Oct. 21, 1958 W. M. BOWEN III 2,856,905

HEAT GENERATING AND EXCHANGING DEVICE

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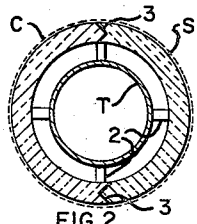


FIG. 2.

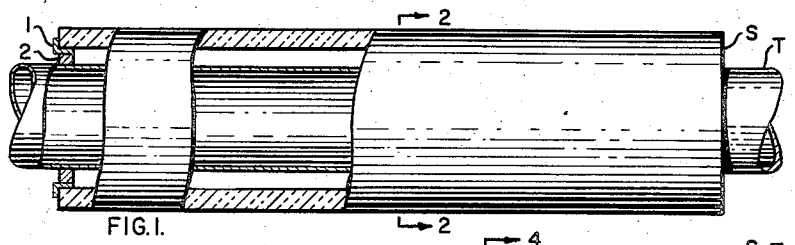


FIG. 1.

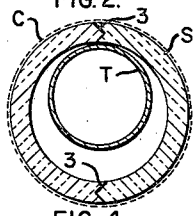


FIG. 4.

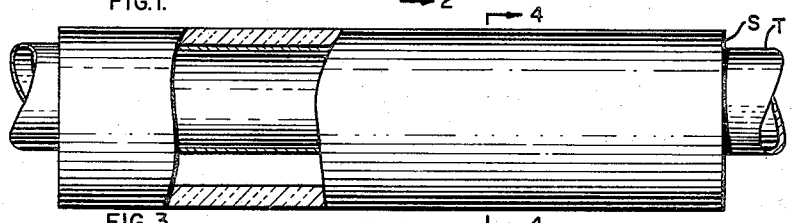


FIG. 3.

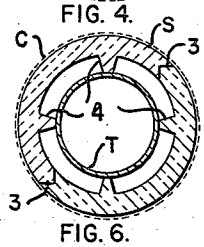


FIG. 6.

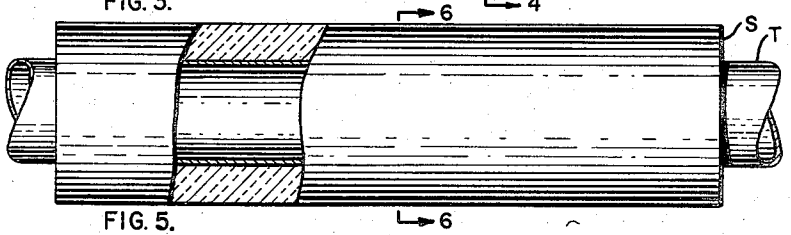


FIG. 5.

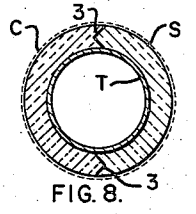


FIG. 8.

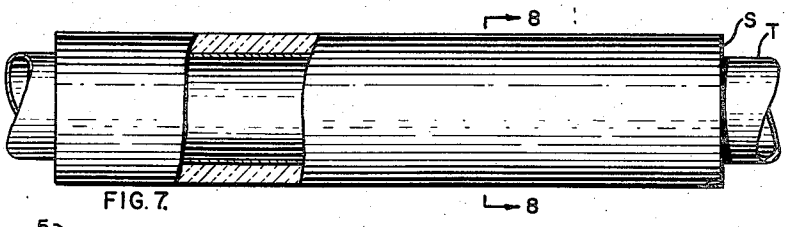


FIG. 7.

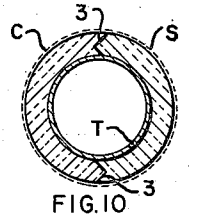


FIG. 10

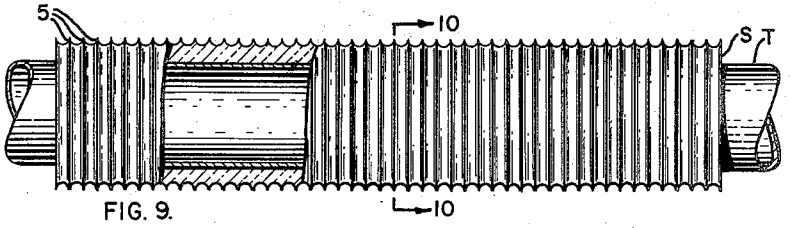


FIG. 9.

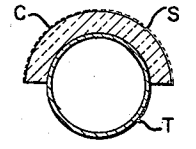


FIG. 12.

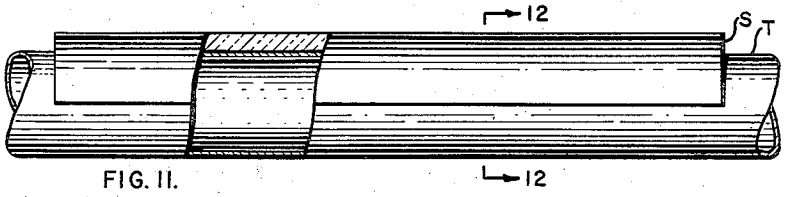


FIG. 11.

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HEAT GENERATING AND EXCHANGING DEVICE

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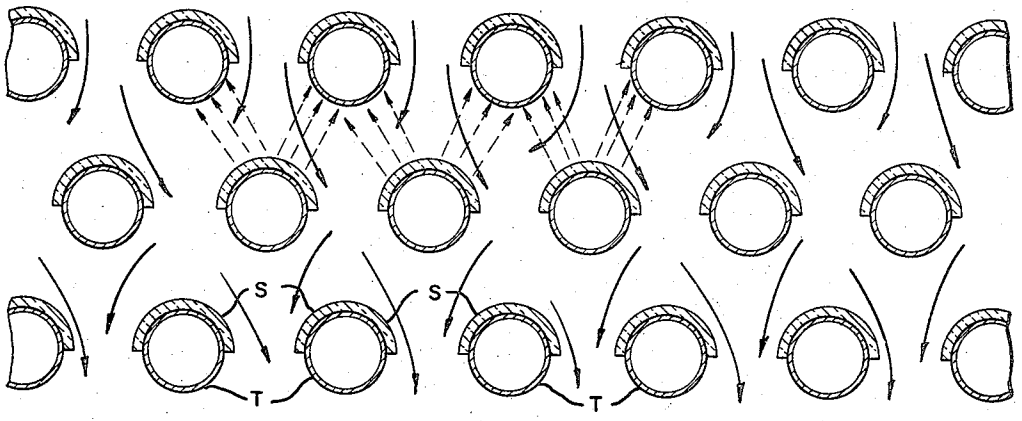


FIG. 14

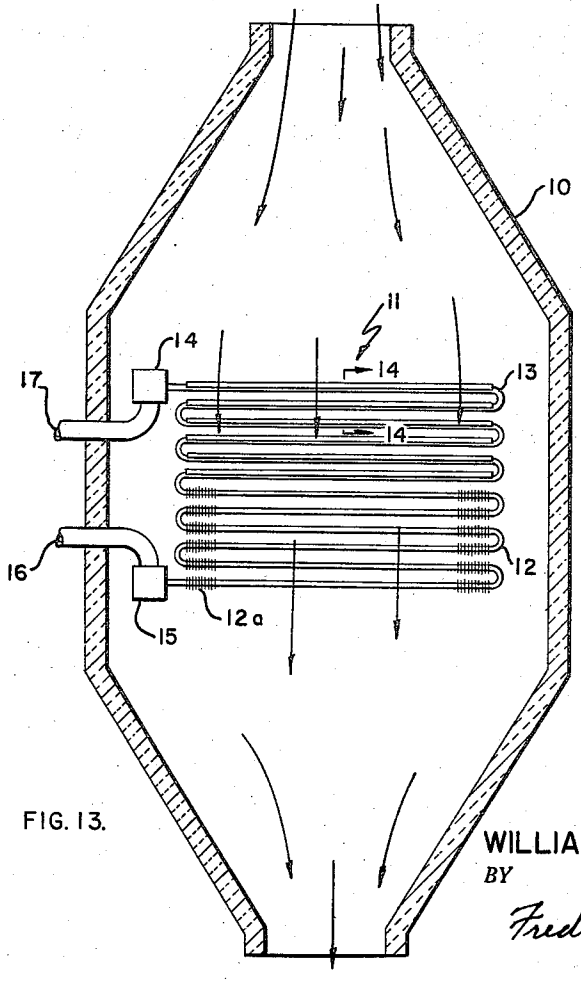


FIG. 13.

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HEAT GENERATING AND EXCHANGING DEVICE

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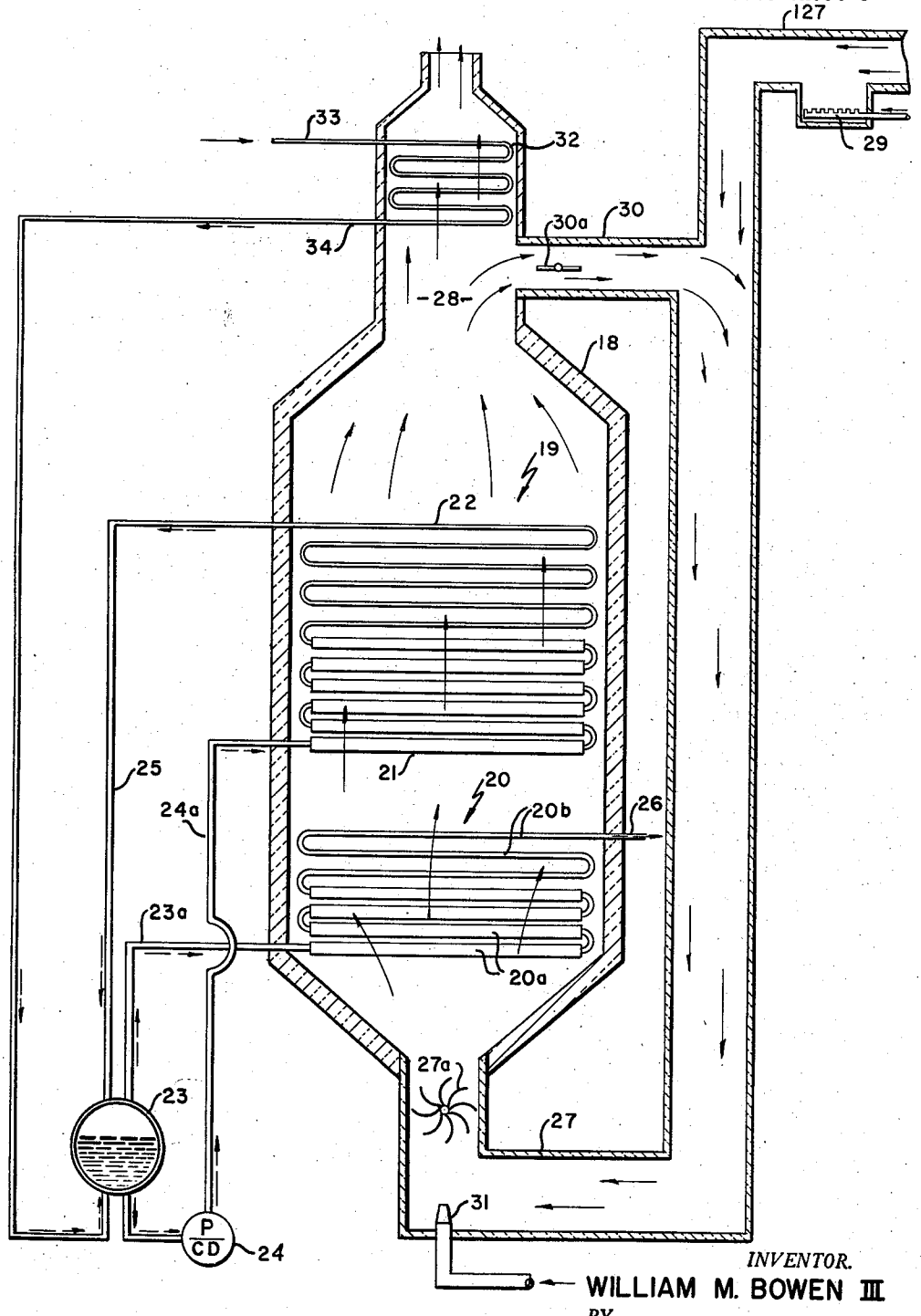


FIG. 15

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HEAT GENERATING AND EXCHANGING DEVICE

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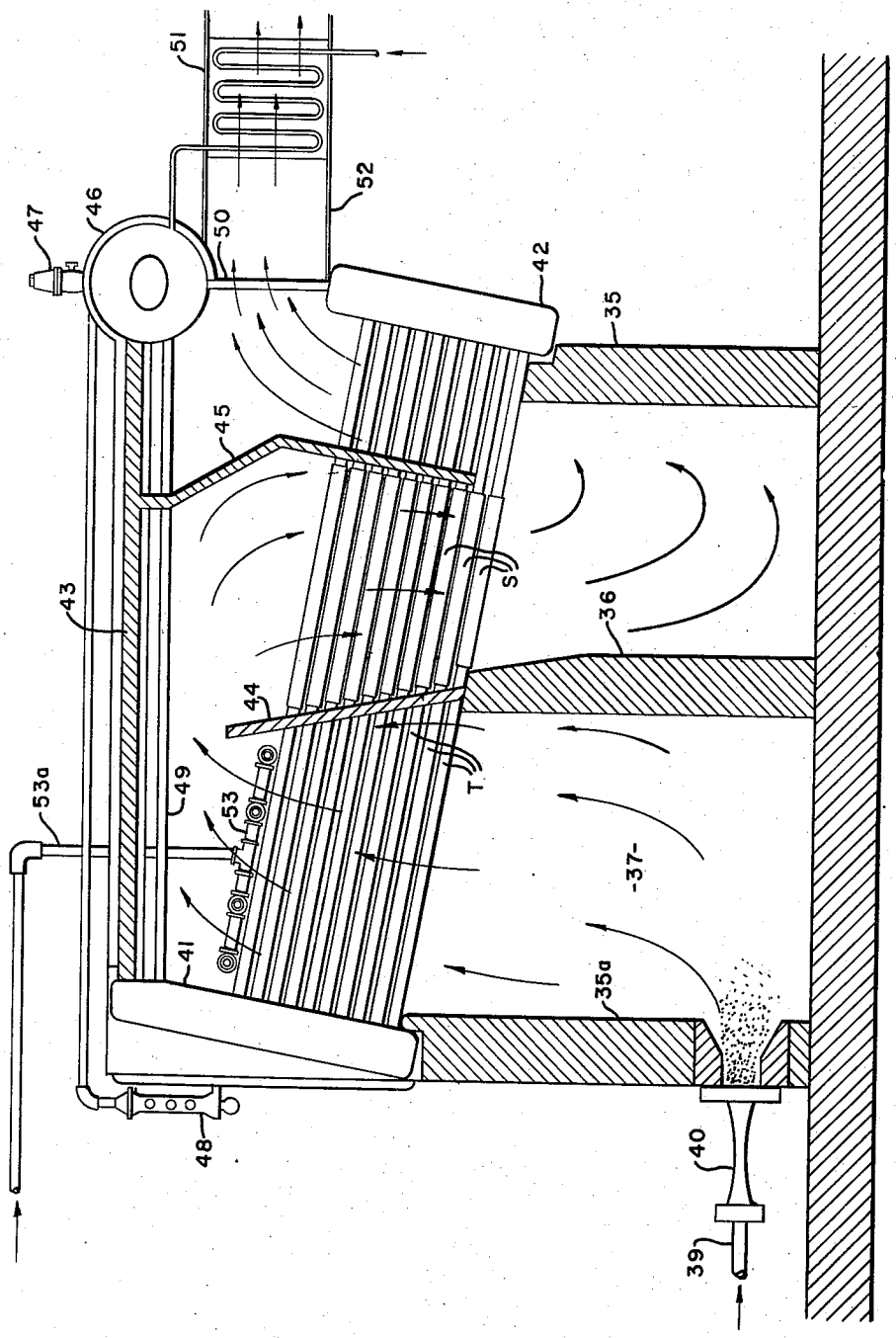


FIG. 16.

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United States Patent Office 2,856,905 Patented Oct. 21, 1958

2,856,905

HEAT GENERATING AND EXCHANGING DEVICE

William M. Bowen III, Paoli, Pa., assignor to Oxy-Catalyst, Inc., a corporation of Pennsylvania

Application April 4, 1955, Serial No. 498,876

15 Claims. (Cl. 122—236)

This invention relates to heat generating and exchanging devices of the type in which heat generated by the oxidation of a fuel is subsequently transferred across the walls of a heat exchanger.

It is an object of the invention to provide heat generating and exchanging means in which heat is generated by oxidation of a fuel in close proximity to a heat exchanger surface.

It is a further object of the invention to provide a heat generating and exchanging device in which heat is transferred to a heat exchanger surface by radiation and conduction.

It is a further object of the invention to provide heat generating and exchanging means in which the fuel is oxidized catalytically on a member disposed adjacent a heat exchanger surface, the member serving as a heat reservoir in radiant and conductive heat exchanging relationship with the heat exchanger surface.

It is a further object of the invention to provide heat generating and exchanging means operative to oxidize fuel with a minimum of excess air.

It is a further object of the invention to provide heat generating and exchanging means operative to utilize as fuels mixtures of combustible gases and oxygen which are outside the limits of flammability.

Further objects of the invention will be apparent from the description which follows.

It has long been known that when a fluid, such as a gas, flows over a surface, a quiescent film will be established between the surface and the moving body of fluid. Such films consist of a layer of fluid composed of particles which, relative to the moving body of fluid, are comparatively stationary. These films are a result of the friction developed by the moving stream of fluid and their exact nature under particular circumstances will depend upon such factors as the physical properties of the fluid, the velocity of the fluid in the moving stream, and the nature of the surface.

The film phenomenon briefly described above is of particular importance in the functioning of many common types of heat generating and devices presently employed. Taking by way of example the case of a water tube boiler, the fuel is burned in the boiler furnace to produce a continuously flowing stream of combustion products. In many cases the furnace of the boiler is equipped with water cooled walls in which case some of the heat released by the oxidation process will be transferred directly by radiation from the flame to these water cooled walls and to the fluid therein. The section of the boiler in which this heat transfer takes place is generally referred to as the radiant section and is characterized by relatively high heat transfer rates. The heat transfer processes which take place in this section of the boiler are not effected to any significant extent by the film phenomenon since heat can be readily transmitted by radiation through such films. However, in order to maintain a high rate of steam production it is necessary to burn the fuel at a relatively high rate and exhaust combustion products from the furnace which are at a relatively high temperature level. Efficiency of operation requires that a substantial portion of the sensible heat of these combustion products be recovered and this is usually accomplished by means of superheaters, boiler tubes, economizers, air preheaters and feedwater heaters. The combustion products flow over these devices and in doing so, give up a portion of their sensible heat to the fluid contained within the various heat exchangers which fluid may be steam, water or air.

Heat transfer of the latter type is generally referred to as convective heat transfer although the actual mechanism by which the transfer is brought about is not convection in the proper sense of the term. The sensible heat of the combustion products is, of course, transferred by convection from the furnace to the vicinity of the water tubes, superheaters, etc., in other words, by actual movement of the stream of gases containing the heat. However, the gases in flowing over the superheater tubes, water tubes, or other heat exchanging devices will establish films of the type briefly described above. The transfer of heat from the moving stream of combustion products to the heat exchanger surface, therefore, involves a transfer of heat across the films and this transfer takes place by the mechanism of conduction, that is by transfer from particle to particle. From these considerations it follows that the thermal conductivity of the gas comprising the film will in part determine the relative ease or difficulty of the heat transfer operation between the moving stream of combustion products and the heat exchanger surfaces in the convection section of the boiler.

As is well known, gases are extremely poor conductors of heat. Because of this fact, the heat transfer coefficient (as expressed in terms of B. t. u./deg. F./hr./ft.^{2} of surface) of the convection section of a boiler is relatively low and comparatively large surface areas are required in the convection section of the boiler to recover the sensible heat of the combustion products. While the heat transfer rates in the convection section of a boiler are affected by other factors (such as the thickness and thermal conductivity of the heat exchanger walls, the thickness of the deposit, if any, on the heat exchanger surface, etc.) the chief factor controlling these transfer rates is the thermal resistivity of the gas films.

While the problem involved in heat transfer by convection is described above with reference to a water tube boiler, the same problem exists in other types of heat exchangers such as devices designed to recover the waste heat of furnaces or ovens. It should also be mentioned that where the velocity of the gas stream is relatively low, as is often the case in waste heat recovery units, the thermal resistance of the gas film is particularly high since at low gas velocities the film is relatively thicker than is the case at high gas velocities.

The present invention provides a method and apparatus for oxidizing fuel in close proximity to the tubes of a heat exchanger in order to effect a relatively efficient transfer of heat to the tube surfaces by radiation and conduction rather than by the above described mechanism which is commonly called convection. In the practice of the invention the heat exchanger tube is provided with a sleeve in at least partially surrounding relationship thereto. The external surface of this sleeve provides a surface of oxidation catalyst so that when gases containing combustible components are passed over this sleeve, the combustible components in the gases will be oxidized. As a result the temperature of the sleeve will be raised to a relatively high level depending, of course, upon such factors as the calorific value of the gases and their inlet temperature, the mass of the sleeve, its heat capacity, etc.,

and the sleeve will transfer heat by radiation and/or by conduction to the tube of the heat exchanger. In this manner the detrimental effects of films in heat transfer operations are mitigated to considerable extent.

The principles of the invention are applicable in virtually all types of heat exchangers in which fuel is oxidized and at least a portion of the heat released is transferred to a fluid across the walls of a heat exchanger. In the case of a water tube boiler, the invention presents a means of increasing the amount of heat transfer which takes place by radiation as compared to conventional boilers. In the case of waste heat recovery units (of the type usable with exhaust gases from drying ovens where volatile solvents are vaporized, for example, or regeneration kilns for petroleum cracking catalyst) the invention provides a means of effecting radiant transfer of heat rather than purely convective transfer.

It should be mentioned that the advantages of catalytic oxidation, as compared to oxidation by flame, accrue to the practice of the invention. Particularly, the invention provides a means of recovering the chemical heat of gaseous mixtures containing combustibles in such minor amounts as to be outside the limits of flammability. The chemical heat of mixtures of this sort can ordinarily be recovered only if they are heated to a relatively high temperature or if their concentration of combustibles is increased. Such measures as these are often so costly as to render recovery of the chemical heat of the gases uneconomic. However, the chemical heat of the gases can be liberated catalytically by merely flowing the gases over a suitable catalyst maintained at a moderate temperature level. Also, where flammable mixtures of gases are oxidized catalytically, the process can be carried out with small percentages of excess air as compared to oxidation by means of a flame. This means, of course, that lower stack losses will result since the volume of the products of combustion is reduced. Finally it should be mentioned that where the fuel is oxidized catalytically, the need for burners and a combustion chamber is completely obviated.

Referring to the drawing,

Fig. 1 is a side view with parts broken away of a preferred embodiment of the invention.

Fig. 2 is a view taken along the lines **2—2** of Fig. 1.

Figs. 3 and 4, 5 and 6, 7 and 8, 9 and 10, and 11 and 12 are side views and sectional views respectively of alternative embodiments of the invention.

Fig. 13 is a sectional view of an embodiment of the invention as provided on a heat recovery unit.

Fig. 14 is a view taken along the lines **14—14** of Fig. 13.

Fig. 15 is a sectional view of a boiler constructed in accordance with the principles of the invention.

Fig. 16 is a sectional view of a conventional boiler as modified in accordance with the principles of the invention.

In the embodiment of Figs. 1 and 2 the letter T represents the tube of a heat exchanging device such as for example an economizer, boiler tube, superheater, or the tube of a waste heat recovery unit. In practice, a plurality of tubes or a continuous reversely bent tube will be provided. In either event, of course, a plurality of tube lengths will be disposed within a given volume of the heat exchanging device or boiler. The tube T may be adapted to accommodate the circulation of any fluid being heated such as water, steam, air or other gases or liquids. The reference letter S indicates a sleeve preferably of ceramic material which is disposed in surrounding relationship to the tube T. The sleeve S preferably extends for a substantial length coaxially with the tube T in that portion of the heat generating and exchanging apparatus through which the hot gases flow (i. e. the gases which give up heat to the fluid being heated). Tube S as shown in Fig. 1 is supported by means of an annular supporting member **1**, L-shaped in cross section, which is spaced from and secured to the tube T by means of members **2**. Preferably a support such as the support **1** is provided at each end of the tube S although intermediate supports may be provided if necessary. As indicated in Fig. 2, sleeve S is of bipartite construction, the meeting edges being provided with interfitting portions indicated by the reference numeral **3**. By virtue of this mode of construction, assembly of the sleeve S to the tube merely requires that the two half sleeve sections be placed over the tube and seated on the support **1**. If desired a suitable ceramic cement may be interposed between the meeting surfaces of the two sleeve halves or a suitable strap of temperature resistant metal, such as stainless steel, may be wrapped around the external surface of the sleeve S to secure the two parts together. The external surface of the sleeve is provided with a coating of oxidation catalyst preferably of a type which will be described in more detail below. This coating, indicated in exaggerated thickness by the dotted line C, should preferably be relatively thin and should be operative in elevated temperature ranges of the order of 800°–1800° F.

In operation of the embodiment of Fig. 1 the stream of hot gases containing some free oxygen and some combustible components such as carbon monoxide, natural gas, propane or other gaseous hydrocarbon or vaporized liquid hydrocarbon fuel, is passed over the sleeve S. The oxidation catalyst C on the surface of this sleeve will of course effect catalytic oxidation of the combustible components in the gases at, or in the immediate vicinity of, the coating. The heat released by this oxidation process will be in part transferred to the sleeve S and in part carried downstream by the gases. The heat imparted to the sleeve S will raise its temperature to a level preferably in the range of about 1200° F. to 1800° F. depending upon such factors as the concentration of combustibles in the gases, the rate of flow of the gases, the rate at which heat is extracted from the sleeve and the specific heat and mass of the sleeve. The internal surface of the sleeve S will, as a result radiate heat to the external surface of the tube T. The external surface of this tube T will be maintained at a comparatively low temperature which will be only slightly above the temperature of the fluid flowing within tube T. Since the rate of heat transfer by radiation is proportional to the difference of the fourth powers of the temperatures of the radiating and receiving surfaces, relatively high transfer rates can be achieved as will be described more fully below.

The film phenomenon previously discussed is of virtually no significance in the above described generation and transfer process. The sleeve S is heated by virtue of the fact that heat is generated by oxidation at, or in the immediate vicinity of, its catalytic surface C and the transfer of heat to the tube T by radiation is not signficantly affected by gas films.

Where a plurality of sleeved tubes of the type shown in Figs. 1 and 2 are provided in a single heat exchanging apparatus, the number of sleeved tubes provided should be sufficient to effect oxidation of substantially all of the combustible components of the gas stream being passed thereover. As the gas stream passes over successive sleeves its temperature will rise as its content of combustibles is oxidized. It should be noted, however, that the temperature of all of the sleeves tend to be relatively uniform; that is the first sleeve or bank of sleeves over which the gases flow will tend to reach approximately the same temperature level as the sleeves disposed downstream therefrom which effect oxidation of the last traces of combustibles in the gas stream. The gases after oxidation can be passed over conventional convection heat exchange surfaces in order to reduce their temperature and recover some of their sensible heat. These principles of the invention will be more apparent from the descriptions hereinbelow of specific heat exchanging apparatus constructed in accordance with the invention.

The equilibrium temperature which will be attained

by the sleeves S when the invention is incorporated into an apparatus such as a boiler or waste heat recovery unit will depend upon factors which determine the heat release rate of the catalyst and the rate at which heat is extracted from the sleeves. The heat release rate of the catalyst (in terms of B. t. u./hr./in.^{2} of catalytic surface area) will depend upon factors such as the type of catalyst employed, the activity of the catalyst at the equilibrium temperature and the mass flow of the gases and their calorific value. The rate at which heat is extracted from the sleeves will depend upon factors such as the area and temperature of tube surface available to receive radiation from the sleeves and the cooling effect of the entering gases. While any specific application of the invention will require an analysis of these various factors in the light of the precise operating conditions encountered, some general discussion can be presented here.

Generally speaking, for a given catalyst, the higher the calorific value of the gases and the higher the mass flow, the higher the heat release rate will be. Obviously, increasing either of these factors tends to increase the B. t. u. available for release by catalytic oxidation. The type of catalyst employed and its activity at the equilibrium temperature will also determine in part the rate of heat release since the activity of a catalyst (i. e. its capacity to effectively promote oxidation) varies for different catalysts and for a given catalyst varies somewhat with temperature. In general, a given catalyst will be more active at higher temperatures than at lower temperatures up to its maximum operating temperature.

As stated above the rate at which heat is extracted from the sleeves will depend upon the amount of heat lost by radiation, the entering temperature of the gases flowing over the sleeves and the heat lost by conduction if any. Heat lost by conduction from the sleeves S will be comparatively insignificant excepting in particular embodiments of the invention described below. As previously mentioned some of the heat released at the catalytic surface C will be used to heat the gases flowing thereover rather than being transferred to the sleeves S and the amount of heat thus imparted to the gas stream will, of course, be a function of the difference in temperature between the incoming and outgoing gases. The gases will generally leave a bank of sleeved tubes at or slightly below the sleeve temperature at the exit end. The amount of heat radiated from the sleeves will be dependent upon the tube area which effectively receives radiation from a given area of sleeve surface which in turn depends largely upon the size of the tube T relative to the size of the sleeve S; and the amount of heat thus radiated will depend also on the respective temperatures of the tubes and sleeves and their respective emissivities. From this standpoint, the radiating and heat receiving surfaces should preferably have high emissivities.

For any specific application of the invention several of the above-discussed variables such as the calorific value of the gases and the temperature of the fluid being heated (and therefore the temperature of the tube surfaces) may be fixed. For instance, it may be desired to provide a heat recovery unit for operation with gases containing about 6% CO at an inlet temperature of 800° F. to generate 400° F. saturated steam. With these conditions fixed, the heat recovery unit can be designed in such manner as to operate with maximum efficiency by varying the remaining factors. In any event, for satisfactory catalyst life, over-heating must be avoided since catalysts can be permanently damaged if heated above their maximum operating temperatures.

As previously mentioned, the sleeve S is preferably composed of ceramic material such as porcelain of the type used in spark plug construction. Porcelain of this grade is relatively stable at a temperature of 1800 or 2000° F. and provides an excellent base for the catalyst coating C which is described in detail below. The thickness of the walls of the sleeve S should be held to the minimum consistent with the provision of sufficient strength for the operating conditions of the sleeve. For example, where the tube T is of 2⅜" outside diameter, sleeve S can advantageously have an outside diameter of about 3½" and a wall thickness of 5/16".

Under some circumstances, it might prove feasible to provide metallic rather than ceramic sleeves as previously described. Metallic sleeves would offer some advantages in that the internal (radiating) surface of a metallic sleeve would maintain in operation a temperature very near the temperature of the catalytic surface because of the excellent thermal conductivity properties of metals. However, it should be mentioned that while catalysts of the type described below can be coated on ceramic surfaces with relative ease, the coating of a metallic surface with catalyst presents difficulties, particularly if the catalyst is to be operated at an elevated temperature in the range of about 1200° F.–1800° F. as with the present invention. It should further be mentioned that a metallic sleeve would of necessity have to be of a temperature resistant material and even with a relatively high quality material, serious limitations would be established as to the maximum obtainable temperature. Finally, it should be mentioned that iron containing materials are in general not suited as carriers for catalysts, particularly where the operating temperature is maintained at a relatively high level.

In the modification of Figs. 3 and 4, the sleeve S rests on the heat exchanger tube T and is supported on the upper surface thereof. This modification presents obvious advantages in that it can be assembled with relative ease, no supports of the type shown in Fig. 1 being required. As with the embodiment of Figs. 1 and 2 the sleeve S is of bipartite construction as indicated by the reference numeral 3 to facilitate assembly. The area of contact between the interior surface of the sleeve and the surface of the tube T will, of course, be at a comparatively low temperature because of direct conduction of heat from the sleeve to the tube. In view of this fact, precautions must be taken against thermal stressing of the sleeve which might cause cracks or failure. In all respects the operation of the embodiment of Figs. 3 and 4 is otherwise similar to the operation of the embodiment of Figs. 1 and 2.

Figs. 5 and 6 show an embodiment in which the internal surface of the sleeve S is provided with integral supports indicated by the reference numeral 4. These supports directly contact the external surface of the water tube T and thereby maintain the sleeve S in spaced relationship in the manner of Figs. 1 and 2. Such supports should preferably be so dimensioned as to permit free thermal expansion of the heat exchanger tube and the sleeve without the development of thermal stresses which might cause fracture.

Figs. 7 and 8 disclose a modification in which a bipartite sleeve S is provided in relatively close embracing relationship to the tube T. In this modification the sleeve S is directly supported by the tube as with the modification of Figs. 3 and 4. The very close relationship of the sleeve S and the heat exchanger tube permits some heat exchange by direct conduction in addition to radiation from the interior surface of the sleeve to the walls of the heat exchanger tube. Ceramic is highly preferable to metal in the practice of this modification of the invention for the reason that if the sleeve S in Fig. 7 is composed of metallic material having high thermal conductivity and if, furthermore, a relatively low temperature is maintained in the fluid being heated (for example 400° F.) the rate of heat flow from the sleeve to the interior of the heat exchanger tube may be sufficiently high to prevent the temperature of the sleeve S from rising to a level at which catalytic oxidation can proceed satisfactorily. As will be explained below, it is desirable to maintain temperatures

at the surface of the sleeve S in the neighborhood of at least 800° or 1000° F. in order to insure successful oxidation of the fuel. If the fluid circulating within the tube T is itself at a relatively high temperature (e. g. 750° F. or above) metallic sleeves in some cases may be practical with the embodiment of Figs. 7 and 8.

Figs. 9 and 10 disclose an embodiment similar in many respects to Fig. 8 and differing therefrom only in the provision of an extended surface on the sleeve S which is provided by grooving the external surface of the sleeve as indicated by the reference numeral **5**. This arrangement, of course, provides a larger surface of catalyst per unit length of sleeve with a resultant increase in the heat release rate per unit volume. Generally, extended surface as shown in Figs. 9 and 10 will be found to be most desirable where the temperature of the fluid within the tube T is relatively low since with an extended surface and high heat release rate it is necessary to extract heat from the sleeve at a relatively high rate to avoid overheating of the catalyst. It is understood, of course, that fins can be substituted for the grooves of Figs. 9 and 10 to further increase the amount of catalyst surface. It is also understood that extended catalytic surface might be provided on any of the previously described embodiments or those described below.

Figs. 11 and 12 disclose an extremely simple modification of the invention which presents particular advantages in heat exchangers providing a plurality of tubes within a relatively small space. In this embodiment the heat exchanger tube T is provided with a split sleeve S directly thereover. Again, the sleeve in this embodiment should be of ceramic rather than metal for reasons explained above with reference to the embodiment of Figs. 7 and 8. As there explained, metal sleeves have a strong tendency to give up their heat by conduction and if the fluid being heated is at a relatively low temperature the sleeve may not be maintained at the operating temperature of the catalyst. The sleeve S of the embodiment of Figs. 11 and 12 is by nature a split sleeve, and must, of course, be so oriented as to face into the gas stream. If the gas flow is downward, the sleeve can be supported on the tube T as shown. If the flow is upward it is necessary to externally support the split sleeve against the underside of the tube T by supporting brackets suspended from the heat exchanger tube or secured on the distributor or header of the heat exchanger. The external surface of the sleeve is provided with a catalytic coating as indicated by the dotted line C. In operation, of course, the gases flowing over the catalytic coating are oxidized to thereby raise the temperature of the split sleeve S and heat is subsequently transferred from the internal surface of the sleeve to the tube T by conduction and by radiation. This modification also permits more effective radiation by the external surface of the sleeve since in a bank of heat exchanger tubes this external surface will be in radiant heat exchanging relationship with the exposed surface of the tubes in adjacent banks as is explained in more detail hereinbelow.

The modification of Figs. 11 and 12 provides only one half as much catalyst surface as a sleeve of comparable diameter which extends fully around the tube T. However, all of the catalyst surface provided by this modification faces into the stream of gases and for this reason the surface provided is somewhat more efficiently utilized than with the modification in which the sleeve S extends entirely around the tube T. In other words, with the modifications of Figs. 1–10 the portion of the surface of the sleeve S which faces downstream is not as effective in promoting catalytic oxidation as the upstream facing portion since the downstream facing portion is not as effectively contacted by the gas stream as the upstream facing portion.

While it is not intended that the invention be limited to a particular catalyst, it should be mentioned that it has been found that catalysts consisting of activated forms of metal oxides impregnated with a finely divided metal have been found to be particularly effective in environments such as those of the present invention. In particular, activated forms of alumina, beryllia, thoria, zirconia or magnesia or mixtures of these oxides can be provided on ceramic or in some cases metallic surfaces. Such activated oxides in the practice of the instant invention are coated on the external surfaces of the sleeves shown in Figs. 1–12. These coatings of activated metal oxides are preferably of the order of 0.0005" to 0.015" thick, the preferred thickness being about 0.003". This coating of metal oxide acts as a carrier for finely divided platinum metal or other suitable metallic catalyst such as palladium, rhodium, ruthenium, silver, copper, chromium, manganese, nickel, cobalt, or combinations of these metals. Particularly good results are obtained for example when metallic platinum is impregnated on a thin film of activated alumina by impregnation of the alumina film with a platinum salt solution such as a solution of chloroplatinic acid followed by decomposition of the platinum salt in situ. Catalysts of this type are described more fully in the copending application of Eugene J. Houdry, Serial No. 312,152 filed September 29, 1952, for Catalytic Structure and Composition.

As previously pointed out, it is necessary to avoid overheating the catalyst during use. Catalyst of the type described above can be operated at temperatures as high as 1800° F. It follows that where such catalysts are incorporated into the present invention, the temperature of the radiating surface (i. e. the internal surface of the sleeve S) should be of the order of 1500° F. to 1700° F. depending, of course, upon the sleeve thickness and the thermal conductivity of the sleeve.

Figs. 13 and 14 disclose an application of the invention to a heat recovery unit for recovering the sensible and chemical heat of waste gases. In many types of industrial operations there is produced a stream of waste gases at an elevated temperature containing considerable combustible materials. However, as previously explained, the recovery of the chemical heat of such gases is generally rendered difficult, if not completely impractical, by the fact that the concentration of combustibles in the gases is relatively low so that in order to recover the chemical heat thereof it is necessary to preheat the gases to a high temperature, for example 1500° F., before they will burn. Such gases containing some combustibles at a somewhat elevated temperature are produced, for example, in the operation of many types of drying ovens where combustible solvents are volatilized, and in the operation of regeneration kilns for catalytic cracking processes where non-flammable gases at a temperature of about 900° F. containing in the neighborhood of 3 to 3% CO are produced. As will be apparent from the following description, the invention provides a particularly economical and convenient method of recovering heat in circumstances such as these.

In Fig. 13 the reference numeral **10** indicates a heat recovery chamber preferably lined with suitable refractory material. Disposed within this chamber is a tube bundle generally indicated by the reference numeral **11** consisting of reversely bent sections of tubing **12**, **13** which are connected at each end to distributor drums **14**, **15** which in turn communicate with fluid circulation pipes **17**, **16**. The section **12** of the tubing may be provided with conventional extended surface such as metallic fins **12***a* since this section of the tubing extracts heat from the gas stream by convection (only a portion of this extended surface being shown in the interest of clarity). The section **13** is provided with split catalytically coated sleeves S, as shown in Fig. 14, of the type described above.

In the operation of the device gases at an elevated temperature of, for example, 900° F. containing free oxygen and some combustible materials are passed downwardly through chamber **10** as indicated by the arrows. Upon

contacting the catalytic surfaces of the sleeves S of the section 13 of the tube bundle the combustible components in the gases will be oxidized and the temperatures of the sleeves and the gases will be raised.

As previously explained the sleeves will, in general, tend to assume a relatively uniform temperature, although some temperature gradient may be established over the tube bundle from the gas entering to gas exit side.

This relative uniformity of temperature probably results from the fact that when the gases first contact the catalytic surfaces of the sleeves S they are relatively rich in combustibles and for this reason a relatively high heat release rate is obtained. As a result these first sleeves are maintained at a relatively high temperature in spite of the fact that the gases flowing thereover are comparatively cool. At any point downstream the heat release rates will be somewhat lower because of the fact that the gases will have a lower concentration of combustibles but the temperature of the gases will be somewhat above the inlet temperature thereby compensating for the lower heat release rates at the surfaces of the sleeves. Furthermore, in the case of sleeves of the types which entirely surround the heat exchanger tube T (Figs. 1–10) some heat will be transferred from each sleeve to its neighbors by radiation, thereby tending to produce a substantially uniform sleeve temperature. With the split sleeve modification, however, this factor is negligible.

A portion of the heat released on each of the split sleeves will be transferred by radiation and conduction to its encompassed tube as previously described. Each of the sleeves will, in addition, radiate from its external surface to the tubes disposed upstream therefrom as clearly shown by Fig. 14. The undersides of the tubes T are, as shown, uncovered and since these undersides of the tubes will be at a relatively low temperature, substantial heat transfer will take place. Thus the split sleeves S of Figs. 13 and 14 will be cooled, both by radiation and conduction from their inner surfaces and by radiation from their external surfaces.

The rate at which heat is transferred from the sleeves S to the tubes T will depend upon the temperature difference between the sleeves and the tubes and the fuel mixture passed through the apparatus is preferably so adjusted that the sleeves S are maintained at a relatively high temperature level as previously explained. Since the sleeves S tend to assume a relatively uniform temperature level, as discussed above, relatively high heat transfer rates can be obtained throughout the sleeved tube section of the apparatus of Fig. 13.

The finned tube section 12 of the tube bundle serves to reduce the temperature of the gases and extract some of their sensible heat by ordinary convection transfer after all of the combustibles therein have been oxidized. The number of the finned tubes contained in the portion 12 and sleeved tubes of portion 13 of the tube bundle will be determinable from a consideration of such factors as the flow rate of the gases, the inlet temperature of the gases, the concentration of combustible in the gases and the relative activity of the catalyst. The extent of the sleeved tube portion of the tube bundle should, in any event, be sufficient to oxidize substantially all of the combustibles in the gas stream. Obviously there should not be an excess of sleeved tubes since, after the combustibles in the gas stream have been oxidized, the sleeves S would impede the transfer of heat to the fluid being heated which flows within the tubes T.

Where the heat recovery unit of Fig. 13 and 14 is utilized as a means of recovering the heat of the gases produced in the regeneration of hydrocarbon cracking catalysts, the inlet temperature will usually be about 700° F. to 900° F. and the gases will contain about 3% to 8% CO and sufficient free oxygen to effect complete catalytic oxidation of this CO. Such mixtures are non-flammable and cannot be burned by conventional methods unless the concentration of combustibles is increased by the addition of fuel or the temperature of the gases is raised to about 1400 or 1500° F. The present invention, however, permits the use of such gas mixtures without recourse to the addition of, or use of, fuel from an extraneous source. Furthermore, since a substantial portion of the heat liberated is transferred across the walls of the tube T by radiation the amount of heat exchange surface required is minimized.

As previously mentioned, the embodiment of Figs. 13 and 14 is operable with gas streams containing volatile combustible solvents and free oxygen. In the operation of drying ovens adapted to the volatilization of solvents, a stream of effluent is often produced which is of some calorific value although it must, for reasons of safety, be outside the limits of flammability. Such effluents constitute a serious air pollution nuisance because of the offensive odors of the solvents. The embodiment of Figs. 13 and 14 provides a means of eliminating this potential nuisance and recovering a substantial portion of the heat of oxidation of the solvents. Finally, it should be mentioned that the embodiment of Figs. 13 and 14 is operable with the mixtures of air or oxygen and ordinary fuel gases such as mixtures of hydrocarbon gases. By virtue of this fact, a heat recovery unit of the type shown in Figs. 13 and 14 can be operated even when the apparatus which ordinarily generates the gases used is shut down. For example, if the device of Fig. 13 is ordinarily operated with effluent from a drying oven and the oven is, for some reason, taken out of service, the device can nevertheless be operated on a mixture of city gas and air. Where such gaseous mixtures are employed, it is, of course, necessary to maintain the fuel concentration at a level such that the catalyst will completely oxidize the fuel.

Fig. 15 shows a steam generating plant constructed in accordance with the principles of the invention. In this figure, the reference numeral 18 denotes a refractory-lined chamber containing a tube bundle 19 and a superheater 20. Tube bundle 19 is divided into an upper convection heat exchange portion 22 and a lower portion 21, the tube sections of which are covered with catalyst-surfaced sleeves of one of the types previously disclosed. Superheater 20 is also provided with sleeves in its lower portion 20*a* while its upper portion 20*b* is devoid of sleeves. Feedwater is circulated from a drum 23 by means of a constant delivery feedwater pump 24 and line 24*a* through the tube bundle 19 and a mixture of saturated steam and water is returned to the drum by means of a line 25. Saturated steam is drawn off of drum 23 by means of a line 23*a* and circulated through superheater 20 to produce superheated steam in line 26. The heat imparted to superheater 20 and tube bundle 19 is provided by a mixture of combustible gases and oxygen which enters chamber 18 through a duct 27. In passing through chamber 18, the combustible portions of the gaseous mixture are oxidized upon contacting the catalytic surfaces of the sleeves which encompass the tube sections 20*a* of superheater 20 and the portion 21 of tube bundle 19. The unsleeved portion 20*b* of superheater 20 extracts some of the sensible heat of the gases and thereby prevents overheating of the catalyst. Heat is transferred by radiation from the sleeves to the tubes of the superheater portion 20*a* and tube bundle portion 21 by radiation in the manner previously described. The sensible heat of the gases is then recovered in part by the convection portion 22 of tube bundle 19. The gases then flow upwardly out of chamber 19 through an outlet 28.

Line 27 is supplied with air by line 127 which is provided with a burner 29 for preheating air which, as explained below, is used only on start up. A recirculation line 30 having a damper 30*a* therein connects line 27 with the outlet 28 in order that a portion of the spent gases can be intermixed with the air flowing in line 27. Gaseous fuel such as gaseous hydrocarbons or vaporized

liquid fuel is injected into the mixture of spent gases and air by means of a fuel injector **31**. A fluid impeller **27***a* driven by a motor (not shown) insures complete intermixing of the fuel with the spent gases and atmospheric air and forces the resulting gaseous mixture through the chamber **18**. The portion of the spent gases which are not recirculated through recirculation line **30** flow upwardly over an economizer **32** which extracts a portion of the remaining sensible heat of the gases. The economizer heats feedwater flowing in lines **33**, **34** supplied to the drum **23**.

In actual operation with, for example, propane as a fuel, air pre-heater burner **29** is started and air is drawn through line **27** under the influence of fan **27***a*. At start up, the air should preferably be heated to about 500° F. Gaseous fuel from injector **31** is intermixed with this stream of preheated air and the gaseous mixture passed through chamber **18** and over the catalyst surface of sleeves on the superheater portion **20***a* and the tube bundle portion **21**.

The unsleeved portions **20***b* of the superheater **20** have the effect of reducing the temperature of the gases after the initial catalytic oxidation reactions take place at the sleeved portions **20***a*. This permits a stepwise process of first oxidizing a portion of the propane in the gaseous mixture at superheater portion **20***a* to thereby raise the temperature of the gases to a level close to the maximum operating temperature of the catalyst and then cooling the gases by means of superheater portion **20***b*. As a result, gaseous mixtures can be used in the apparatus which contain relatively high concentrations of combustibles while at the same time avoiding the damaging effects of overheating the catalyst. In some instances it might prove desirable to provide several unsleeved tube portions (such as the unsleeved superheater portions **20***b*) interspersed throughout the apparatus and thereby permit repeated heating of the gases by catalytic oxidation up to the maximum operating temperature of the catalyst and cooling of the gases by convective heat exchange with unsleeved tubes. This arrangement is particularly feasible where the fuel gas used is of relatively high calorific value such as propane.

The sleeves will transmit their heat by radiation and to a minor extent by conduction from the sleeves, and by convection in the unsleeved tube sections to the fluid being circulated within the tube bundles **19** and **20**. The gases pass over the convection section of the tube bundle **19** which should preferably provide sufficient surface to reduce the exit gas temperature to about 1000° F. After leaving tube bundle **19** about one-half of the stream of gases for example, may flow through line **30** and be intermixed with approximately equal volumes of air in line **27** to produce a gaseous mixture containing about 10% O_2 at a temperature of about 500° F. The air preheat burner **29**, is of course, turned off when the process is started since the necessary preheat is supplied by the admixture of hot spent gases. The remaining portion of the spent gases in flowing over economizer **32** will have their temperature reduced to about 500° F. thereby minimizing stack losses.

The apparatus of Fig. 15 may be operated with a gas mixture which is outside the limits of flammability in order to entirely obviate the possibility of explosion. Where propane is utilized, for example, the gaseous mixture introduced into chamber **18** through line **27** should consist of not more than about 2% of propane and about 10 to 12% O_2. Since the lower limit of flammability of propane in air is 2.1%, and since such mixtures contain less O_2 than air, mixtures in this range are obviously nonflammable and, therefore, create no explosive hazards. Furthermore, such mixtures provide sufficient O_2 to effect substantially complete oxidation of the propane with little excess so that stack losses due to free oxygen will be minimized. Thus intermixing of the spent gases at an elevated temperature with air can be so regulated as to reduce the oxygen content of the gaseous mixture to the desired level while conserving a large portion of the sensible heat of the spent gases.

Flammable mixtures of propane and air may be used if precautions are taken against explosion such as maintaining a gas velocity in excess of the velocity of flame propagation. If a stoichiometric mixture of propane and air for example is used, it would be necessary to provide more convective heat exchange surface interspersed among the sleeved portion **21** of tube bundle **19** and the sleeved portion **20***a* of superheater **20** in order to avoid overheating and damaging of the catalyst. The use of, for example, a stoichiometric mixture of propane and air would, of course, provide a higher rate of heat release and therefore a higher rate of steam generation for an apparatus of given size. It should be pointed out that preheating of the air with a stoichiometric propane mixture could not be carried out as shown in Fig. 15 by admixture with spent gases since the method shown reduces the O_2 content to about 10 percent. With a stoichiometric mixture preheating would be accomplished by indirect heat exchange with the exit gases from the apparatus.

It is apparent from the foregoing that the embodiment of Fig. 15 provides a steam generating system which obviates the need of a furnace or combustion chamber and permits a substantial saving in space and capital equipment such as burners and high temperature refractories. The embodiment also provides for complete oxidation of the fuel without appreciable excess air and thereby minimizes stack losses. At the same time the advantages of radiant heat exchange, as in the furnace of a conventional steam generating plant are retained.

Fig. 16 discloses the manner in which a conventional boiler can be modified to incorporate the principles of the invention. In this figure the reference numerals **35***a*, **35** indicate the front wall and rear wall respectively of the boiler. A bridge wall **36** extends parallel to the front and rear walls and defines a combustion chamber **37** in which fuel is burned. In the disclosed embodiment gaseous fuel is supplied from a line **39** to a burner **40** mounted in front wall **35***a*. Headers **41**, **42** rest on the front and rear walls respectively and support therebetween a plurality of tubes T. The top of the boiler setting is covered over by means of a masonry roof **43**. Baffles **44**, **45** extend upwardly from firewall **36** and downwardly from roof **43** to force the gases flowing over the tubes to follow a tortuous path as indicated by the arrows. A steam drum **46** having an associated safety valve **47** and water level gage **48** is mounted upon the roof **43**. This steam drum is connected by means of lines **49**, **50** to the headers, **41**, **42** in order to permit circulation of the fluid therein. An enconomizer **51** is provided in flue **52** which accommodates the passage of gases from the tube section of the boiler. This economizer accommodates the circulation of feedwater supplied to drum **46**.

The portions of the tubes T disposed between the baffles **44**, **45** are provided with catalyst-surfaced sleeves S of one of the types previously described. Fuel injection means **53**, for injecting vaporized liquid or gaseous fuel into the stream of combustion products, is disposed upstream from these sleeved tubes preferably between the first and second passes of the boiler as shown. The fuel is supplied from a line **53***a*.

In operation, combustion of the fuel will take place in the combustion chamber **37**. It is understood that the fuel burned in combustion chamber **37** might be coal, oil or fuel gas and that the modification of Fig. 16 is operable with any of these although the use of gaseous fuel only is shown in the drawing. For whatever type of fuel used, the combustion thereof will ordinarily be carried out with a rather large percentage of excess air, which may be 15% to 50% or more, in order to insure complete combustion. This is common practice for the reason that if no excess air is used in the combustion of fuel, incom-

plete combustion will result and the stack gases will be found to contain combustible gases. However, the use of excess air militates against efficient operation since the volume of stack gases produced is increased. It follows that optimum conditions of operation require that excess air be supplied in amounts such that no CO, H_2 or other combustibles will be present in the stack gases although the percentage of excess air supplied should be held to the minimum level necessary to achieve this condition.

The gaseous products of combustion, consisting mainly of CO_2, H_2O, N_2 and free O_2 will flow over the sections of the tubes disposed above the combustion chamber and, in doing so, will give up a portion of their sensible heat to the fluid flowing in the tubes. For example, the temperature of the combustion products might be reduced from about 2000° F. to 800 or 1000° F. The gases are then enriched with fuel such as CO, propane, vaporized oil or other liquid or gasesous fuel injected by means of the injectors 53. The mixture then flows over the sleeved portions of the tubes of the second pass disposed between baffles 44 and 45. During passage, the injected fuel is oxidized by the catalytic surfaces of the sleeves thereby raising the temperatures of both the sleeves and the gases and consuming the free oxygen of the gases. Radiant and/or conductive transfer of heat will take place between the sleeves S and the tubes T in the manner previously described. Subsequently the gases, which may be at a temperature in the range of for example 1200° F. to 1800° F., flow over the sections of the tubes T in the third pass (between header 42 and baffle 45 and over economizer 15). During this travel of gases, convective heat exchange between the gases and tube and economizer surfaces will reduce the temperature of the gases to the desired level. Under some circumstances an air preheater might be provided downstream from economizer 51 in order to recover an additional amount of the sensible heat of the gases by convection.

The modification of Fig. 16 thus permits a substantial lowering of the free O_2 in the stack gases with an attendant improvement of overall efficiency. Furthermore, the heat transfer rates (B. t. u./ft.^{2}/hr.) of the second and third passes of the boiler are substantially higher than is the case with a conventional boiler by virtue of the oxidation process which takes place and the radiant transfer of the heat. In the third pass, higher transfer rates are achieved because of the fact that the combustion products are at a higher temperature as a result of the catalytic oxidation of the injected fuel. Because of these higher transfer rates, the steam producing capacity of the boiler is considerably higher than is the case with a conventional boiler.

While the embodiment of Fig. 16 is herein described with particular reference to the modification of existing boilers, it is understood that the principles of this embodiment are applicable to new construction. It is also understood that while one fuel injection station and one section of sleeved tubes is shown in the drawing, under some circumstances it may prove desirable to provide several fuel injection stations and several passes of the boiler with sleeved tubes.

The heat release rates, in terms of B. t. u./hr./ft.^{3} of sleeved tube volume obtainable in the practice of all of the embodiments of the invention, will depend upon the factors affecting the heat release rate of the catalyst (discussed hereinabove) and the amount of catalyst surface area provided per cubic foot. With a platinum-alumina catalyst of the type previously described heat release rates of up to 15,000 B. t. u./hr./ft.^{2} of catalyst surface are readily obtainable. If, in a particular embodiment, a bank of sleeved tubes is provided on centers spaced on equilateral triangles (as is conventional) with the spacing between sleeves being equal to the sleeve diameter, heat release rates of the order of 40,000 to 60,000 B. t. u./hr./ft.^{3} can be obtained where the sleeve diameter is 3". Higher heat release rates of the order of 80,000 B. t. u./hr./ft.^{3} of sleeved tube volume are, of course, obtainable if the sleeve diameter is decreased or if sleeves having extended surface are employed to thereby increase the catalyst surface area.

The invention thus provides heat release rates which compare favorably with those of a conventional furnace such as a gas fired boiler furnace where heat release rates in the range of 20,000 to 40,000 B. t. u./hr./ft.^{3} of furnace volume are commonly obtained. However, the comparison of heat release rates obtainable in the practice of the invention with those obtainable in a conventional boiler furnace is not entirely significant for the reason that where the fuel is oxidized in accordance with the principles of the invention, the need for a boiler furnace is entirely obviated and the reactions are carried out at the relatively low temperatures of 1600–1800° F. This results in a considerable saving of space as well as capital equipment such as refractories, burners, etc. Furthermore, the space within which the fuel is catalytically oxidized (i. e. the space within chamber 18 of Fig. 15 which is occupied by the sleeved tubes) provides a relatively large amount of radiant heat exchange surface per unit volume as compared with the radiant section of a conventional boiler furnace. In the latter case, only the tube-lined walls of the furnace combustion chamber and possibly a radiant superheater function to receive heat radiantly from the flame.

The fact that the reactions are carried out at comparatively low temperatures reduces the upkeep and replacement costs for any application of the invention. Refractories used in an apparatus embodying the invention are not subject to the severely high temperatures encountered in the furnace portion of a conventional heat generating and exchanging system and will therefore have a longer useful life. Furthermore, the fact that the normal operating temperatures are lower than in the case of conventional devices permits use of cheaper materials.

Embodiments of the invention, other than those of Figs. 13, 14, 15 and 16 will be apparent to those skilled in the art. For example, it is contemplated that the principles of the invention might be applied to a heat exchanger operating on automotive exhaust gases. Such gases contain up to 8% CO at idle and smaller amounts at partial or full load. In the light of the present invention automotive exhausts can be utilized in a heat exchanger to heat air for the passenger compartment of the vehicle since both the sensible heat of the exhausts and the heat of oxidation of the CO and other combustible components of the gases are available. Such a heat exchanger would comprise a plurality of tubes adapted to accommodate the circulation of the space heating air. Sleeves would be provided in encompassing relationship to some of these tubes in order to effect oxidation and radiant heat transfer as previously described. The remaining tubes would, of course, be adapted to recover sensible heat by convection.

Other modifications within the spirit and scope of the appended claims will be apparent to those skilled in the art.

I claim:

1. Heat generating and exchanging means for heating a fluid flowing within a tube comprising a ceramic member at least partially surrounding said tube, said member being in heat exchanging relationship with said tube, the exterior surface of said member providing a surface of oxidation catalyst whereby upon flowing a stream of gases containing free oxygen and combustible components over the external surface of said member, said combustible components are oxidized thereby raising the temperature of said member, and heat is transferred from said member to said tube to heat said fluid flowing within said tube.

2. Heat generating and exchanging means for heating a fluid flowing within a tube comprising a ceramic sleeve at least partially surrounding said tube, said sleeve being in heat exchanging relationship with said tube, the

exterior surface of said sleeve providing a surface of oxidation catalyst whereby upon flowing a stream of gases containing free oxygen and combustible components over the exterior surface of said sleeve, said combustible components are oxidized thereby raising the temperature of said sleeve and heat is transferred from said sleeve to said tube to heat said fluid flowing within said tube.

3. Heat generating and exchanging means comprising a tube adapted to accommodate the circulation of a fluid being heated, a ceramic sleeve at least partially surrounding said tube, said sleeve having an internal surface in radiant heat exchanging relationship with said tube, said sleeve having an external surface providing a surface of oxidation catalyst whereby upon flowing a stream of gases containing free oxygen and combustible components over said external surface, said combustible components are oxidized thereby raising the temperature of said sleeve and heat is transferred from said internal surface to said tube to heat said fluid circulating within said tube.

4. Heat generating and exchanging means comprising a tube adapted to accommodate the circulation of a fluid being heated, a ceramic sleeve at least partially surrounding said tube, said sleeve having an internal surface in radiant heat exchanging relationship with said tube, said sleeve having an external surface provided with a coating of oxidation catalyst, said coating comprising a film of catalytically active metal oxide having a thickness of not less than 0.0005" and not more than 0.015", said film being impregnated with a minor amount of finely divided catalytically active metal whereby upon flowing a stream of gases containing free oxygen and combustible components over said external surface, said combustible components are oxidized thereby raising the temperature of said sleeve and heat is transferred from said internal surface to said tube to heat said fluid circulating within said tube.

5. Heat generating and exchanging means comprising, a tube adapted to accommodate the circulation of a fluid being heated, a ceramic sleeve in surrounding relationship to said tube, said sleeve having an internal surface spaced from and in radiant heat exchanging relationship with said tube, said sleeve having an external surface providing a surface of oxidation catalyst whereby upon flowing a stream of gases containing free oxygen and combustible components over the external surface of said sleeve, said combustible components are oxidized thereby raising the temperature of said sleeve, and heat is radiantly transferred from the internal surface of said sleeve to said tube to thereby heat said fluid being circulated therein.

6. Heat generating and exchanging means comprising, a tube adapted to accommodate the circulation of a fluid being heated, a ceramic sleeve substantially coaxial with and in surrounding relationship to said tube, said sleeve having an internal surface spaced from and in radiant heat exchanging relationship with said tube, said sleeve having an external surface providing a surface of oxidation catalyst whereby upon flowing a stream of gases containing free oxygen and combustible components over the external surface of said sleeve, said combustible components are oxidized thereby raising the temperature of said sleeve, and heat is radiantly transferred from the internal surface of said sleeve to said tube to thereby heat fluid being circulated therein.

7. Heat generating and exchanging means comprising, a tube adapted to accommodate the circulation of a fluid being heated, supporting means on said tube, a ceramic sleeve supported by said supporting means in surrounding and coaxial relationship to said tube, said sleeve having an internal surface spaced from and in radiant heat exchanging relationship with said tube, said sleeve having an external surface providing a surface of oxidation catalyst whereby upon flowing a stream of gases containing free oxygen and combustible components over the external surface of said sleeve, said combustible components are oxidized thereby raising the temperature of said sleeve, and heat is radiantly transferred from the internal surface of said sleeve to said tube to thereby heat fluid being circulated therein.

8. Heat generating and exchanging means comprising, a tube adapted to accommodate the circulation of a fluid being heated, a split ceramic sleeve disposed coaxially with said tube, said split sleeve having an internal surface in heat exchanging relationship with said tube, said split sleeve having an external surface providing a surface of oxidation catalyst whereby upon flowing a stream of gases containing free oxygen and combustible components over said external surface, said combustible components are oxidized thereby raising the temperature of said split sleeve and heat is transferred from said split sleeve to said tube to heat fluid circulating therein.

9. Heat generating and exchanging means comprising, a tube adapted to accommodate the circulation of a fluid being heated, a split ceramic sleeve disposed coaxially with and partially surrounding said tube, said split sleeve having an internal surface disposed adjacent and in heat exchanging relationship with said tube, said split sleeve having an external surface providing a surface of oxidation catalyst whereby upon flowing a stream of gases containing free oxygen and combustible components over said external surface, said combustible components are oxidized thereby raising the temperature of said split sleeve and heat is transferred from said split sleeve to said tube to heat fluid circulating therein.

10. Heat generating and exchanging means for use in a gas stream containing free oxygen and combustible components comprising, a plurality of fluid carrying tubes disposed within said gas stream, some of said tubes being provided with ceramic sleeves in heat exchanging and at least partially surrounding relationship therewith and some of said tubes being devoid of sleeves, said tubes provided with sleeves being disposed upstream from tubes devoid of sleeves, the exterior surfaces of said sleeves providing surfaces of oxidation catalyst whereby the oxidizable components of said gas stream are oxidized at said surfaces to thereby raise the temperatures of said gases and said sleeves, and heat is transferred from said sleeves to said tubes provided with sleeves, and subsequently heat is transferred by convection from said gases to said tubes devoid of sleeves.

11. Heat generating and exchanging means comprising a plurality of spaced apart tubes adapted to accommodate the circulation of a fluid being heated, at least some of said tubes being provided with a split sleeve encompassing a portion of the exterior surface thereof and leaving a second portion unencompassed, the encompassed portion of the surface of each of said tubes being in heat exchanging relationship with the interior surface of its respective sleeve, said tubes being arranged relative to each other in such manner that unencompassed portions of the surfaces of individual tubes are in radiant heat exchanging relationship with exterior surfaces of split sleeves of adjacent tubes, the exterior surfaces of said split sleeves providing surfaces of oxidation catalyst whereby upon flowing a stream of gases containing combustible components over the exterior surfaces of said split sleeves, said combustible components are oxidized at said surfaces of oxidation catalyst thereby raising the temperature of said split sleeves and heat is transferred to each of said tubes and the fluid circulating therein from the interior surface of its respective encompassing spilt sleeve and from the exterior surfaces of split sleeves of adjacent tubes.

12. Heat generating and exchanging means comprising a plurality of spaced-apart tubes adapted to accommodate the circulation of a fluid being heated, each of said tubes being provided with a split sleeve encompassing a portion of the exterior surface thereof and leaving a second portion unencompassed, the encompassed portion of the surface of each of said tubes being in heat

exchanging relationship with the interior surface of its respective sleeve, all of said sleeves being arranged generally similarly with respect to each other in such manner that said encompassed portions of the exterior surfaces of all of said tubes and the exterior surfaces of all of said split sleeves face generally in a first direction, and the unencompassed portions of the exterior surfaces of all of said tubes face generally in a second direction opposed to said first direction whereby the exterior surfaces of said split sleeves are in radiant heat exchanging relationship with unencompassed exterior surfaces of adjacent tubes, the exterior surface of each of said split sleeves providing surfaces of oxidation catalyst whereby upon flowing a stream of gases containing combustible components from said first direction over said sleeves and said tubes, said combustible components are oxidized at said surfaces of oxidation catalyst thereby raising the temperature of said sleeves, and heat is transferred to each of said tubes and the fluid circulating therein from the interior surface of its respective encompassing split sleeve and from the exterior surfaces of split sleeves of adjacent tubes.

13. Heat generating and exchanging means comprising a plurality of spaced-apart substantially parallel tubes arranged in a plurality of substantially parallel planes, said tubes being adapted to accommodate the circulation of a fluid being heated, each of said tubes being provided with a split sleeve encompassing a portion of the exterior surface thereof and leaving a second portion unencompassed, the encompassed portion of the surface of each of said tubes being in heat exchanging relationship with the interior surface of its respective sleeve, all of said sleeves being arranged parallel and similarly to each other in such manner that said encompassed portions of the exterior surfaces of all of said tubes and the exterior surfaces of all of said split sleeves face in a first direction and the unencompassed portions of the exterior surfaces of all of said tubes face in a second direction opposed to said first single direction whereby the exterior surfaces of said split sleeves are in radiant heat exchanging relationship with unencompassed exterior surfaces of tubes in adjacent planes of tubes, the exterior surface of each of said split sleeves providing surfaces of oxidation catalyst whereby upon flowing a stream of gases containing combustible components from said first direction over said sleeves and tubes, said combustible components are oxidized at said surfaces of oxidation catalyst thereby raising the temperature of said sleeves, and heat is transferred to each of said tubes and the fluid circulating therein from the interior surface of its respective encompassing split sleeve and from the exterior surfaces of split sleeves of tubes in adjacent planes.

14. Heat generating and exchanging means for use with a gas stream containing combustible components comprising a plurality of tubes adapted to accommodate the circulation of a fluid being heated, at least some of said tubes being provided with a split sleeve encompassing a portion of the exterior surface thereof and leaving a second portion unencompassed, the encompassed portion of the surface of each of said tubes being in heat exchanging relationship with the interior surface of its respective sleeve, the exterior surfaces of each of said split sleeves and the encompassed portions of the surfaces of said tubes facing generally upstream and the unencompassed portions of the surfaces of said tubes facing generally downstream with relation to said gas stream, the unencompassed portions of the surfaces of at least some of said tubes being in radiant heat exchanging relationship with the exterior surfaces of the sleeves of tubes disposed downstream therefrom, the exterior surfaces of said sleeves providing surfaces of oxidation catalyst whereby said combustible components of said gas stream are oxidized at said surfaces of oxidation catalyst thereby heating said split sleeves, and heat is transferred to said tubes and said fluid circulating therein from the encompassing sleeves thereof and by radiant heat transfer from the exterior surfaces of sleeves disposed downstream therefrom.

15. Heat generating and exchanging means adapted to extract the chemical and sensible heat of a moving gas stream containing free oxygen and combustible components comprising, a plurality of tube lengths accommodating the circulation of a fluid being heated, a first group of said tube lengths being provided with split sleeves in surrounding relationship thereto and a second group of said tube lengths being devoid of split sleeves, said first group of tube lengths being disposed upstream of said second group, each of said split sleeves encompassing a first portion of its associated tube length and leaving a second portion unencompassed, the internal surface of each of said split sleeves being in heat exchanging relationship with its associated tube length, the external surface of each of said split sleeves being in radiant heat exchanging relationship with the unencompassed portions of tube lengths disposed upstream therefrom, the external surfaces of said split sleeves providing surfaces of oxidation catalyst whereby said combustible components of said gas stream are oxidized at said surfaces thereby heating said split sleeves and said gases, and each of said sleeves transfers heat to its associated tube length from its internal surface and to the unencompassed portions of tube lengths disposed upstream therefrom, and said gases subsequently flow over said second group of tube lengths thereby heating said second group of tube lengths by convection, said heat transfer to said tube lengths effecting heating of said fluid circulating therein.

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