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Shefsiek et al.

[11] **3,859,040**

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[54] **RECUPERATOR FOR GAS-FIRED RADIANT TUBE FURNACE**

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[73] Assignee: **Holcroft & Company,** Livonia, Mich.

[22] Filed: **Oct. 11, 1973**

[21] Appl. No.: **405,442**

[52] **U.S. Cl.** .... **432/214,** 110/97 D, 165/154
[51] **Int. Cl.** **F23l 15/04**
[58] **Field of Search** .... 432/214, 223; 165/154; 110/97 D

[56] **References Cited**

UNITED STATES PATENTS

1,344,437	6/1920	Buell, Jr.	432/179
2,969,967	1/1961	Buhrer et al.	165/155 X
3,189,086	6/1965	Esser et al.	165/155 X
3,195,623	7/1965	Chapin	165/154 X

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Attorney, Agent, or Firm—Whittemore, Hulbert & Belknap

[57] **ABSTRACT**

The recuperator unit is shown in association with a gas-fired furnace of the closed loop radiator type, (specifically U-shaped) as a substitute for the usual furnace exhaust stack or flue. It incorporates a set of vertically elongated internal, axially telescoped and radially spaced cylindrical wall or shell members, of which three optionally define a bidirectional passage for a continuous flow of blower-supplied air to be preheated prior to its combustion with a heating gas. The path of flow of the air upon entry from the blower line and in being preheated is initially upward through an annular, radially outer passage zone of the recuperator, thence downwardly upon reversal in a parallel annular flow through a radially inner passage or zone, thence radially outwardly to the hot air discharge piping of the unit and the furnace radiator. The radial spacing of the shell structure which defines the air flow path, and its heat transfer relation to a combusted air discharge flow from the radiator, is arrived at as the result of a careful combination of empirical and mathematical constraint considerations. The recuperator has a well-insulated external stack wall structure within which said radially spaced shells are disposed; and an upright and vertically elongated ceramic core member is positioned within the innermost of the wall parts or shells above referred to, controlling an upward flow of gaseous products of combustion issuing from the furnace's radiator loop.

17 Claims, 5 Drawing Figures

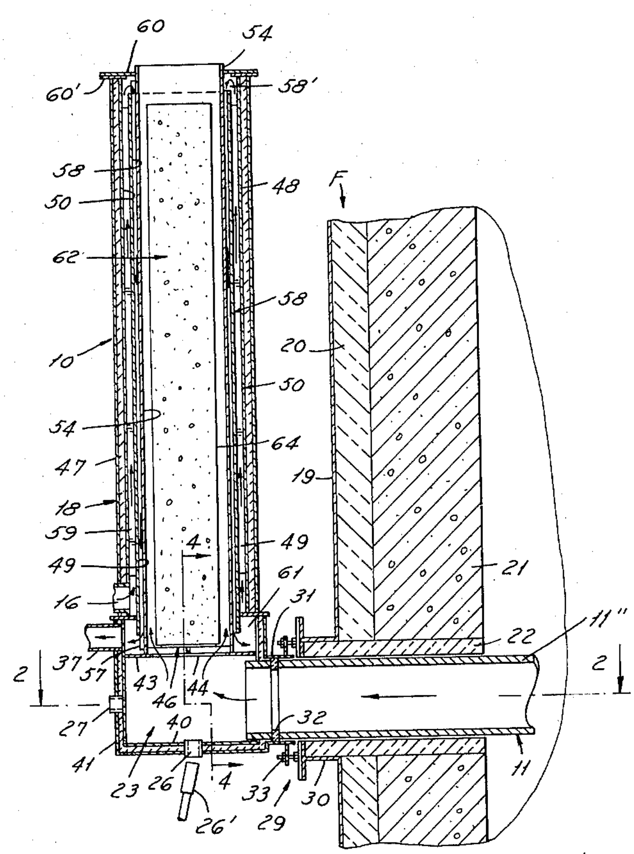


FIG.1

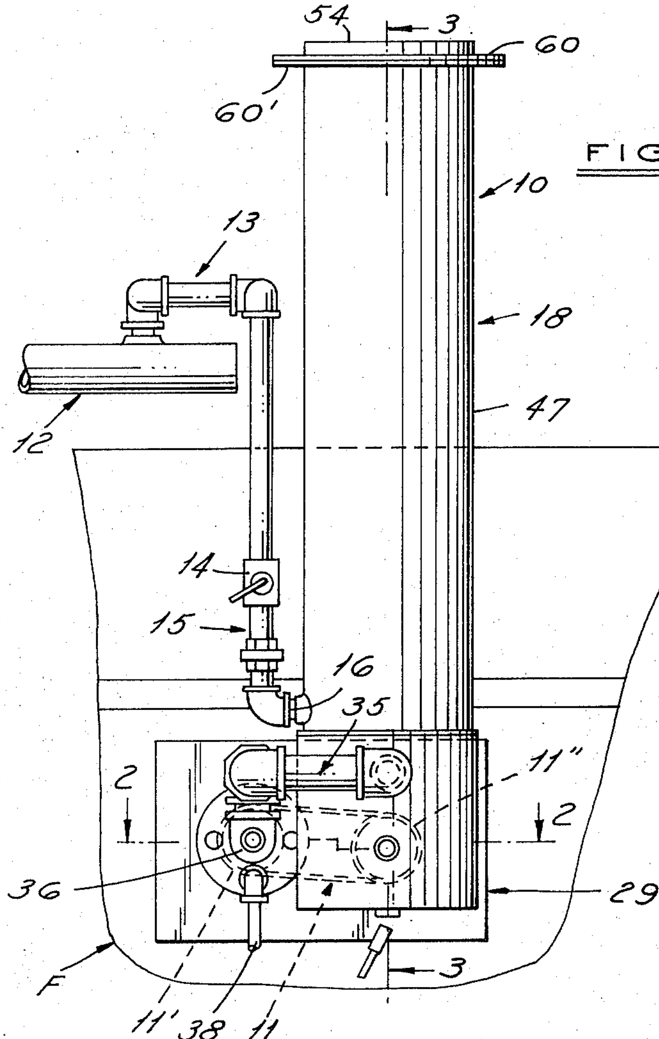

54
3
60
60'
10
13
18
12
47
14
15
16
35
11"
2
2
36
29
F
3
11'
38
11

FIG.2

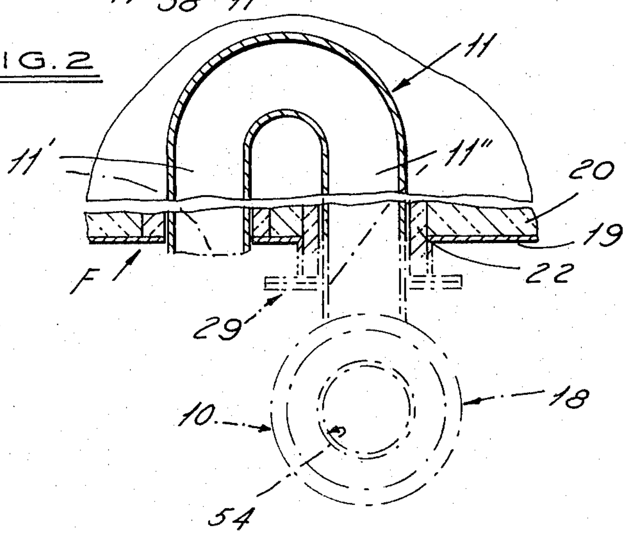

11
11'
11"
20
19
F
22
29
18
10
54

FIG. 3

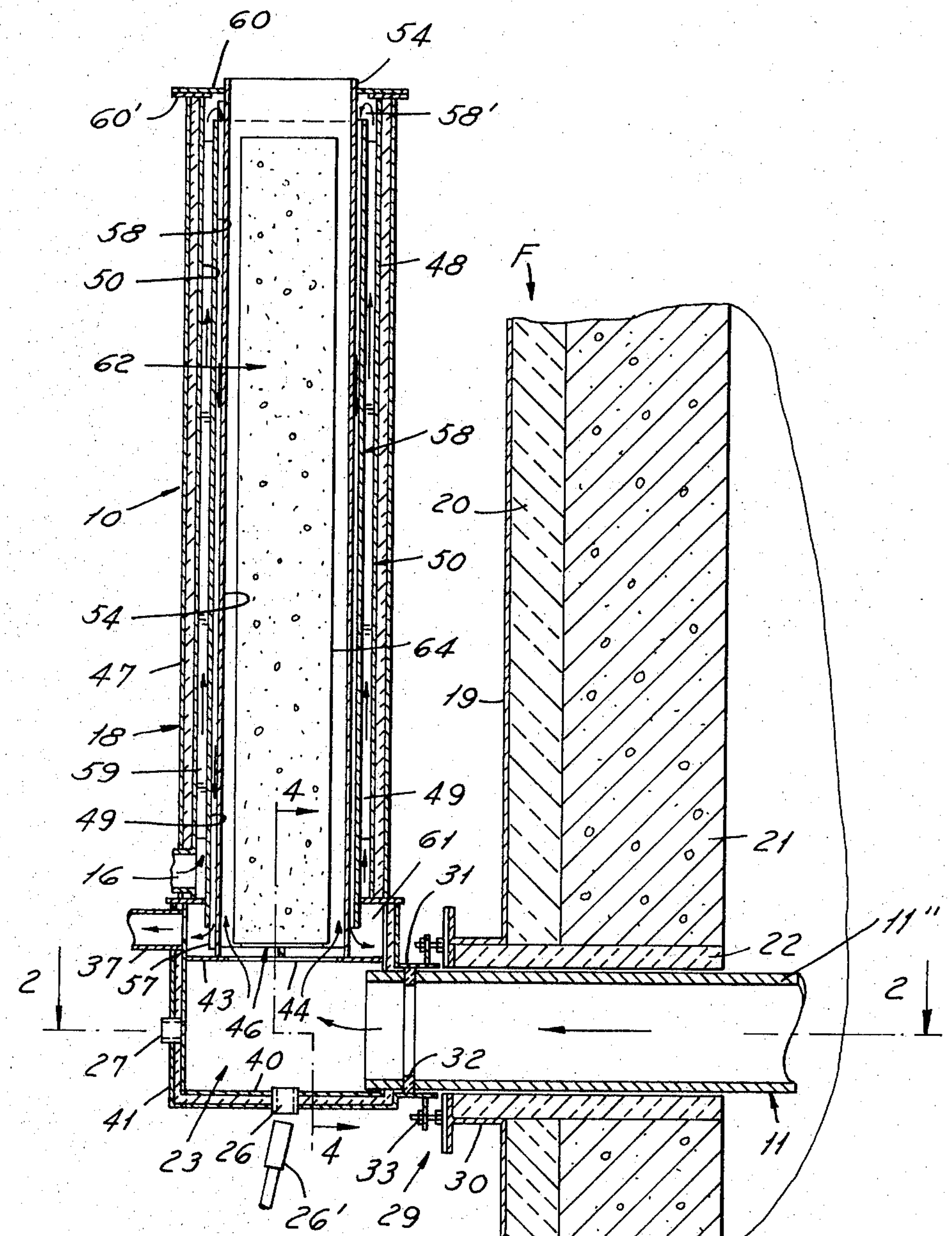

60
54
60'
58'
58
50
48
F
62
58
20
10
50
54
64
19
47
18
59
49
49
61
21
16
31
11"
22
37
57
43
46
44
2
2
27
32
40
41
23
26
4
33
30
11
29
26'

FIG. 5

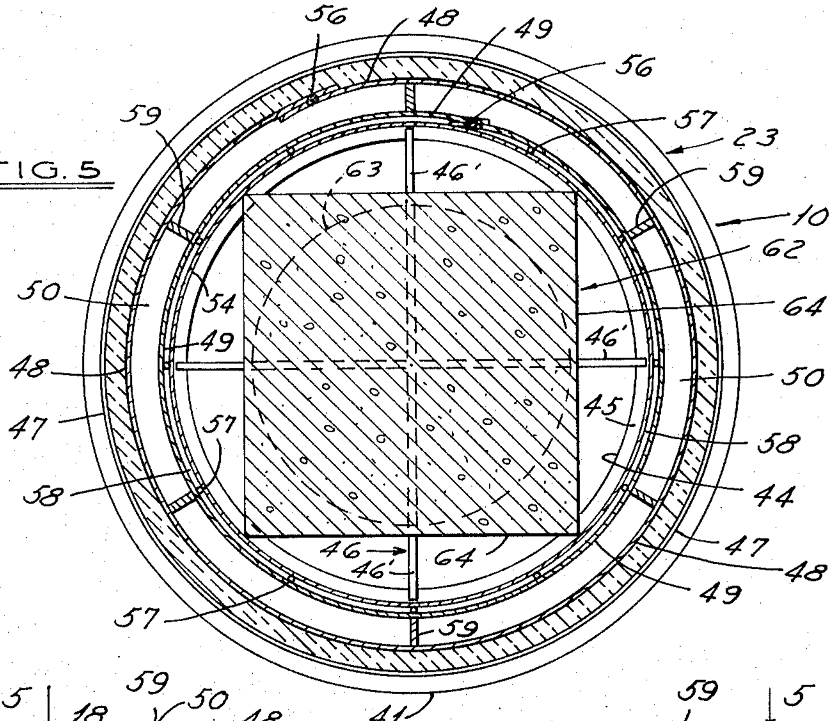
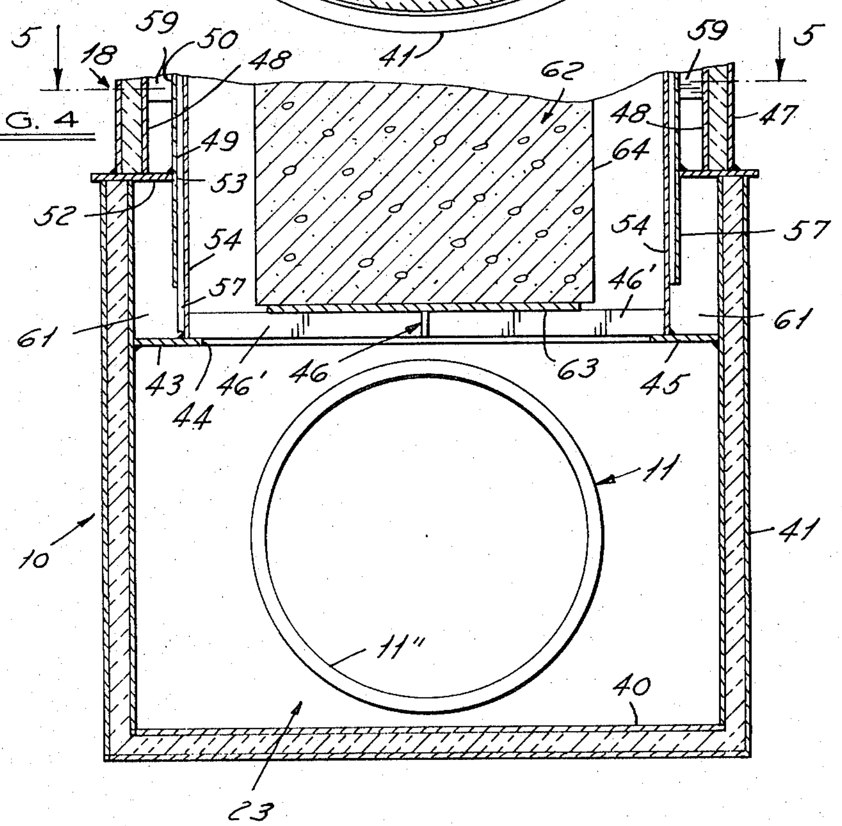

56
48
49
56
59
57
23
59
10
63
46'
62
50
54
64
49
46'
48
50
45
47
57
58
58
44
46
46'
64
47
48
49
57
59
41

FIG. 4


5
59
50
18
48
62
59
5
48
47
49
64
53
52
54
57
54
57
46'
61
61
43
44
46'
46
63
45
11
10
41
11"
40
23

RECUPERATOR FOR GAS-FIRED RADIANT TUBE FURNACE

BACKGROUND OF THE INVENTION

1. Field of the Invention

An object of the invention is the improvement of the operation of industrial gas-fired radiant tube furnaces of a considerable number of types used for a considerable number of purposes, in all of which cases the recuperator improves the overall efficiency and economy of furnace operation, to at least the extent that the higher is the pre-heat temperature of the combustion air, the higher is the saving in combustion fuel.

2. Description of the Prior Art

A search has revealed the following patents:

Bloom et al	3,079,910	March 5, 1963
Cone et al	2,849,218	August 26, 1958
Krause	2,709,128	May 24, 1955
Knight	2,700,380	January 25, 1955
Corns	2,602,440	July 8, 1952
Edge	2,391,447	December 25, 1945
Eisenlohr	2,318,206	May 4, 1943
Dreffein	2,255,540	September 9, 1941
Buell	1,344,437	June 22, 1920

Of the foregoing, the patents to Knight, Corns, Bloom et al., and Edge show types of closed loop radiator tube unit; and the patent to Holcroft et al., of common ownership, U.S. Pat. No. 3,105,863, issued Oct. 1, 1963 does likewise. Eisenlohr and Krause disclose types of heat exchange elements very generally similar in function to a core-breaker; and in this context the Krause patent discusses in a general way the problem of avoiding an excessive pressure drop while obtaining a turbulent intermix of flowing gases, although not in a heat exchange operation. The patents to Cone et al., Buell and Dreffein show arrangements of axially telescoped tubular wall or partition components in furnace recuperator, preheater or economizer units. However, critical factors of the present improvement in regard to radial spacing and other dimensional factors are not shown or suggested.

SUMMARY OF THE INVENTION

The recuperator of the invention, as constituted by special components and their relationships briefly described in the Abstract, is the fruit of a combination of mathematically and experimentally or empirically justified considerations, which combination achieves a desirable and valuable balancing of certain operational variables as to design size, back pressure, etc., also as to practical expediency for optimum heat transfer to an incoming blower cold air supply prior to its admixture and combustion with a heating gas. A most important objective is to produce an ample volume of flow of the burning mixture in the radiator unit of the furnace without creating undue back pressure therein. In these respects, the invention improves very materially over general conceptions taught by the prior art, particularly in matters of concern to the industry in terms of manufacturing feasibility, efficienty and cost of production.

The improved recuperator occupies very little or in effect no additional available space over what is necessary to accommodate conventional stack or flue structures of known radiant tube furnaces. It combines different modes of heat transfer, i.e., free convection and radiation on the exhaust gas side and turbulent forced

convection on the combustion air side, thus maximizing the preheat temperature within the constraints of recuperator size, blower pressure and radiant tube pressure.

Structurally, the recuperator is very simple, being made by known and inexpensive sheet metal fabrication techniques, in particular as regards the wrapped or rolled tube design of its set of separator walls or shells. More particularly, its construction technique using spacers and wrapping metal to form and maintain the circulatory passages required for turbulent forced convection heat transfer is a very economical method; for in general standard available commercial pipe and/or tubing will not accommodate the design factors which produce optimum heat transfer, in this case reducing to optimum preheat temperature. The volumetrically proportional double pass flow of the combustion air afforded by the improvement materially increases the preheat temperature; it also assists in maintaining acceptable outside surface temperatures.

While reference has been made above (and will later be) to the operation of the furnace with gas as its fuel, the present recuperator also operates well in liquid fuel-fired installations. Similarly, although the radiant tubing has been described in terms of a U-type structure, it is to be understood that different types of tubes, i.e., straight-through, W-shaped and loop type are contemplated for the radiator components.

The recuperator requires no special castings, new burner heads, etc., as has sometimes been the case in heat exchange recuperators or economizers of the prior art. It produces significant fuel savings, observed as up to 30 percent under practical industrial conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a face elevational view, fragmentary in nature, illustrating a typical installation of the recuperator of the invention on a standard gas-fired radiant tube-type furnace;

FIG. **2** is a view in horizontal section, as on line **2—2** of FIGS. **1** and **3**, generally and quite schematically showing the U-shaped configuration of the radiant heating tube unit of the furnace, contours of the recuperator and its connections appearing only in dot-dash line;

FIG. **3** is a fragmentary enlarged scale view in vertical cross section of the recuperator installation, as on line **3—3** of FIG. **1**;

FIG. **4** is a larger scale view in vertical section on broken line **4—4** of FIG. **3**, affording a better illustration of certain quite critical dimensional relationships of the recuperator structure; and

FIG. **5** is a view in horizontal section on line **5—5** of FIG. **4**.

DESCRIPTION OF A PREFERRED EMBODIMENT

FIGS. **1** and **3** best show the improved recuperator unit of the invention, generally designated **10**, as operatively installed on a typical gas-fired radiant tube-type furnace F, the structure of which constitutes no part of the invention, save very generally in the fact that it utilizes a series of U-shaped or closed undulatory loop-type heat radiators **11**. In the simple form illustrated herein, each is characterized, as appears in FIGS. **1** and **2**, by an elongated intake leg **11'** through which a gas-air combustion mix enters the radiator tube and a discharge leg **11''** from which the products of combustion enter the bottom of recuperator **10**, thence traveling in a manner to be described upwardly through a flue or stack of the unit.

Air to be preheated for combustion is supplied by an appropriately rated blower unit **12** (FIG. **1**) which discharges via standard piping connections **13**, a manual regulating valve **14** and further pipe connections at **15** to a welded radial air intake fitting or nipple **16** of recuperator **10**, which fitting is in communication with a lower portion of a stack wall structure **18** of the recuperator. As indicated above, the furnace F is entirely conventional, typically comprising a relatively thin external sheet metal casing or sheath **19** having an insulating wall portion **20** (for example of insulating fiber board or the like) directly inwardly of the sheath, backed by an inner wall member **21**, preferably of insulating fire brick. Combusted heating product exits from radiant heater **11** through the heater's discharge leg **11''**, the latter being positioned within a cylindrical ceramic receiving sleeve **22** traversing the furnace wall structure, and a similar sleeve receives the radiator's intake leg **11''**. As shown in FIG. **3**, the products of combustion enter an insulated bottom intake manifold or chamber **23** of the recuperator unit **10**, exiting the latter after serving their purpose through a top stack or flue portion of the unit.

The bottom wall of chamber **23** carries a gas pilot opening **26** at which a burner **26'** initiates a flash-back ignition of the gas-air mixture of tube **11'**, and the front chamber wall portion is shown as equipped with a peep-sight **27**. The burners can be ignited in other ways, but flash-back ignition works well because of the low back pressure in the radiator tubing.

Recuperator **10** is fixedly mounted to the furnace F, with its vertical center typically spaced a foot forward of furnace casing **19**, by an adaptor arrangement **29** (FIG. **3**) including a sheet metal stamped sleeve **30** fast on the outer end of the ceramic furnace sleeve **22**; and a stamped wall portion externally defining the intake chamber **23** of the invention is equipped with an integral radially extending and cylindrical sleeve **31** which telescopes over the end of outer leg **11''** of burner **11**, as well as an annular sealing gasket **32** carried by the leg. Adjustable screw means **33** connect a radial flange portion of sleeve **30** with a corresponding flange portion of the mounting part **30**.

Referring to FIGS. **1** and **3**, preheated air departs from recuperator **10** through a nipple and ell connection **35**, entering the intake leg **11'** of burner **11** via another L-type union **36**. The connection **35** couples onto a welded radial discharge fitting **37** of the recuperator, just below its air intake at fitting **16**, through which line, as indicated by arrow in FIG. **3**, the heated air goes to the burner. A combustion gas line **38**, as supplied by a suitable source (not shown), similarly enters the burner tube leg **11'** adjacent its preheated air entry.

In a typical installation, air to be heated is furnished at the recuperator's air intake fitting **16** at a temperature of, say, 80°–100° F, and it exits from the recuperator fitting **37** at a temperature of from 800° F to 1,000° F. Air heating combustion product enters the recuperator proper from chamber **23** fed by the radiator discharge leg **11''** at a typical 1,700°–1,900° F.

The recuperator's intake manifold space or chamber **23** is of double-walled construction, including an inner, cylindrically cup-shaped sheet metal wall component **40** and a concentric, similarly sectioned and internally nested outer wall part **41**. The burner tube leg **11''**, peep-sight **27**, pilot opening **26** and heated air discharge fitting **37** all extend through this composite wall structure, which is filled between its chamber wall parts **40** and **41** with a compacted fibrous insulating material.

A circular sheet metal plate **43** defines the top of chamber **23**, being welded marginally to wall member **40** in a horizontal zone slightly above the discharge leg **11''** of the radiator tube. Plate **43** is provided with a large diameter circular center opening **44** through which the products of burner combustion travel upwardly, as indicated by arrow in FIG. **3**. As best appears in FIG **4**, the inner marginal portion of plate **43** affords an annular shelf portion **45**, which is employed as a support for a spider unit **46** (FIG. **5**). This is constituted by four 90° intersecting welded legs **46'** and serves a purpose to be described.

Recuperator **10**, as best illustrated in FIGS. **3**, **4** and **5**, also has an insulated double wall stack structure **18** above its intake manifold **23**, this structure including an outer cylindrical wall or shell **47** of **22** gauge steel of but slightly less diameter than the outer manifold wall **41**, and an intermediate **14** gauge sheet metal wall or shell part **48**, with the annular space between these telescoped concentric members being filled by a compacted fibrous or equivalent insulating material. Shell **48** outwardly defines a cold combustion air intake space of circular cross section and extensive axial height; said space is designated **50** (FIG. **4**), being radially inwardly defined by a second **14** gauge sheet steel separator wall or shell **49**, and the sectional area of the circulatory space **50** thus defined bears, in the specific two-walled combustion air-circulatory concept herein illustrated, a predetermined mathematically and empirically determined rough relationship to a second and inner air circulatory space **58** in the stack structure **18** of recuperator **10**. However, the invention more generally goes to a relationship of air and combusted gas flow modes or characteristics internally of recuperator **10**, as will be described.

Referring to FIGS. **3** and **4**, it is seen that the insulating wall or shell members **47**, **48** of structure **18** rest upon a circular divider plate **52** lying atop and fixedly secured similarly to the wall structure of intake manifold space **23**; and wall or separator shell member **49** of the stack structure projects downwardly through a circular opening **53** in panel or wall **52**, being tack welded about said opening and terminating somewhat above the apertured top panel **43** of the manifold chamber **23**. The shells **48**, **49** have gas-tight welds to divider plate **52**, but shell **47** may be tack-welded to that plate.

The wall structure of the recuperator stack **18** is completed by a radially innermost, vertically elongated cylindrical shell **54** of 1/32 inch sheet steel; and the shell members **48**, **49** and **54** are all by preference, as appears in FIG. **5**, formed of sheet steel wrapped or rolled 360°, end-overlapped and seam welded to one another in a vertical zone at **56**. An extremely inexpensive, custom-proportionable stack structure is thus possible. The diameters and gauges of the shell components above described are in the main optional; of more importance are the relationships in point of area of the spaces defined by the components.

Inner shell **54**, as best shown in FIG. **4**, extends fully downwardly into engagement with the top of the intake manifold top panel **43**, to which it is gas-tight welded; and an accurate and predetermined radial spacing of the telescoped separator shells **49** and **54** is insured by the interposition therebetween of a plurality of vertically elongated spacer rods **57**, which are distributed equidistantly about the circumference of said shells, being tack-welded at their bottoms and top between shells **49** and **54**. They thus afford a relatively precise radial width of an air circulatory space, passage or zone **58** (see FIG. 5) extending vertically substantially the entire height of the stack structure. The top of space **58**, as best illustrated in FIG. **3**, is in open communication at **58'** with the larger radius, and annular radial area, air circulatory space **50**, for a flow of air to be preheated in an initial upward and reversed final downward flow, per the arrows in FIG. **3**, from the cold air intake fitting **16** and ultimately outwardly through the radial fitting **37**.

Vertically elongated bars **59** spaced equally circumferentially about the vertical axis of the recuperator serve to maintain the desired radial width of the cold air intake leg or space **50**, the bars being tack-welded to and between shells **48** and **49**.

Stack structure **18** is in effect completed by a two-piece top horizontal plate unit **60, 60'** (FIG. 3). Of this pair, the upper plate **60** is provided with a central circular aperture through which the inner shell member **54** projects upwardly as a central exhaust flue of recuperator **10**, being marginally welded to plate **60**. Lower plate **60** is welded to the top of recuperator shell **48**, and plates **60** and **60'** are welded to one another. Thus said plates serve as an extension unit connecting the hot shell member **54** and the colder shell **48**. The reduced radius circulatory area passage **58** opens beneath its inner end defined by wall portion or shell **49** into a relatively large diameter air discharge manifold space **61** of the recuperator, just above the lower intake manifold **23**, and the manifold **61** is in direct radial outward communication with the outlet fitting **37**, as best appears in FIG. **3**.

A vertically elongated center core **62** (also known as a core buster) of an appropriate heat radiating ceramic or metal refractory material is received in the central space of stack structure **18** within the latter's innermost shell **54** thus forming, between the core **62** and the shell **54**, a vertical exhaust gas passageway **65** for the upwardly flowing exhaust gas from exhaust products manifold **23**. Core **62** is 6 ⅝ inches square in horizontal cross section (FIG. 4) and rests on a rigid 6 inches diameter metal plate **63**, which plate is in turn supported by the spider unit **46**, with the latter's arms **46'** roughly centering outwardly against the inner surface of cylindrical separator shell **54**. FIG. **4** shows the square-sectioned core **62** as thus being similarly centered at its corners by and within the same shell member **54**.

In a typical installation, the recuperator **10** will, among other and less significant dimensions, have a vertical height, between the upper plate **52** of its discharge manifold **61** and the top flue plate **60**, of approximately 46 inches, this height therefore representing that of the outer intake air circulating passage, zone or space **50**. On such a dimensional basis, the inner diameter of the inner insulated wall part **48** will be about 10 ½ inches, the corresponding diameter of the inner shell **49** of space **50** will be about 9 ½ inches, and the I.D. of the innermost separator shell or wall portion **54** will be about 9 inches. In a combination of shell components dimensioned as described, the radial width of the inner air circulatory space **58** will be about ⅛ inch, and the corresponding width of outer circulatory space **50** will be ½ inch.

This results in a rough ratio of 5:1 in the respective annular areas of the passages **50** and **58** in a plane at 90° to their common axis. Actually a ratio as small as 4:1 is acceptable in a dual wall reversal air flow passaging of the recuperator as represented by the distinct shells or partition walls **50** and **58**. However, for a reason to appear the presence of a distinct external zone **50** is of perhaps secondary importance in the overall light of the invention's objectives.

Assuming a 9 inches inner diameter of the separator shell **54** in the illustrated adaptation of the invention, and with the 6 ⅝ inches square core **62** centered therein by its diagonal corners, there is left within the shell **54** approximately 22½ sq. in. of effective combustion product-circulating space outwardly of the core and within the shell, i.e., in the total area of the four inwardly truncated quadrantal or generally lunate areas outwardly of the core side walls **64**. This of course represents a very large multiple of the combined area of air circulation in spaces **50** and **58**.

The generous circulatory area for products of combustion ascending stack structure **18** upwardly through vertical passageway **65** is to be compared with an approximate 5 sq in. cross sectional annular area of the inner air circulating downward passage or zone **58** defined between shells **49** and **54**; and the effect is to set up within shell **54** and externally of core **62** a heat transfer condition on the exhaust gas side of furnace radiator **11** which is altogether different from the heat transfer condition on the outer, combustion air side of shell **54**. While the presence of the radially outermost upward air circulating space or zone **50** is desirable, as indicated above, particularly in that it insures a relatively cool external surface of the recuperator **10**, the above described general relationship in point of the nature of heat transfer directly within and without the shell **54** is a factor of major importance to the invention. It insures against undue back pressure in burner radiator **11** using a shell construction of industrially acceptable size and design.

To the attaining of these objectives, (a) there exists on the outer, combustion air side of partition shell **54** a forced air flow and resultant relatively turbulent mode of radial heat transfer, and (b) there exists on the inner, exhaust gas side of shell **54** a mode of free convective and radiative heat transfer at minimal pressure and velocity, such as maximize air preheat transfer within the imposed limitations of recuperator size and blower, and at minimal radiant tube back pressure. This follows from a practical and industrially acceptable mathematical and empirical balancing of certain known facts and factors.

Thus, it is to be assumed that the preheated temperature, designated T_{ph}, of combustion air exiting the fitting **37** of recuperator **10** is a function of the wall area of shell **54** (A_s) separating the exhaust gas from said combustion air being heated, and of a parameter called the overall heat transfer coefficient (U). That is, T_{ph} is proportionate to A_s times U. In a practical situation an upper limit on the value of A_s arises by reason of size and cost of materials such as would make the recuperator uneconomical. Furthermore, U is limited because it is a function of the blower pressure which drives the combustion air through the recuperator, another size and cost consideration.

There are three constraints in designing any radiant tube furnace recuperator. Two are discussed above, namely the limiting parameters as to size of the recuperator and the blower pressure; another is the constraint that the radiant tube should be non-pressurized to the greatest extent possible under common practices within the radiant tube furnace industry. As has appeared above, for example, it is highly desirable practice to operate the radiant furnace tube unit **11** at a low pressure of discharge from its exhaust leg **11** inches approaching atmospheric pressure or slightly below atmospheric.

Further, the overall heat transfer coefficient U is a function of two other parameters as follows: $1/U = 1/h_E = 1/h_A$ where h_E and h_A are respectively the heat transfer coefficients between the exhaust gases sweeping the inner surface of the separator wall or shell **54**, and the combustion air traversing the outer surface of that separator.

The values h_E and h_A are thus a function of that portion of the blower pressure which is used on the respective sides of the recuperator. U is maximum when h_E and h_A are equal. However, designing a recuperator on this arbitrary mathematical basis would produce a back pressure in the radiant tube **11** which is again, not consistent with constraints of normal practice in the building of radiant tube furnaces, as mentioned above.

The value U is always less than h_E or h_A, so that it has become a problem to maximize h_E without unduly pressurizing the tube unit **11**, and to use all the pressure from the blower to maximize h_A so that U is maximum. The factors h_E and h_A increase in value when the velocity of the exhaust gases and combustion air adjacent to the separator **54** are increased by restricting the area through which these gases and air flow. But the more these velocities are increased the more pressure is required, in turn subject to predetermined imposed furnace design limitations. Accordingly, in the light of the various dimensional relationships above described and explained as to effect, in the normal operation of the typically dimensioned recuperator **10** described above, it may be assumed that 0.05 inch of water column is set for the exhaust gas side pressure and 22 inches of water column at the combustion air supply side, with an air flow through the recuperator spaces **64** and **58** at the rate of 5,000 cubic feet per hour on the air side, and with an exhaust gas flow externally of core **62** produced by burning 500 cubic feet of natural gas with the instanced preheated 5,000 cubic feet per hour of air.

What is claimed is:

1. The combination with a furnace having a gas-fired radiant tube with its intake and discharge legs projecting through the furnace exterior, of a recuperator unit mounted externally of the wall of the furnace and providing an upright, vertically elongated stack structure, said structure including an insulated outer tubular wall portion and internal separator shell means defining substantially concentric separated and vertically elongated combustion air-receiving and products of combustion-receiving spaces within said wall portion, the combustion air-receiving space being radially external of the combustion product-receiving space, and of relatively limited radial width, the upper end of said air space also being in communication with a source of combustion air and the lower end of said air space being connected to said intake leg of said radiant tube, the other and internal combustion product-receiving space being of an effective cross sectional area in a plane at 90° to the axis of said stack structure which is a large multiple of the said corresponding effective cross sectional area of the combustion air-receiving space, the lower end of said combustion product-receiving space being in substantially unimpeded communication with said discharge leg of said radiant tube, the sectional relationship of said spaces as to effective area being such that the air-receiving space circulates combustion air downwardly in a relatively turbulent forced pressure flow and the combustion product-receiving space circulates the product upwardly from said discharge leg in a relatively freely convective and radiative, low pressure heat transfer relation to said shell means and the combustion air-receiving space external of said means, with minimized back pressure on the interior of the radiating unit, in which the recuperator unit further includes a vertically elongated core disposed in and subdividing the interior of said shell means into a plurality of parallel vertical passages external of the core, in which passages the combustion product circulates upwardly in outward surface contact with said shell means.

2. The combination of claim **1**, in which said vertically elongated core is of solid square cross section and fabricated of a heat absorbing and radiating material, said core being disposed in and subdividing the interior of said shell means into a plurality of parallel vertical passages external of the core sides, in which passages the combustion product circulates in outward surface contact with said shell means.

3. The combination of claim **1**, in which the passages subdivided by said core aggregate in effective cross-sectional area said multiple of the effective cross-sectional area of said combustion air-receiving space.

4. The combination of claim **2**, in which the passages subdivided by said core aggregate in effective cross-sectional area said multiple of the effective cross-sectional area of said combustion air-receiving space.

5. The combination with a furnace of the type having an internally heated radiating tube unit in communication with the furnace exterior, of a recuperator unit mounted externally of said furnace and providing an upright and vertically elongated stack structure, said structure including an external insulated outer tubular wall portion and inner and outer separator shells disposed in radially spaced relation to one another within said wall portion, said shells defining combustion air and combustion product circulating zones within said wall portion, the combustion air circulating zone defined by said shells comprising a pair of parallel, radially separated annular air-circulating passages extending vertically and in communication with one another adjacent an axial end thereof, including a first annular passage whose cross sectional area in a plane at 90° to the axis of said stack structure is at least a substantial multiple of the corresponding cross sectional area of the other air-circulating passage, said first passage of larger area being in communication with a source of combustion air, the other passage being in communication with the leg of the furnace radiating tube unit, the stack structure also including a central inner space within said shells which at least in part affords the combustion product-circulating zone, being in communication with the radiating tube unit.

6. The combination of claim **5**, in which the recuperator unit further includes a vertically elongated core, said core being disposed in and subdividing the interior of said inner shell into a plurality of parallel vertical passages external of the core in which the combustion product circulates in outward surface contact with said inner shell.

7. The combination of claim **5**, in which the recuperator unit further includes a vertically elongated core of solid square cross section and fabricated of a heat absorbing and radiating material, said core being disposed in and subdividing the interior of said inner shell into a plurality of parallel vertical passages external of the core sides in which the combustion product circulates in outward surface contact with said inner shell.

8. The combination of claim **6**, in which the passages subdivided by said core aggregate in effective cross-sectional area a large multiple of the effective cross-sectional area of the combustion air-circulating zone.

9. The combination of claim **7**, in which the passages subdivided by said core aggregate in effective cross-sectional area a large multiple of the effective cross-sectional area of the combustion air-circulating zone.

10. The combination of claim **5**, in which the ratio of the cross-sectional areas of said first and other annular combustion air-circulating passages approximates at least 4:1.

11. The combination of claim **6**, in which the ratio of the cross-sectional areas of said first and other annular combustion air-circulating passages approximates at least 4:1.

12. The combination of claim **7**, in which the ratio of the cross-sectional areas of said first and other annular combustion air-circulating passages approximates at least 4:1.

13. The combination of claim **9**, in which the ratio of the cross-sectional areas of said first and other annular combustion air-circulating passages approximates at least 4:1.

14. The combination of claim **5**, in which said first air-circulating passage of larger area is radially external of said other air-circulating passage, the last-named passages communicating with one another adjacent the top thereof and respectively accommodating an upward and a downward flow of air being heated.

15. The combination of claim **6**, in which said first air-circulating passage of larger area is radially external of said other air-circulating passage, the last-named passages communicating with one another adjacent the top thereof and respectively accommodating an upward and a downward flow of air being heated.

16. The combination of claim **1**, in which said internal separator shell means comprises an inner shell and an outer shell, the space between said outer shell and said outer tubular wall forming an upwardly directed annular air passage, and the space between said outer shell and said inner shell forming a downwardly directed annular air passage whereby said source of combustion air passes first upwardly on the outside and then downwardly on the inside through said annular passages, the cross sectional area of said upwardly directed outer annular passage being a large multiple of the area of said downwardly directed inner annular passage.

17. The combination of claim **16**, in which said large multiple is at least 4:1.

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