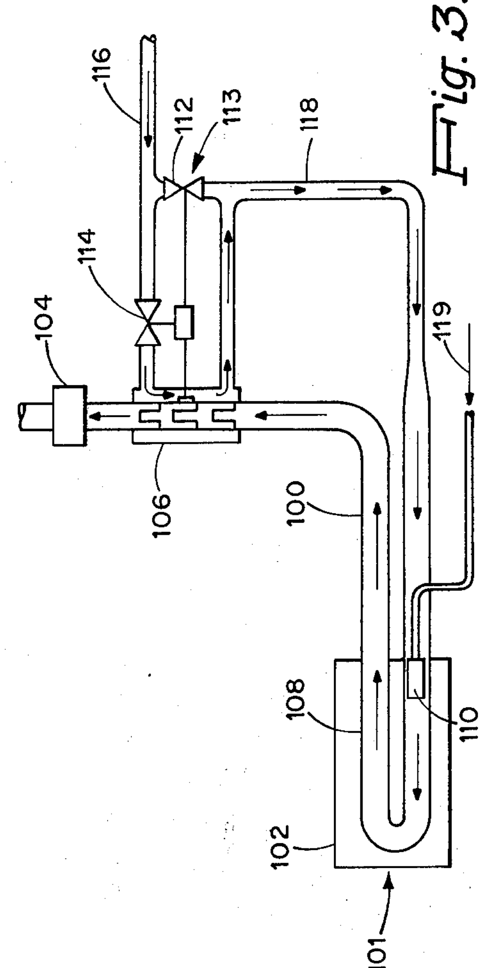

Fig. 3.

JET IMPINGEMENT RECUPERATOR

BACKGROUND OF THE INVENTION

Because of the current energy shortage, it is becoming increasingly important to reduce fuel consumption through more efficient combustion. A practical means of producing more efficient burning of fuels is through the use of a heat exchanger to preheat the fuels or air by placing them in proximity with the hot exhaust gases.

In radiant tube furnaces, 60 percent of the input energy is usually lost to the atmosphere if recuperation is not used, but many heat exchange devices that are now available are too expensive and too inefficient to justify, from an economic point of view, whatever savings in fuel that may result from their use. One way to obtain efficient preheating of the fuel in a multiple tube radiant tube furnace is to employ one large heat exchanger for all of the radiant tubes and channel all exhaust gases into it and all pre-combustion air through and out of it into each radiant tube. However, this method involves great installation costs, complex apparatus and resulting maintenance problems, a large space requirement because of the size of the system, and heat loss in the connecting pipes.

Another way to preheat fuel or air is to build a heat exchanger to fit each radiant tube so that the operation of each tube is independent of any other. However, prior art devices adapted for use with radiant tubes are typically expensive and characterized by a low heat transfer coefficient. Thus, there is a need for an inexpensive recuperative heat exchanger that is small enough to be fitted onto one radiant tube yet efficient enough to produce high heat transfer coefficients.

One problem with any recuperative heat exchanger is that components in contact with hot flue gases tend to wear out rather quickly and must be replaced. If these components are not easily removable, the entire heat exchanger has a short life and replacement costs become high.

Another problem with radiant tube heat exchangers is that they tend to develop deposits in the hot flue gas conduit during the period that the radiant tube is warming up. This phenomenon occurs because the gases are not yet hot and are easily cooled by the relatively cool air flowing through the outer conduit. This condensation process can drastically reduce the operating life of the heat exchanger.

Within many radiant tube furnaces the composition of the atmosphere surrounding the radiant tubes is closely controlled and it is highly undesirable for flue gases to leak from the radiant tube and to contaminate the furnace's controlled atmosphere. Pin holes and other small fissures tend to develop in a radiant tube while it is in use. Leakage resulting therefrom can be eliminated by minimizing the pressure differential between the interior of the radiant tube and the furnace's atmosphere filled volume. This low pressure differential although easy to be achieved in the case of a non-recuperative radiant tube can only be achieved whenever a recuperator is being used, if the pressure drop through the recuperative heat exchanger is also minimized. Too great a reduction in the flue-gas-side pressure drop tends however to result in an unacceptably low heat transfer coefficient for the heat exchanger if conventional heat transfer techniques are to be employed.

SUMMARY OF THE INVENTION

This invention relates to heat exchangers or recuperators generally and to jet impingement recuperators specifically. A general object of this invention is to reduce fuel consumption by providing an efficient and economical means of heating combustion air prior to entry into a burner. Another object is to provide small and economical recuperators which may be individually associated with a radiant tube furnace. Another object of the invention is to construct a recuperator so that vital and sensitive parts may be easily replaced or removed for servicing and cleaning.

This recuperator includes two concentric cylindrical tubes which define two separate flow conduits for two gases. One conduit is through the inner tube and the other conduit is through the annular space between the two tubes. These gases are confined on either side of the wall of the inner tube which acts as a heat exchange surface. Each conduit contains a set of cylindrical perforated baffles through which gases are forced. These gases then impinge upon the heat exchange surface in a plurality of small jets to produce efficient heat exchange between the two gases. In the preferred embodiment, the combustion products flow through the central conduit while the relatively cooler combustion air destined for the burner passes through the outer conduit defined by the annular space between the two cylinders in an opposed flow mode. When the recuperator is mounted upon a radiant tube heater, the inner tube of the recuperator may be merely an extension of the radiant tube itself.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a preferred embodiment of the heat exchanger;

FIG. 2 is a cut-away view illustrating the baffles in the interior and exterior conduits and the flow of gases through them; and

FIG. 3 is a schematic diagram showing the heat exchanger of FIG. 1 in conjunction with a radiant tube furnace.

DETAILED DESCRIPTION OF THE DRAWINGS

FIGS. 1 and 2 illustrate a preferred embodiment of a heat exchanger **106**. The heat exchanger consists of two concentric tubes, an inner tube **10** and an outer tube **12**. These tubes **10** and **12** may be of any convenient shape, but the preferred shape is cylindrical. Tubes **10** and **12** define two conduits, an exterior conduit **16** in the annular space between the tubes **10** and **12** and an interior conduit **14** within the inner tube **10**. The interior conduit **14** is adapted for a flow of relatively hot gases from an inlet end **36** of the interior conduit **14** to an outlet end **38** thereof, while the exterior conduit **16** is adapted for a flow of relatively cool gases from an inlet port **22** to an outlet port **24**. A portion of the inner tube **10** forms a heat exchange wall **56** with heat exchange surfaces along each side thereof. The outer tube **12** is attached and sealed to the inner tube **10** by members **18** and **20** and a gasket **28**. The only permitted flow of relatively cool gases is in the inlet port **22** and out the outlet port **24**.

The interior conduit **14** contains a longitudinally stacked series of perforated baffles **30, 32** and **34**, concentric with and wholly contained within the inner tube **10**. The cross sectional shape of the baffles **30, 32** and

34 should be the same as that of the tubes **10** and **12.** The shape preferably is cylindrical. The total number of baffles used in series depends on the requirements of the heat exchanger, since the number is a function of the allowable pressure drop from the inlet end **36** to the outlet end **38** of the inner conduit **14.** The baffles **30,** 32 and **34** have closed ends **40, 42** and **44,** respectively, facing the outlet end **38** of the interior conduit **14,** and open ends **46, 48** and **49,** respectively, facing the inlet end **36.** The open end of each baffle includes a thermally expansible protruding lip **54** which expands to engage the heat exchange wall **56** during operation of the heat exchanger **106** in response to the resulting temperature increase. This lip **54** prevents gases from entering the space **58** between the baffle and heat exchange wall **56** except through openings **60** on side walls **62** of the baffles **30, 32** and **34.** The openings **60** may be of any suitable shape but are preferably substantially circular. Each such wall **62** is so aligned that gases flowing from the inlet end **30** to the outlet end **38** must pass through the openings **60** and impinge on the heat exchange wall **56** to form a plurality of jets. The side walls **62** are separated from the heat exchange wall **56** by a distance **64** the value of which depends upon the requirements of the particular use to which the heat exchanger is intended.

The baffles **30, 32** and **34** are stacked within the interior conduit **14** so that the separation between the closed end of one baffle and the adjacent open end of the next baffle is sufficiently large to permit the unimpeded flow of gases between the baffles without any discernible loss of pressure. Baffles **30** and **32** are secured to a rod **68** which passes through a hole in their closed ends **40** and **42** and extends through the baffles along their longitudinal axes. The rod ends at the closed end **44** of the baffle **34** where it is securely attached by a washer and nut assembly **78.** The attachment of the closed end **44** to the rod **68** may also be effected by a weld.

The baffles **30, 32** and **34** may be held in place in several ways. They may be welded to the rod **68.** Also, they may rest on cylindrical sleeves **75, 76** and **77** which are only slightly larger in diameter than the rod **68** and surround it. One end of the sleeve **76** abuts the top of the baffle **34** and the other rests against the baffle **32.** In a like manner, sleeve **77** separates baffles **32** and **30** while sleeve **75** separates the baffle **30** and a spider arrangement **72.**

The end of the rod **68** which faces the outlet end **38** of the interior conduit **14** is attached to the inner tube **10** by means of a pronged spider **72.** The rod **68** is either welded or bolted, in a manner similar to that used to secure the baffle **34** to the other end of the rod **68.** The prongs of the spider **72** are bolted to the wall of the inner tube **10** at ends **74.**

The entire baffle assembly including elements **30, 32, 34** and **68,** hereafter designated assembly **65,** may be removed for cleaning, repair or replacement. When the heat exchanger is not in operation, the protruding lips **54** contract and the assembly **65** is supported only by the spider **72.** Thus, if the bolt **70** or the bolts at the end of each prong **74** are removed, the entire baffle assembly **65** can be easily extracted. The individual baffles can then be separated and the various parts cleaned or replaced.

The exterior conduit **16** also contains a stacked series of baffles **80** which contain openings **82** and which are intermediate and concentric with the tubes **10** and **12.** The baffles **80** have the cross sectional shape of the tubes **10** and **12.** The openings may be of any suitable shape but are preferably substantially circular. This spacing of the baffles **80** from the heat transfer surface depends on the requirements of the recuperator. These baffles **80** may be welded to the outer tube **12** along one rim **88** while the other rim **90** rests against the wall of the inner tube **10** where an airtight seal is formed by thermal expansion and an interference fit of the rim **90** when the heat exchanger **106** is functioning. The baffles **80** are aligned so that the welded rim **88** is closer to the outlet port **24** than is the free rim **90** and so that gases flowing from the inlet port **22** to the outlet port **24** will be forced to pass through the openings **82** and impinge upon the heat exchange wall **56** in a plurality of jets. The positioning of these baffles **80** results in the formation of a series of annular plenum chambers **120** adjacent to the outer tube **12** and another series of annular plenum chambers **122** adjacent to the inner tube.

FIG. 3 depicts a preferred embodiment of the heat exchanger **106** as a recuperator in a radiant tube furnace **101.** The radiant tube furnace **101** comprises a furnace enclosure **102** and a radiant tube means **108.** The radiant tube means **108** comprises a fuel burner means **110,** a valve means **113** for controlling the flow of combustion air into the burner means **110,** a tube **100** for conducting combustion products from the furnace **101** to the heat exchanger **106,** an inlet **119** for introducing fuel into the burner, a blower means **104** for drawing combustion products out of the radiant tube **108,** and a heat exchanger **106** for heating combustion air prior to its entry into the burner means **110.** The heat exchanger **106** is small enough to be easily attached to a single radiant tube means **108.** In fact, diameter of the radiant tube means **108** may equal the diameter of the inner tube **10.**

In a controlled atmosphere radiant tube furnace it is desirable to maintain a pressure differential from the interior of the radiant tube **108** to an atmosphere of a furnace enclosure **102** which approximates zero. The creation of the negligible pressure differential is necessary to minimize leakage of combustion products from within the radiant tube **108** into the atmosphere of the furnace enclosure **102** through cracks and holes that may develop. A suction blower means **104** may be used to evacuate the combustion products from the interior of the radiant tube **108** and to lower the pressure therein. Primarily, the heat exchanger is so designed that there is a very low pressure drop through the interior conduit **14,** a necessary condition for the creation of a low pressure differential from the interior of the radiant tube **108** to an atmosphere of a furnace enclosure **102.** It is desirable to establish a pressure drop across the interior conduit **14** of the recuperator **106** not greater than 1 inch of H_2O if the low pressure differential across the wall of the radiant tube **108** is to be maintained. A pressure drop of 0.1 inch of H_2O is preferred. This must be obtained with a typical radiant tube heat input of 100,000–800,000 BTU/hr. Such a low pressure drop produces a relatively low velocity flow of gases through the openings **60** which may be laminar in nature throughout the interior conduit **14.** The number of baffles in the interior conduit **14** is preferably from one to three. The resulting compact recuperator may be 36 inches or less in length.

The openings **60** in the baffles **30, 32, 34** preferably are substantially circular, but they may be of other shapes. Each opening **60** should be separated from the heat exchange surface **56** by a distance **64** having a ratio to the hydraulic diameter of the opening not less than one or greater than four. Openings **60** are preferably spaced in a diamond-shaped configuration. The ratio of the distance between opening centers to the hydraulic diameters of the openings should not be less than two or greater than seven. An optimum hydraulic opening diameter lies between one-eighth and one-half inch.

In the exterior conduit **16,** although the magnitude of the pressure drop from the injection port **22** to the extraction port **24** is not as critical as in the interior conduit **14,** the pressure drop preferably does not exceed 10 inches of water. Thus, the flow of gases through the exterior conduit **16** is also of relatively low velocity and may be liminar in nature. The openings **82** in the baffles **80** should be substantially circular, but they may also be of other shapes. The openings **82** should be separated from the heat exchange surface **56** by a distance **84** whose ratio to a hydraulic diameter of an opening **82** is not less than one or greater than three. The openings **82** are preferably spaced in a diamond-shaped configuration, and the ratio of the distance between opening centers to the hydraulic diameter of the openings should be not less than two or greater than six. An optimum hydraulic diameter is between one-sixteenth and one-fourth inch.

The configuration and special arrangement of the openings **60** and **80** are defined in terms of hydraulic diameter. This term, employed in fluid dynamic technology, is used here since it is applicable both to circular and non-circular openings. The hydraulic diameter of an opening is defined as 4 times its cross-sectional area divided by its perimeter. The hydraulic diameter of a circle equals its diameter. It is important that each jet formed by the gases passing through an opening in a baffle have a minimum of interference with any other jet formed by that baffle, and that each such jet impinge directly upon the heat exchange wall **56.** Maximum heat exchange coefficients will be achieved when interference is minimized and the gaseous flow maximized.

The operation of the heat exchanger **106** of FIGS. **1** and **2** in conjunction with a radiant tube means **108** illustrated in FIG. **3** will now be discussed. Combustion air enters the system through a pipe **116** and passes to a valve means **113** including a first valve **112** and a second valve **114.** It is either directed to the burner through the second valve **114** or to the exterior conduit of the heat exchanger **106** through the first valve **112.** Thereafter, it is introduced into the burner.

The valve means **113** serves three functions. First, during start up, the combustion products in the inner conduit **14** are not yet hot, and if cooler combustion air is allowed to circulate in the exterior conduit **16,** the combustion products are cooled to a point where condensation of certain of the combustion products occurs. This is highly undesirable, so during these periods, the cooler combustion air is not allowed to enter into the exterior conduit **16** but is diverted directly to the burner means **110** through the second valve **114** while the first valve is closed. Secondly, the ratio of cool to preheated combustion air entering the burner means **40** may be varied to regulate the temperature in the radiant tube **108.** In many conditions, after an initial startup period, all air will be directed through the exterior conduit **16.** Thirdly, the amount of air entering the exterior conduit **16** through the first valve **112** may be regulated to influence the temperature of the heat exchanger **106.**

The combustion air that passes through the valve means **113** enters the exterior conduit **16** at its injection port **22** and proceeds into an annular plenum chamber **120.** The combustion air is forced through the openings **82** in the baffle **80,** thus forming a plurality of jets which impinge upon the heat exchange wall **56.** Thereafter, the air is forced from the plenum chamber **122** adjacent the heat exchange wall into the next plenum chamber **120** in the series. The combustion air is again forced through the openings **82** as jets and this flow pattern continues until the combustion air reaches the exhaust port **24** of the exterior conduit **16.** The combustion air then passes through a pipe **118** to the burner means **110.** The resulting combustion products then pass through the length of the radiant tube **108** heating it. Thereafter, they reach the heat exchanger **106.**

The inner tube **10** of the heat exchanger **106** is an extension of the radiant tube **108.** The inner tube **10,** tube **100** and radiant tube **108** may actually be integral. Combustion products enter the inlet end **36** of the interior conduit **14** and are forced through the baffles **30,** 32, 34, thus forming a plurality of jets which impinge upon the heat exchange wall **56.** Heat is transferred from these jets to the heat exchange wall **56** and thence to the cool jets in exterior conduit **16** impinging on the other side of the heat exchange wall. Subsequently combustion products are exhausted through the outlet end **38.** The baffles **30, 32, 34** become heated and radiate energy to the heat exchange wall **56** in significant quantities. This total radiation transfer may contribute up to 40 percent of the total heat transfer in the heat exchanger **116.**

The protruding lip **54** on the open ends **46, 48, 49** of each baffle expands in response to an increase in temperature caused by contact with the hot combustion products. The lip **54** then sealingly engages the heat exchange wall **56.** Thus combustion products are prevented from entering the space **61** between the baffles and the heat exchange wall without passing through the openings **60.**

The direction of flow of the combustion products in the interior conduit **14** should be counter to the flow of the combustion air in the exterior conduit **16** to promote the most efficient exchange of heat between the combustion air and the combustion products. However, the flows may be parallel and still permit heat exchange.

In operation, the heat exchanger **106** has produced heat transfer coefficients of 13.5 BTU/°F. This effectiveness makes possible the small recuperative heat exchanger capable of fitting directly into the radiant tube **108.** Installation is reiatively simple and inexpensive. The result is a low equipment cost. In addition, the removeability of the baffles **30, 32, 34** cuts the replacement and maintenance costs significantly. Finally, this heat exchanger provides substantially reduced fuel consumption.

While this invention has been described with respect to the details of various specific embodiments, many changes and variations which can be made without departing from the scope of the invention will be apparent to those skilled in the art.

I claim:

1. A controlled atmosphere radiant tube heating device comprising a fuel burner means, air intake means for injection of combustion air into the burner means, a radiant tube heated by combustion products from the burner means, an exhaust tube for conducting combustion products from the radiant tube, a length of the wall of the exhaust tube forming a heat exchange surface on each side thereof, an outer tube concentric with and surrounding the exhaust tube forming an exterior conduit for confining a flow of combustion air adjacent the heat exchange surface, means for directing the flow of combustion air into the exterior conduit at an inlet end thereof, means for directing the flow of combustion air from the exterior conduit at an outlet end thereof to the burner means, baffle means interior of the exhaust tube, the baffle means having openings therein for directing jets of combustion products onto said length of the wall, the openings having hydraulic diameters not less than one-eighth inch and not greater than one-half inch, the ratio of separation of centers of mass of the openings to the hydraulic diameter of the openings being not less than two or more than seven.

2. A radiant tube heat exchanger as defined in claim 1 wherein the exterior conduit contains second baffle means having openings therein for directing jets of the combustion air onto the heat exchange surface.

3. A radiant tube heat exchanger as defined in claim 1 wherein the ratio of the separation of an opening in the baffle means from the heat exchange surface to the hydraulic diameter of the opening is not less than one or greater than four.

4. A radiant tube heat exchanger as defined in claim 1 wherein the spatial pattern of the openings in the baffle means is diamond shaped.

5. A radiant tube heat exchanger as defined in claim 2 wherein the second baffle means comprises a plurality of sections aligned such that one end of each section is closer than the other end to the inlet end of the exterior conduit, and wherein for each section one end is fixedly attached to either the exhaust tube or the outer tube while the other end of each section comprises thermally expansible means for sealingly engaging the wall of the other tube means.

6. A radiant tube heat exchanger as defined in claim 5 adapted for laminar flow in the exterior conduit and a low pressure drop from the inlet end to the outlet end thereof wherein the second baffle means in the exterior conduit comprises not more than eight annular baffle plates dividing the exterior conduit into a series of annular plenum chambers, the plenum chambers and the openings in the baffle plates constituting the sole passage for the flow of combustion air through the exterior conduit.

7. A radiant tube heat exchanger as defined in claim 6 wherein an optimal ratio of the separation of an opening in the second baffle means from the heat exchange surface to the hydraulic diameter of such an opening is not less than one or greater than three.

8. A radiant tube heat exchanger as defined in claim 6 wherein an optimal hydraulic diameter of the openings in the second baffle means is not less than one-sixteenth inch or greater than one-fourth inch.

9. A radiant tube heat exchanger as defined in claim 6 wherein an optimal ratio of a distance between centers of the openings in the second baffle means to the hydraulic diameter of such an opening in the second baffle means is not less than two or greater than six.

10. A radiant tube heat exchanger as defined in claim 6 wherein an optimal spatial pattern of the openings in the second baffle means is diamond shaped.

11. A radiant tube heat exchanger as defined in claim 6 wherein the openings in the first said baffle means are substantially circular in shape.

12. A radiant tube heat exchanger as defined in claim 6 wherein the openings in the second baffle means are substantially circular in shape.

13. A radiant tube heat exchanger as defined in claim 1 wherein said baffle means comprises a series of baffles; further comprising a rod extending centrally through each baffle in the series and attached thereto for enabling the extraction as a unit of the series of baffles from the exhaust tube, thermally expansible sealing means on each baffle in the series of baffles along the portion thereof facing the injection end of the exhaust tube for sealingly engaging the heat exchange surface only in response to temperature above a predetermined temperature.

14. A controlled atmosphere radiant tube heating device comprising a fuel burner means having a heat output between 100,000 and 800,000 BTU/hr., air intake means for injection of combustion air into the burner means, an enclosure adapted to confine a controlled atmosphere, a radiant tube within the enclosure, the radiant tube confining and being heated by combustion products from the burner means, an exhaust tube for conducting combustion products from the radiant tube, a length of the wall of the exhaust tube forming a heat exchange surface on each side thereof, an outer tube concentric with and surrounding the exhaust tube forming an exterior conduit for confining a flow of combustion air adjacent the heat exchange surface, means for directing the flow of combustion air into the exterior conduit at an inlet end thereof, means for directing the flow of combustion air from the exterior conduit at an outlet end thereof to the burner means, baffle means interior of the exhaust tube for producing a pressure drop not substantially greater than 0.1 inch of water across the exhaust tube, the baffle means having openings therein for directing jets of combustion products onto said length of the wall, the openings having hydraulic diameters not less than one-eighth inch and not greater than one-half inch, the ratio of separation of centers of mass of the openings to the hydraulic diameter of the openings being not less than two or more than seven, each baffle opening being separated from the adjacent heat exchange surface by a distance not less than the hydraulic diameter of the opening or more than 4 times the hydraulic diameter of the opening.

15. A radiant tube heat exchanger as defined in claim 14 wherein the exterior conduit contains second baffle means having openings therein for directing jets of the combustion air onto the heat exchange surface.

16. A radiant tube heat exchanger as defined in claim 15 wherein the second baffle means comprises a plurality of sections aligned such that one end of each section is closer than the other end to the inlet end of the exterior conduit, and wherein for each section one end is fixedly attached to either the exhaust tube or the outer tube while the other end of each section comprises thermally expansible means for sealingly engaging the wall of the other tube means.

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