

Nov. 24, 1959

J. H. SHAPLEIGH

2,914,386

TUBULAR FURNACE

Filed Dec. 20, 1954

4 Sheets-Sheet 1

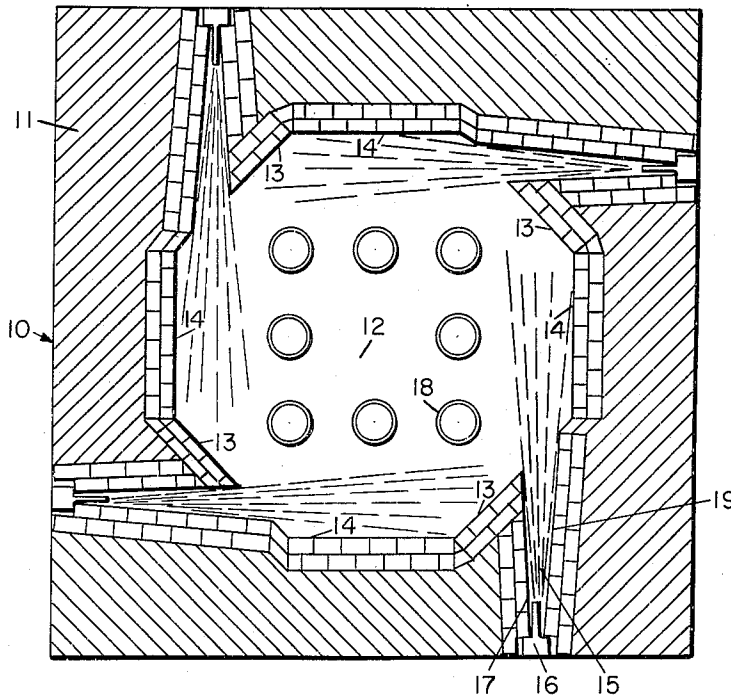


FIG. 1

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4 Sheets-Sheet 2

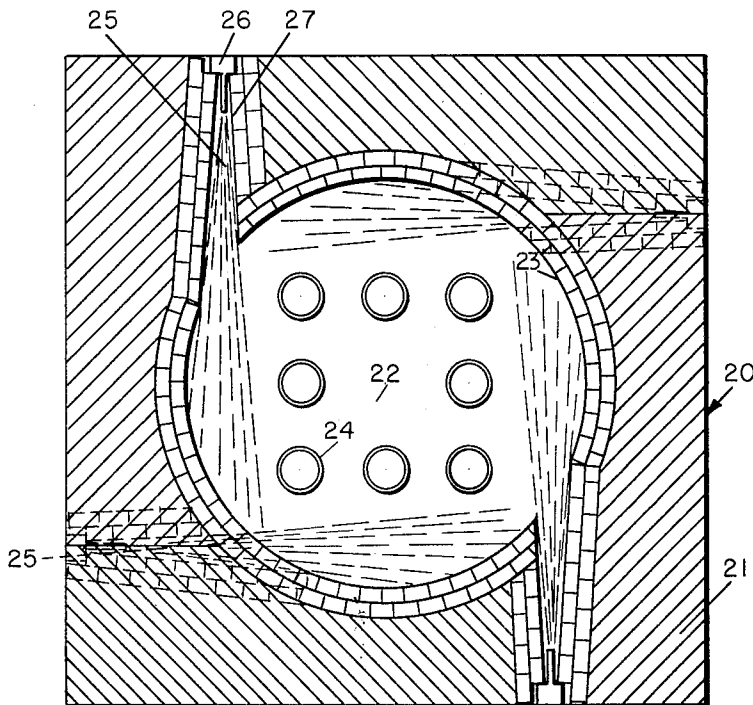


FIG. 2

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4 Sheets-Sheet 3

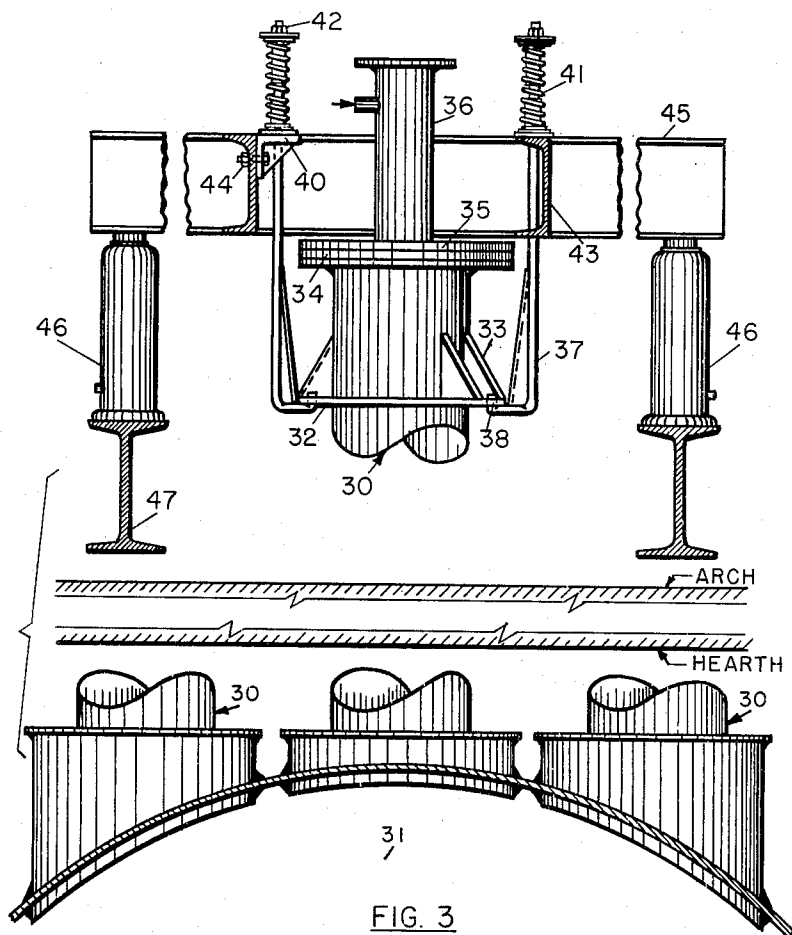


FIG. 3

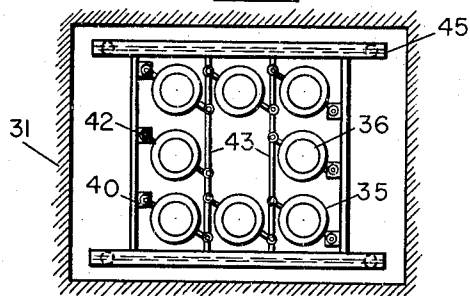


FIG. 4

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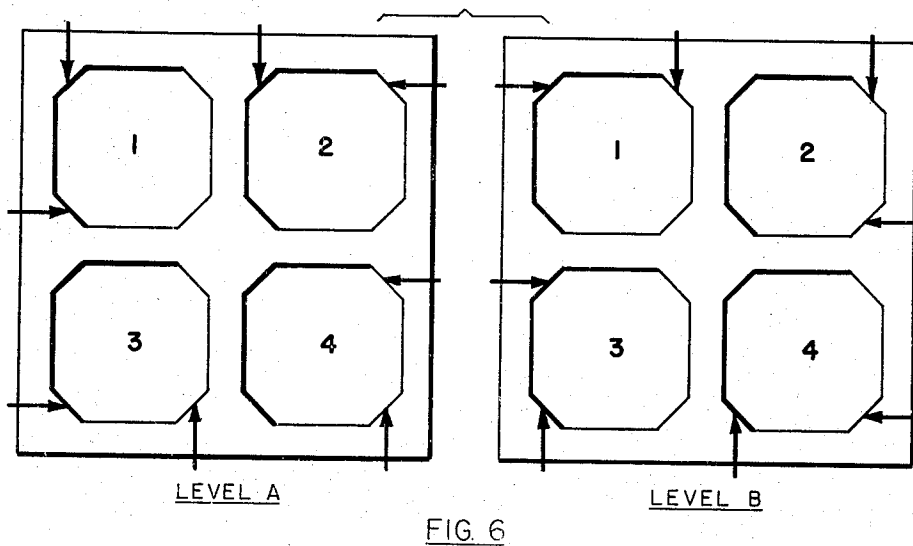
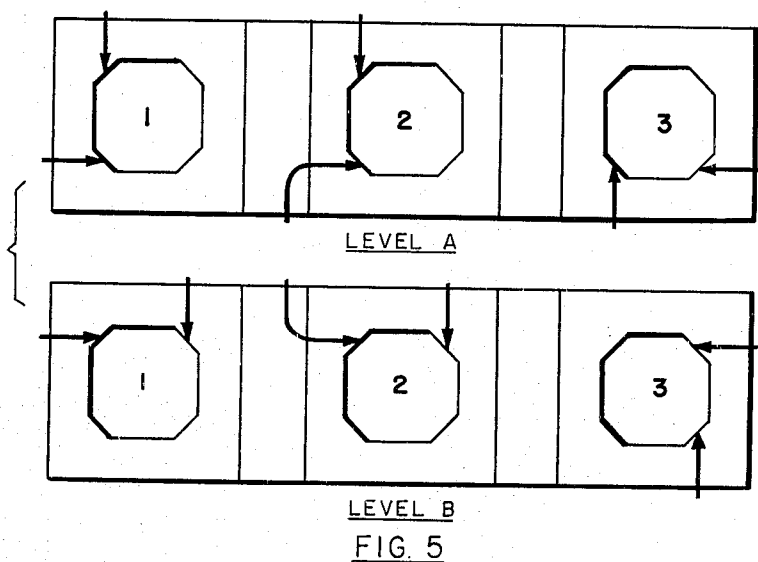
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4 Sheets-Sheet 4



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TUBULAR FURNACE

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Application December 20, 1954, Serial No. 476,201

11 Claims. (Cl. 23—277)

This invention relates to tubular furnaces and more particularly to improved apparatus and process for more efficient and economical treatment of fluid reactants in tubular furnaces.

In recent years the tube type furnaces, wherein thin walled metallic reaction tubes are passed through a refractory heating chamber and externally heated by means of combustion gases, have become very popular particularly in the production of hydrogen and various olefins from fluid hydrocarbons. Despite the wide use of such furnaces and a great deal of development directed to their improvement, these furnaces are still characterized by several disadvantages, the obviating of which would be most beneficial, particularly to the hydrocarbon reforming or cracking art.

Reaction tubes employed in tubular furnaces are generally elongated alloy tubes such as 310 metal ranging from 4 to 10 inches in diameter and having a tube wall thickness in the neighborhood of $\frac{3}{16}$ to $\frac{1}{2}$ inch. In the currently employed furnaces larger heating chambers are employed than would be desirable from the standpoint of economy in construction.

Many furnaces are fired with gaseous fuels rather than liquid fuels even in geographic locations where the liquid fuels are cheaper. In locations where gaseous fuels are prohibitively expensive, the installation of tubular furnaces has been retarded by fear of detrimental effects on metal tubes when operated at the high temperature generated by liquid fuels. While problems exist in tubular furnaces employing gaseous fuels when attempt is made to attain the full potential of high metal temperatures, these problems are greatly increased when liquid fuels are employed. Liquid fuel has been employed in tubular furnaces in both the United States and Europe but these installations are still lacking in the attainment of advantages which have been long sought in the tubular furnace art.

Criticism has been leveled at the tube-type furnace to the effect that it is difficult to obtain a high heat input to the tubes because, to avoid physical damage to the metal, temperatures must be below 1600° F. Actually, this criticism is completely unjustified and it has been demonstrated, particularly with gas firing, that with proper furnacing techniques considerably higher temperatures may be employed. Nevertheless, even those skilled in this advanced state of tubular furnacing realize that there exists a large field of improvement still to be obtained which would greatly broaden the scope of use of tubular furnaces and constitute great improvement over the present state of development in this field. For example, it would be highly desirable to obtain one or more of the following improvements: gain in capacity per unit of investment which would approach current refinery capacities in terms of barrels per day; use in high temperature reactions generally thought to be out of the field of tubular furnace practice; a marked reduction in the quantity of catalyst necessary per unit of output from a catalytic process; an increased use of heavy liquid as

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process feedstock; and broader use of pressures above atmospheric and particularly above 100 p.s.i. In the path of obtaining such desired results, however, stand one or more of the following hindrances which are applicable to both the use of gaseous or liquid fuel in the firing of the present tubular furnaces: difficulty in attaining and controlling combustion in furnacing to give short flame length (i.e., about one foot for gaseous fuels and about three feet for the heavier liquid fuels); the lack of appreciation of the advantages of short flames and their relationship to physical factors important to economical operation; the damage to tube metal due to impingement of flame or extremely hot combustion gases; the intermittent detrimental breaking and reforming of metal oxide films on reaction tubes by presence of atmospheres alternately oxidizing and reducing, and the lowering of the strength of such films; the improper interference of combustion gas from two burners which promotes tube hot spots; the appearance of spots and deposits on reaction tubes from the impingement of combustion gas streams from oil fired burners, partly related to vanadium in the oil and low fusion point ash; uneven tube temperatures at points 180° apart on the tube causing permanent tube deterioration; damage to the internal form of the metal and structure; tube blistering and bloating; difficulty of control of luminous flames; and improper application and control of tube tension.

In present tubular designs, one of the most popular of which is disclosed in U.S. Reissue 21,521, one or more reaction tubes are suspended through the central portion of a heating chamber and gases of combustion are introduced into the chamber to transfer heat by convection and radiation to both the tubes and the refractory furnace walls. The furnace chamber walls then radiate the heat thus received to the tubes. The burners spaced vertically introduce combustion envelopes or streams between the tubes and the adjacent furnace wall or else between rows of tubes according to the number and spacing of the tubes in the particular furnace cell. It has heretofore been found necessary to leave a considerable space between the tubes and furnace wall and/or between the rows of tubes where firing is performed between the tubes, thereby necessitating an undesirably large firing chamber. Although this particular arrangement has been used on a worldwide basis and has been considered a very satisfactory furnace, inadequacies are nonetheless present when it is desired to increase tube capacity, to employ larger tubes, to use tubes under pressure, to employ intensified and more critical reaction zone conditions and in general to pass into improved fields of operation (particularly with liquid hydrocarbon firing) and to the use of liquid feedstock or highly unsaturated feedstock instead of the usual gaseous, paraffinic feedstock.

In prior art tubular furnaces the walls of the heating chamber have had the sole purpose of forming a refractory walled enclosure in the simplest and least expensive manner consistent with the necessary structural strength. The furnace walls have been of uniform thickness, the actual thickness being varied according to well-known tables of heat loss to prevent external radiation insofar as it is economically feasible. The furnaces have been rectangular or round and have been about 25 feet high between arch and hearth. The burners in such furnaces have been mounted in burner blocks and while the burner nozzles have not been aimed directly at the tubes in the better designs, the incompletely oxidized gas envelopes have extended into the chambers to produce fluctuating reducing and oxidizing atmospheres highly conducive to tube damage.

The problem of economically introducing heat into reaction tubes is further complicated by the current

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belief in the art that the reaction tubes must be widely spaced from each other in order to effect high percentage absorption of radiant heat and to allow sufficient circulation of combustion gases therebetween to prevent uneven tube temperature. Such uneven heating on opposite sides of the tube may cause cracking. Moreover, such cracks cause pressurized streams of burning reactants to jet into the combustion chamber and damage closely adjacent tubes. Thus, the chambers of tubular furnaces currently employed have been further enlarged due to this wide tube spacing and the necessity for spacing the outermost tubes far enough from the furnace chamber wall to prevent detrimental flame impingement.

The supporting of the reaction tubes in the tubular furnace has also presented many difficult problems to the art. Some of the shortcomings of tubular furnaces in some high temperature reactions are due to the effect on tube metal of the temperatures necessary to the desired reactions. Metal temperatures within the apparatus, particularly in the production of hydrogen either by reforming methane or by cracking of liquid hydrocarbons, may range from a black heat at the furnace arch to as high as 2000° to 2400° F. at the furnace hearth. Within this range, and particularly at temperatures between 1100° to 1700° F., serious weakening effects arise during service due to carbide precipitation inherent in the otherwise desirable stainless steels. Moreover, these highly heated reaction tubes, generally employed in lengths of 20 to 30 feet, undergo expansion of as much as 5 to 7 inches when heated to these high metal temperatures. In most furnace designs the tubes normally pass through both the arch and the hearth and are subject to binding stresses caused by temperature effects. In addition to elongation, there is a tendency for the tubes to bloat due to internal pressure during operation and to low creep strengths at high temperature. The weakening effects caused by these changes have in the past been partially offset by supporting the reaction tubes from above in order that the weight of the tube, together with the weight of manifolding below the furnace hearth, plus the weight of the catalyst, will exert a downward pull on the tube wall, thus placing the tubes under axial tension. Such an arrangement constitutes a considerable improvement over prior practices where the tubes were anchored below the furnace and where the effluent was removed from the top of the tubes rather than from base points below the furnace. However, the use of downwardly applied tension in suspended tubes has in turn worked a very undesirable temperature limitation since, as the tension is increased for a given tube of given wall thickness, the upper limit of temperature which can be employed must be correspondingly decreased to prevent structural failure of the tube itself. This difficulty can be readily appreciated when it is realized that a reaction tube made of type 310 metal, 30 feet in length and 8 inches in diameter with a wall thickness of about 1/4 inch will normally weigh about 800 pounds. Depending upon the specific catalytic reaction being conducted, this tube may contain from about 600 to 1200 pounds of catalyst. Thus, when the weight of the manifolding below the furnace is added to the weight of tube and catalyst, it will be seen that a force of about 2000 pounds is being directed downwardly along the tube. In addition there will be a downward thrust on the bottom of the tube enclosure related to the pressure within the tube. These various effects result in a tube tension which is normally highest at the bottom of the tube where the greatest temperatures will normally be applied and therefore where the tube will have its lowest creep strength. Thus, the temperature must be lowered to a point corresponding to the strength of the tube at a sacrifice of reaction efficiencies, throughput or both.

Further, in multiple tube furnaces with tubes joined in a common manifold at their base below the hearth, the separate tubes undergo unequal expansion. This

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unequal expansion creates a condition wherein the floating position of the manifold is determined by tubes in a different state of tension, the tube of highest temperature normally being in the state of least downward tension. In fact, under extreme conditions a tube might approach zero downward tension and actually expand upwardly in a state of compression. Thus, it is common in current industrial practice to have manifolded tubes suspended by means of springs from above the furnace arch in states of downward tension substantially less than that of a fully suspended tube in downward tension under its own weight. In practice, however, these spring mounts have been found to be inadequate in many ways. Primarily there is insufficient control of tension on the individual tube and warping has resulted. Moreover, the creep of the tube is not under positive control and excessive changes in length occur. Tube life is thereby shortened.

Now in accordance with the present invention, it has been discovered that one or more of the difficulties above discussed may be obviated by a new furnace design and a new process of furnacing whereby a new and greatly broadened scope of use is opened up to tubular furnaces.

Generally described, the apparatus of the invention relates to a tubular reaction furnace having in combination a shell comprising a refractory walled heating chamber having spaced portions of greater thickness than the intermediate portions, vertically disposed metallic reaction tubes passing through the heating chamber and spaced from the chamber walls, and fluid hydrocarbon burners to furnish hot combustion gas to the heating chamber mounted in elongated tunnels formed in the thicker portions of the chamber walls, said tunnels being located at a plurality of vertical levels and so disposed in the chamber wall that the extension of a straight line drawn from the burner nozzle to the end of the innermost wall of the tunnel will pass between the reaction tubes and the adjacent chamber wall. Although the shell may have any desired outer configuration, it will preferably be substantially rectilinear in cross-sectional exterior configuration.

In such apparatus the thickness of the portion of the chamber walls containing the burner tunnels will be controlled by the particular reaction for which the furnace is constructed and the type of fuel employed. It is desired to retain as much as possible of the combustion envelope from the burners in the burner tunnels. By use of the burner tunnel in accordance with the invention, the hot combustion gas streams into the heating chamber and out of direct contact with the tubes to prevent detrimental flame impingement and to protect the tube from damage due to fluctuating conditions. Even when employing gas as a fuel, it is a difficult matter to consistently retain the entire combustion flame within a tunnel. When employing oil as a fuel, it is impossible to retain all of the flame within a tunnel of any practical length. However, with either fuel the flame which does emit into the heating chamber is directionalized and controlled. With either gas or oil firing, therefore, the reaction tubes may be disposed closer to the chamber walls and in a chamber of the same size more reaction tubes can be employed than in furnace designs heretofore employed, thus greatly increasing the efficiency and economy of the furnacing operation.

As indicated, the furnace itself will preferably be rectangular in cross-sectional external configuration. The internal cross-sectional configuration of the heating chamber will preferably be either elliptical, octagonal or circular. Thus, the portions of the chamber wall adjacent the furnace shell corners will be thicker than the intermediate portions. In this manner thickened portions may be economically provided adjacent the corners for the disposition of burner tunnels without the necessity of providing Dutch oven type effects and without the necessity of providing a furnace wall of a uniform thickness sufficient to accommodate adequate burner tunnels.

Moreover, due to the thickness of the corner portions of the structure, regions of higher heat capacity are provided which add to the use and performance of the furnace.

In one preferred embodiment of the invention the tubes will be spaced from each other on centers of from $1\frac{1}{2}$ to $2\frac{1}{2}$ tube diameters. It has been discovered that when care is taken to avoid detrimental flame impingement, and particularly in the improved furnace design of the invention, adequate heat input to the tubes can be obtained with this relatively close tube spacing which has heretofore been deemed undesirable by the art. Thus, in a chamber of given size, the closer spacing of tubes provides more space between the tubes and the chamber walls and further enhances the controlled protective combustion gas flow characterizing the invention. Alternatively, where this additional protection is unnecessary, chamber size can be reduced with corresponding economies.

In accordance with another preferred embodiment of the invention, the reaction tubes will be anchored below the furnace hearth to support members, manifolding, a quench tank, a secondary furnace or other process equipment and tension will be applied in the upward direction by means disposed above the furnace arch. Such means may be manually or automatically controlled to exert the desired amount of tension on the tubes and thus permit the use of higher temperatures which in turn will derive the highest efficiencies from the metals employed. Thus, where a tensile force of as much as 2000 pounds has been employed in prior art designs where the tubes are suspended even though it is only necessary to employ, for instance, a 200 pound tension to minimize binding, bloating, or warping, it is possible in accordance with the present invention to apply exactly the amount of tension desirable and thus remove undesirable temperature limitations.

In terms of process, the invention relates to a process for applying heat to vertically disposed metallic reaction tubes passing through the refractory walled heating chamber of a tubular furnace which comprises, at a plurality of vertical levels introducing streams of hot combustion gas into the heating chamber along paths obliquely disposed to the surfaces through which the streams emit and which paths direct the streams between the tubes and the adjacent refractory wall, maintaining said streams out of contact with the tube until substantially complete combustion of the gas has occurred, continuously maintaining a blanket of the fully oxidized gas around the tubes to provide a continuous oxidizing atmosphere for the tubes, said blanket diluting the streams of gas entering the chamber at the interfaces formed between the blanket and streams and said blanket being continuously replenished from said diluted portion, and leading the combustion gases in the path between the tubes and chamber wall and in the blanket through the chamber in substantially parallel relationship to heat the tubes by convection and radiation from the gas and by radiation from the refractory wall. Preferably the combustion gases will be led spirally upward to exit adjacent the top of the furnace structure. However, the exit flue may be located in the bottom of the furnace, at the mid point of the chamber or at any other desirable position since it is the relation between gas and tubes which is important rather than the location of the flue.

In a preferred embodiment of the process of the invention, tension will be applied to the reaction tubes from a point above the arch of the furnace.

In employing the apparatus of the invention, new and beneficial heat relationships are set up within the furnace chamber. As the furnace operation is initiated, hot combustion gases are introduced into the chamber from the burner tunnels and flow along the chamber wall between the wall and the nearest tubes. As this gas comes from the burner and begins to burn, reducing conditions are

present and continue to be present until complete combustion is achieved. Then the gas, containing water and from about 2% oxygen depending on firing conditions, becomes an oxidizing gas. In the invention, it is desirable to effect as nearly complete combustion in the burner tunnels as possible. In any event, even if complete combustion has not occurred in the tunnel, the directionalized flow along the wall allows complete combustion to take place before tube contact. This gas, now an oxidizing gas, proceeds upwardly or downwardly around the chamber wall, depending on the location of the flue, with a portion diffusing inwardly into the center of the chamber and circulating about the tubes. As operations continue, this centrally disposed body of oxidizing gas continues to surround and bathe the tubes in a continuously oxidizing atmosphere. As the relatively hotter fresh combustion gas emits from the tunnels, usually at a temperature of about 3500°F. , it flows peripherally around the outer portion of the chamber. Even when combustion is not complete at the mouth of the tunnel and reducing conditions exist at that point, the tubes are protected by the inner body of oxidizing gas. The inner fringe of the gas stream emitting from the tunnels and circling around the chamber is constantly diluted by the relatively cooler oxidizing gas and diffuses inwardly to become part of the inner protective columnar body, a corresponding portion of which exits from the flue with the other gas.

In a single cell furnace it is preferred that the combustion gas streams all flow into the chamber in the same direction. In this manner, smoothest flow of gas is obtained and the stream from each burner joins the unidirectional flow. However, this arrangement is not always practical, especially in some multiple cell furnaces where it may be desirable to fire from only two faces. In multiple cell furnaces, for example, it may be desirable to fire from two faces at each level with gas flow being in opposite directions at each level. While such flow causes turbulence, the gas stream from each burner becomes completely oxidized in its travel from the burner tunnel to the far side of the chamber and the turbulence is not detrimental.

The use of burner tunnels, the controlled peripheral flow and the presence of the inner protective body of relatively cooler oxidizing gas results in great advantages in terms of tube life and permissible temperatures. Not only is detrimental flame impingement eliminated, but of equal importance, the tubes in the furnace are not exposed to the metal damaging fluctuation between oxidizing and reducing conditions which is present in the prior art apparatus. Therefore, the tubes are immediately coated with a thin, permanent, protective film of metal oxide which is smooth, ductile and elastic. This film is fluid impervious and prevents or minimizes detrimental tube damage resulting from vanadium and low fusing alkali sulfates present in fuel oil. In prior furnaces, tube metal was liable to attack of varying degree of frequency first by an oxidizing atmosphere and later by a reducing atmosphere due to insufficient latitude against mechanical and human failure in control with the resulting scaling of metal causing decreased tube life.

Moreover, the method of heating in the apparatus and process of the invention keeps the hottest gas close to the refractory wall thus more efficiently heating the primary source of radiant heat to the tubes. If desired, oxygen or oxygen enriched air can be employed together with the hydrocarbon feed to generate hotter flame and hotter gases of combustion due to the new protection afforded to the tubes. Thus, substantially greater heat input can be obtained without tube damage.

The introduction of gas into the chamber along a path disposed obliquely to the furnace face from which the gas emits adds considerably to the efficiency of the furnace. Each portion of the longer, outer wall of the tunnels which extends beyond the end of the shorter

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inner wall of the tunnel becomes a highly heated radiating surface which would otherwise be lost if the tunnel walls were of equal length.

Having generally described the invention, more specific illustration of the structure and process will be presented with reference to the accompanying drawing in which like symbols refer to like structural elements. In the drawing Figs. 1 and 2 are cross-sectional views of furnace chambers in accordance with the invention. Fig. 3 is an elevational view showing apparatus for the application of upward tension to reaction tubes and the anchoring of the tubes below the furnace. Fig. 4 is an elevational plan view showing the support means for the tubes in an entire cell of a furnace in accordance with the invention. Figs. 5 and 6 are diagrammatic views of multiple cell furnaces illustrating schemes of burner placement.

In Fig. 1 a single cell furnace 10 has a refractory wall 11. The external cross-sectional configuration of the furnace is rectangular while the internal cross-sectional configuration of the heating chamber 12 is octagonal. Four of the sides 13 of the octagon forming the walls of the heating chamber 12 are parallel to the hypotenuse of an isosceles right triangle incorporating the right angle forming an external corner of the furnace wall. The furnace walls formed by the walls 13 are considerably thicker than those formed by the intermediate walls 14 of the octagon. Burner tunnels 15 are formed in these thickened portions and a fluid hydrocarbon burner 16 is located in each of the tunnels 15. The inner wall 17 of each of the tunnels is angled in such a manner that the extension of a straight line drawn from the burner nozzle to the intersection of the wall 17 and the face 13 passes between the reaction tubes 18 and the wall of the heating chamber 12. The reaction tubes 18 pass vertically downwardly through the chamber 12 and are spaced from each other in the form of a hollow square on centers of 2 tube diameters. In the structure shown in Fig. 1, the four burners 16 are disposed on the same horizontal level. Preferably, several such levels will be employed. Although four burners per level are shown in Fig. 1, one, two, three or four burners per level may be employed as desired.

In operation of the furnace of Fig. 1, fluid hydrocarbon is introduced into the burners 16 and ignited. The combustion gas streams are directionalized by the walls of the tunnel, and particularly the wall 17, so that the hot gases will pass between the tubes 18 and the wall of the furnace without detrimental flame impingement on the tubes. The gases which diffuse inwardly are completely oxidized and heat the tubes 18 by convection and radiation. The refractory furnace walls are highly heated by the peripheral flow of hot gas from the tunnels and radiate heat to the tubes. Due to the oblique surfaces involved, the gases from the burners are conducted smoothly around the tubes in a spiral path. The gases diffusing inwardly to form the protective blanket of fully oxidized gas also move generally spirally about and between the tubes and continuously bathe the tubes in an oxidizing atmosphere. The gases are withdrawn from a flue, not shown, at the top of the chamber and thus progress in an ascending path around the tubes. The eight angular internal surfaces add to the efficiency of the radiation from the refractory walls of the furnace to the reaction tubes. In addition to these eight walls the portions of the burner tunnel walls 19 extending beyond the termination point of the wall 17 also furnish radiation surfaces for the heating of the tubes 18. Due to the inclination of the wall 13 to the axis of the burner tunnel, the streams of hot gaseous heating medium emit from the tunnels through chamber wall faces which are obliquely disposed to the path of the streams emitting from the tunnels through the faces 13.

In Fig. 2, a single cell furnace 20 is shown which has a refractory brick wall structure 21. The outer cross-

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sectional configuration of the furnace 20 is rectangular. The inner cross-sectional configuration of the heating chamber 22 is circular and forms a continuously curving inner wall 23. Reaction tubes 24 pass vertically downwardly through the heating chamber 22 and are spaced from each other in a hollow square on centers of two tube diameters. Two burner tunnels 25 are formed at each burner level in the thickened corner portions of the furnace wall adjacent the corners of the structure. Fluid hydrocarbon burners 26 are mounted in the tunnels 25 and produce hot combustion gases for introduction into the chamber 22. In the structure shown, two burners are disposed at each vertical level but all gas streams emitting from the tunnels flow in the same direction around the chamber. As in the case of the octagonal internal configuration shown in Fig. 1, the use of a circular chamber 22 within the rectangular furnace 20 results in thickened corner portions for housing the burner tunnels 25 and the burners 26.

The operation of Fig. 2 is similar to that of Fig. 1. The hot combustion gases are directed between the tubes 24 and the furnace wall 23 by the short walls 27 of the burner tunnels and due to the circular configuration of the chamber are led in an even smoother fashion spirally around the tubes and downwardly to the flue (not shown) located at the bottom of the chamber. The protective inner blanket of fully oxidized gas is similarly formed by inward diffusion of the diluted combustion gas. The circular inner wall of the chamber is a very efficient radiant surface which produces radiation to all of the tubes from all angles, thus heating the tubes in a very efficient manner. As in Fig. 1, any desired number of vertical burner levels may be employed. More than two burners may be employed at any one horizontal plane if desired.

In Fig. 3, elongated reaction tubes 30 are anchored to a quench tank 31. A support flange 32 provided with stressing members 33 is formed about the upper portion of the tube above the arch of the furnace. The top of the tube is sealed by means of sealing flanges 34 and 35. Reactants are introduced into the tube through an injection tube 36. Upward tension is applied to the tube by means of hangers 37 which are secured to the support flange 32 at 38 and pass upwardly through a bracket 40. The hanger members 37 pass through compression spring mounts 41 and are secured above the mount by a nut 42. The brackets 40 are secured to the supporting channel irons 43 at 44 by suitable nuts and bolts. The channel irons 43 are welded to a support frame 45. Upward pressure is applied to the support frame 45 at each corner by a hydraulic jack 46 which is supported on an I-beam 47. The upward force applied by the jacks 46 is applied evenly to the support frame 45 and thus is transmitted evenly through the channel irons 43 to the hanger assembly 37. The spring mounts 41 are provided to compensate for individual stress conditions which may arise in any particular tube during operation and thus prevent failures due to a too rigid mounting.

By the means shown in Figs. 3 and 4, the desired amount of upward tension can be applied to the tubes without necessitating a sacrifice of temperature due to application of more than the necessary tension. Most of the weight of the tube and the catalyst it may contain is borne by the support below the hearth of the furnace. The hydraulic fluid to the jacks 46 may be manually or automatically applied as desired to produce and maintain the desired tension which is necessary with the particular temperatures employed in the furnace.

In Fig. 5, two levels of a three cell furnace 50 are shown to illustrate burner tunnel placement. Level A is the lower or ground level and level B is the second level in which the burners are vertically spaced from the burners in level A by any desired distance such as from two to three feet. The plans of these two levels are alternated until the desired height is reached.

Fig. 6 shows two levels of a four cell furnace 60 in

which the cells are arranged in the form of a square. Level A is the ground or first level and level B is the second level in which the burners and tunnels are vertically spaced from those of level A by the desired distance as in the furnace in Fig. 5. These plans are alternated until the desired height is reached.

In designing a furnace in accordance with the invention, it is preferred that the wall thickness at the thinnest point be normally no less than about 12 to 14 inches in order to obtain the desired heat capacity. It is at once apparent that burner tunnels of sufficient length cannot be had in a wall of this thickness. However, by employing the preferred octagonal, circular, or elliptical internal configuration of the chamber, the corner portions of the furnace become thick enough for the formation of burner tunnels, desirably about three feet in length. If desired, impingement devices or baffles may be employed within the tunnels to promote more rapid combustion.

As indicated, in a furnace composed of a single cell as illustrated in Figs. 1 and 2, firing may be effected from a single face, from two, from three or from all four furnace faces. Where two or more adjacent cells form the furnace, as in Fig. 5, firing will desirably be effected from two or three faces per cell. If four cells are employed to compose the furnace, as in Fig. 6, firing will advantageously occur from two faces of each cell. However, despite the number of cells or the number of faces from which the furnace is fired, advantage is gained due to the relative freedom from flame or hot gas impingement as described.

While it is necessary that the inner boundary of the gas streams or envelopes emitting from the tunnels do not cut the cross-sectional area of any of the tubes, the contacting of the wall of the furnace directly adjacent the mouth of the tunnel is desirable to highly heat the primary radiating surfaces.

As previously indicated, the angular or curved faces of the furnace opposite the mouth of the burner tunnels act as deflecting faces and direct the extended ends of the combustion envelopes or streams around the periphery of the chamber. Thus, where the burners are all aimed in a similar clockwise or counterclockwise direction, the gas will flow smoothly about the furnace in a direction parallel to the walls. This arrangement provides for minimum flow around individual tubes and is preferred. As indicated, however, if turbulence is desired it can be produced by opposed gas flow from burners aimed in opposite directions. While the burner tunnels shown are substantially horizontal, such disposition is not essential and the burners may be aimed upwardly or downwardly as desired to obtain the desired gas behavior and temperature control within the chamber. In general, it is desired that the angle of flare of the burner tunnel be between about 20° and about 30° for best results, although for specific purposes greater or less flare may be desirable. The use of tunnels in general not only provides for directionalization but broadens the group of fuels which can be employed. For example, residues from thermal cracking of oils, asphaltics and the like may be employed with excellent results.

With regard to tube spacing, it is not essential that each tube be spaced from the adjacent tube by the same distance. Any desired tube arrangement may be employed, such as parallel rows, on rectangular centers, in hollow squares or rectangles or in single or concentric circles and the like. The discovery that it is possible to obtain completely satisfactory results by the closer spacing of the reaction tubes in accordance with the invention makes it possible to obtain the same throughput with a smaller, less expensive furnace or to obtain greater throughput with a furnace of the size currently employed but having more tubes.

Where upward tube tension is employed, the hydraulic means shown in Figs. 3 and 4 is preferred with desired flexibility being introduced into the structure by spring

mountings for the individual tubes. Preferably, the tension will be applied to the reaction tubes by means of an automatically controlled hydraulic system which maintains the average tension on a supported group of tubes within reasonably close limits. Since reaction tubes in tension undergo slow axial creep, it is preferred that the tension be at a minimum which will provide freedom from binding and warping. In the application of upward tension to reaction tubes it is preferred to employ devices for measuring, indicating or recording the tension of one or more tubes showing average spring loading, although instruments may be employed to measure the individual tension on each of the tubes and to provide for rapid determination for the particular tube. Preferably one tube in each cell will be employed as a guide for control and its tension recorded by means of an oscillograph or other visible indicator. Although the application of any positive upward tension to the upper part of the tube is within the scope of the invention, it is preferred to employ only sufficient tension to counteract unequal expansion in the tube, to counteract binding stress against the tube, and yet sufficiently small to resist rupture at grain boundaries weakened by carbide precipitation, intergranular corrosion and/or chromium depletion.

In operation, cracking of tubes can be caused by sharp changes of stress due to slugs of condensate being introduced into the tubes. In a tube under downward tension the effect of sudden temperature change from water slugs results in a drastic effort to lift the entire mass within the tube. With a tube in upward tension, however, application of a similar water shock only causes the tube to contract in a normal and nearly effortless manner. When a tube has become warped or is just beginning to show warp, tension should preferably be increased either by applying additional tension to the entire support frame or at the springs supporting the individual tubes. In this way it is possible to apply tension in amounts ranging from just slightly positive to amounts that would exceed the short time yield point of the type of metal employed. For best results the amount of tension should be used which meets the objective of the particular condition encountered which may in some instances be as low as 10 p.s.i. but which normally will be well below the tension prevailing in tubes under downwardly applied tension which produces stretch at a rate of about ½ inch per year in a 25 foot tube.

Tubes in which partial combustion reactions are carried out can be seriously damaged by the high and fluctuating temperatures involved. This is particularly true in tubes subjected to downwardly applied tension wherein the high and often unnecessary amount of tension tends to pull apart the grain structure of the metal. Consequently, controlled upward tension in accordance with the invention is most beneficial in this type of reaction. Cast tubes with their characteristic large grain structure are likewise susceptible to shorter life because of the unnecessary high downward tension currently employed. Carbide precipitation and sigma phase formation augments this deleterious effect. Similar difficulties are encountered in the neighborhood of welds. Consequently, controlled upward tension also broadens the scope of use of cast and welded structures.

When putting a new furnace into operation in which upward tension is employed, it is desirable to adjust tension at intervals as the tubes are brought to their normal operation temperature. The tension should be stabilized at a level not in excess of 50 p.s.i. for a period of time and then adjusted thereafter as tube behavior is observed. It is especially advantageous in employing the invention to know the exact state of tension of the reaction tubes and it is desirable that in continuous operation the tension should be applied automatically to a predetermined level or else where a manual control is em-

ployed suitable warning devices be installed to give visible or audible indication that the tension is no longer within the desired range.

The jacks preferred for exerting upward pressure on the support members may be either manually or hydraulically controlled or may be automatic in operation. If automatic, the system will preferably be controlled by manually selecting and setting a pressure to be maintained in the hydraulic system. Alternatively, the pressure may be automatically controlled in accordance with the metal temperature of the tube. Springs may be substituted for jacks although the use of jacks is preferred.

Where upward tension is applied and the tubes are anchored below the furnace hearth, anchoring may be to a support member or to other apparatus employed in conjunction with the furnace such as a quench chamber or secondary furnace. Where a quench chamber is employed, the tube or tubes will preferably extend a short distance into the tank. Preferably, a single cylindrical tank will be employed and all of the tubes in a cell or series of cells will be anchored to the tank as described. Such a tank will preferably be disposed horizontally with its longitudinal axis immediately beneath the longitudinal axis of the furnace. The tank should be suitable to withstand pressures above atmospheric. Such a tank may be, for example, four or more feet in diameter and from ten to forty feet long in conventionally employed furnace sizes. The dimensions are not as important as the volume relationships to the tubes in use.

The above-described combination of a multi-tube arrangement with the support anchor forming a header which preferably is in itself a spray chamber, a container for quench liquid and a principal piece of apparatus in a circulatory quench system, comprising a pump, a waste heat boiler and spray, is an extremely efficient combination. In this combination the hot effluent from the tubes is almost instantaneously intermixed with injected quench media. Processwise a certain amount of volume is required in the quench chamber in order that the sensible heat of the gaseous effluent may be first reduced to condensate producing temperatures. The effluent upon continued cooling requires both sensible and latent heat removal. In current practice the gases are normally conducted outside of the furnace confines by conduits only large enough to suffice as conduits, whereupon the effluent enters fractionating towers or other cooling devices. Such conduits are highly unsatisfactory when the gaseous effluent from the reaction tubes contains high boiling materials which form tar or coke and the like on the hot walls of the process piping. The support anchor-quench system as described is highly advantageous in the avoidance of the formation of such detrimental solids or highly viscous material. Troublesome joints are eliminated and a simple equipment combination is substituted for the complex, thus facilitating control and operation continuity. Moreover, the immediate introduction of the effluent from the tube into a relatively large quench tank provides volume in the apparatus where it is most needed while utilizing the volume so provided as a path for the conducted, cooled effluent gas from the furnace confines.

If, for example, the particular cell or furnace employs three rows of 8-inch tubes disposed in the form of a hollow square centered at right angles to the axis of the quench tank and spaced apart on centers of two tubes diameters, the tank diameter will preferably exceed four tube diameters and would have a diameter of at least 32 inches. Actually, it is preferred to employ a tank for such a structure having a diameter of 4 feet or more. With regard to tank length, it is preferred to extend at least one end of the tank beyond the furnace as shown in Fig. 4 to take off composite gases substantially free of entrainment by means of a single conduit substantially directly into the nearest associated piece of apparatus, thus the tank itself performs a multiple function in being

a quench tank, a preliminary separator, and an effective conduit.

In operation of the quench system it is preferred to circulate quench liquid, normally condensate or of higher average boiling point, through a heat exchanger type waste heat boiler for generation of steam which may be employed either as process steam to the reaction tubes or injected with oil employed for oil firing in the furnace. The waste heat boiler and quench tank may be combined within a single piece of apparatus, although it is preferred to employ a separate waste heat boiler and a separate quench tank.

The gaseous effluent from the tubes will normally exceed a temperature of 1000° F. and it is therefore normally preferred to cool a part of the tank adjacent the tubes to maintain tank temperatures at a black heat or below to preserve physical strength. This cooling may be accomplished by means of a suitable jacket through which is circulated any suitable coolant. It is also preferred to employ some insulation around the joint between the reaction tube and the tank. The gaseous effluent will normally be cooled to a temperature of about 400° F. when a waste heat boiler is employed. During cooling substantial liquid hydrocarbon may be obtained dependent upon the feedstock, the type of cracking performed and the temperature of the coolant. This liquid is in part condensate and in part absorbed material which may be preferred to as cracking residue and may either be recycled to the tubes in admixture with fresh charging stock, withdrawn for further process treatment for upgrading and recovery of products of substantial value or employed as fuel.

The foregoing description with regard to quenching is primarily directed to processes and apparatus for the production of olefins. However, it is a further advantage of the invention that the tank itself or a smaller vessel, if desired, may be employed, in the same position, as a secondary furnace in a catalytic reforming or cracking process. Thus, the tank may be suitably equipped with charging ports in order that catalyst may be readily inserted and removed when the equipment is employed as a secondary furnace. Catalyst within the tank may be supported on a grid or catalyst may be introduced into the top of the tube and allowed to fall into the tank forming a cone beneath each tube and above the normal level of the catalyst bed within the tank. By this arrangement the catalyst forms its own support for the catalyst column within the tube and ultimate removal of tube catalyst is simplified in that the tube catalyst is dropped by simply withdrawing the secondary furnace catalyst. The length of such a cone may be readily controlled by extending the cracking tube into the secondary furnace tank for a greater distance.

The part of the tube extending into the tank may be perforated, if desired, to permit low resistance flow of gas from the cracking tube to the zone above the catalyst bed in the secondary furnace. The tubes may actually be extended in this manner all the way to the bottom of the tank, thus providing support for the tubes within the secondary furnace itself. In this case, an expansion joint must be provided inasmuch as the tube would then be fixed at two points, that is, within the secondary furnace and where the tube passes through the shell of the secondary furnace.

As indicated, the apparatus and process of furnacing may be employed for any desired reaction which lends itself to tubular processing. However, greatest utility will be found in the hydrocarbon field and particularly in the manufacture of hydrogen and olefins. All of the normally employed feedstocks ranging from methane through crude oils may be employed. In like manner the reforming and cracking catalyst employed by the art may be used in the catalytic reactions.

Since many modifications of the invention as disclosed will be apparent to those skilled in the tubular furnace

art, it is intended that the invention shall be limited only by the scope of the appended claims.

What I claim and desire to protect by Letters Patent is:

1. A tubular reaction furnace comprising in combination a shell comprising an elongated refractory walled heating chamber having spaced wall portions of greater thickness than the intermediate portions; metallic reaction tubes passing centrally through the said heating chamber and spaced from the said chamber walls; fluid hydrocarbon burners to furnish hot combustion gas to the heating chamber, supported so as to maintain burner nozzles thereof mounted substantially coaxially in elongated conduit type tunnels formed in the thicker portions of the chamber walls; said tunnels being positioned at a plurality of different levels about the periphery of said chamber and directed away from said tubes toward a point intermediate said tubes and a wall portion of said chamber, and each said tunnel being so disposed that a straight line drawn therein from the burner nozzle to a point at the end of the tunnel wall closest to said nozzle, will pass, when extended, without intersecting any of the tube surfaces.

2. In a tubular reaction furnace of claim 1 said reaction tubes being anchored below the heating chamber, and spring tensioning means above the heating chamber adapted to exert upward tension on the tubes from their anchoring point below the heating chamber.

3. A tubular reaction furnace of claim 1 in which the said tubes are spaced from each other on centers of from $1\frac{1}{2}$ to $2\frac{1}{2}$ tube diameters.

4. A tubular reaction furnace according to claim 1 in which the tubes are anchored to and in communication with a quench tank disposed below the furnace.

5. A tubular reaction furnace according to claim 1 in which the tubes are anchored to and in communication with a secondary furnace disposed below the first said furnace.

6. A tubular reaction furnace comprising in combination a hollow refractory walled shell, the cross-sectional external configuration of which is substantially rectangular and the cross-sectional internal configuration of which is substantially octagonal; four alternating sides of the resulting octagonal surface defining an elongated heating chamber, and each said side being substantially parallel with the hypotenuse of an isosceles right triangle incorporating a right angle defining an exterior corner of the shell and forming chamber wall portions of greater thickness than those formed by the remaining four intermediate sides; metallic reaction tubes passing centrally through the said heating chamber and spaced from the chamber walls; fluid hydrocarbon burners to furnish hot combustion gas to the heating chamber, supported so as to maintain burner nozzles thereof mounted substantially coaxially in elongated conduit type tunnels formed in the said thicker portions of the chamber walls, said tunnels being positioned at a plurality of different levels about the periphery of said chamber and directed away from said tubes toward a point intermediate said tubes and a wall portion of said chamber, and each said tunnel being so disposed that a straight line drawn therein from the burner nozzle to a point at the end of the tunnel wall closest to said nozzle, will pass, when extended, without intersecting any of the tube surfaces.

7. A tubular reaction furnace comprising in combination a hollow refractory walled shell, the cross-sectional

external configuration of which is substantially rectangular and the cross-sectional internal configuration of which is substantially circular to define a heating chamber formed by shell walls having thicker portions adjacent the external corners and thinner portions therebetween, metallic reaction tubes passing centrally through the said heating chamber and spaced from the chamber walls; fluid hydrocarbon burners to furnish hot combustion gas to the heating chamber supported so as to maintain burner nozzles thereof mounted, substantially coaxially in elongated conduit type tunnels formed in the said thicker portions of the chamber walls, said tunnels being positioned at a plurality of different levels about the periphery of said chamber and directed away from said tubes toward a point intermediate said tubes and a wall portion of said chamber, and each said tunnel being so disposed that a straight line drawn therein from the burner nozzle to a point at the end of the tunnel wall closest to said nozzle, will pass, when extended, without intersecting any of the tube surfaces.

8. In a tubular reaction furnace containing at least one metal alloy reaction tube, longitudinally, and centrally, extending through the heating chamber thereof; a plurality of conduit type tunnels in the chamber wall disposed at different levels about the periphery of the chamber; and a nozzle assembly in each said tunnel for supplying, and directing, hot combustion gas into said chamber so as to heat each such tube; the improvement comprising each said nozzle disposed coaxially with said tunnel containing same, and each said tunnel being directed away from all said tubes toward a point intermediate all of said tubes and a wall of said chamber, and each said tunnel being so disposed that a straight line drawn therein from the said nozzle to a point on the end of a tunnel wall closest to said nozzle, will pass, when extended, without intersecting any of the tube surfaces.

9. A tubular furnace of claim 8 wherein the angle of flare of at least one of the said burner tunnels is between about 20° and 30° .

10. In the improved furnace of claim 8 means for applying upward tension to each said tube comprising a beam assembly outside said chamber, operatively connected with the end of each said tube, above said furnace, as described hereinafter; a pair of spring mounts supported on said beam assembly, connected through said assembly with each said tube and adapted to impose variable stress against said beam assembly, and hydraulic lifting means operatively connected with said assembly for raising and lowering same.

11. A tubular reaction furnace of claim 8, anchored at a level below the said heating chamber, and spring tensioning means above the said heating chamber adapted to exert upward tension on the said tubes from the anchoring point below the said chamber.

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