Sept. 11, 1951 P. D'HUC DRESSLER ET AL 2,567,556

METHOD AND APPARATUS FOR REGULATING THE OPERATION OF AN OPEN-FIRE TUNNEL KILN

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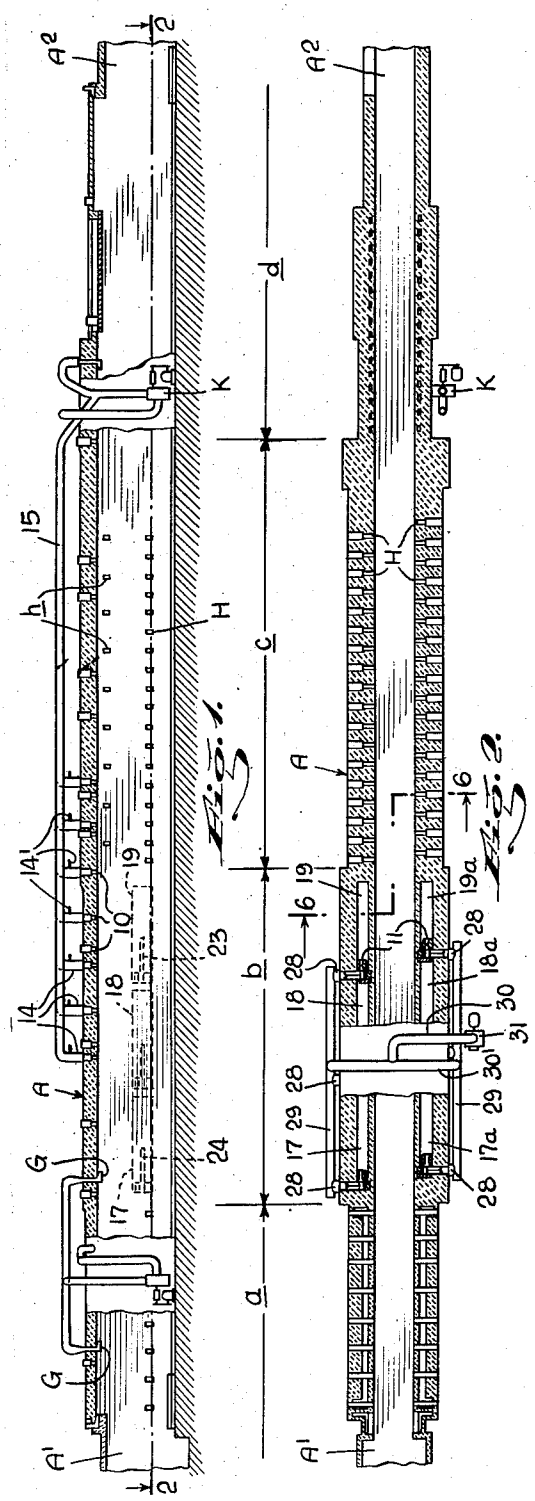


Fig. 1.

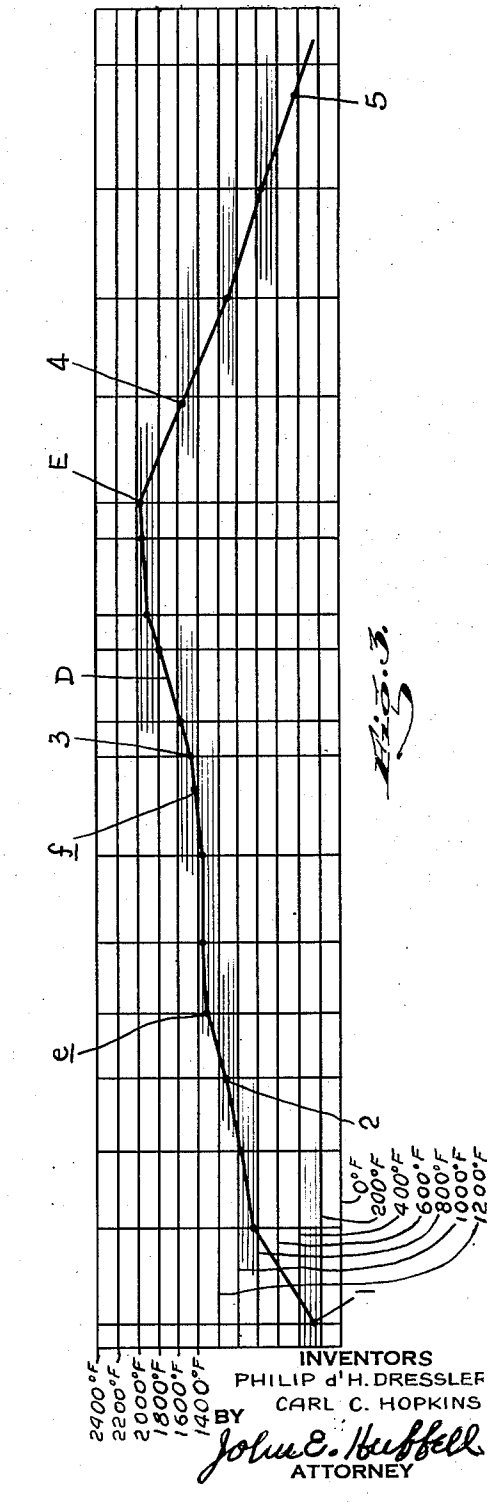


Fig. 2.

Fig. 3.

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Fig. 4.

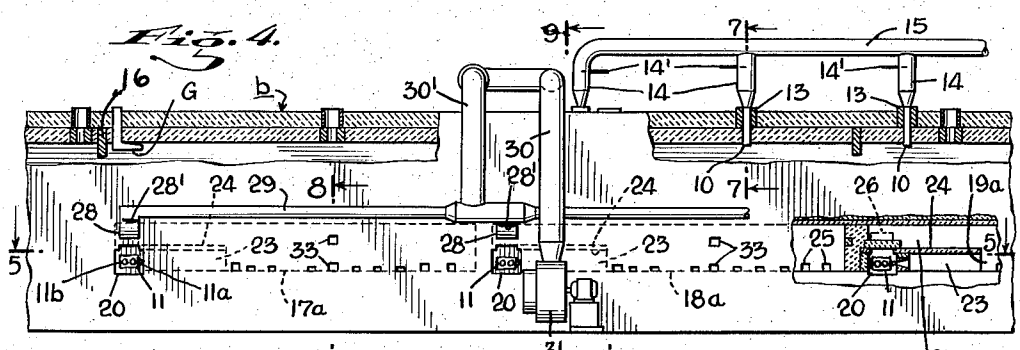


Fig. 5.

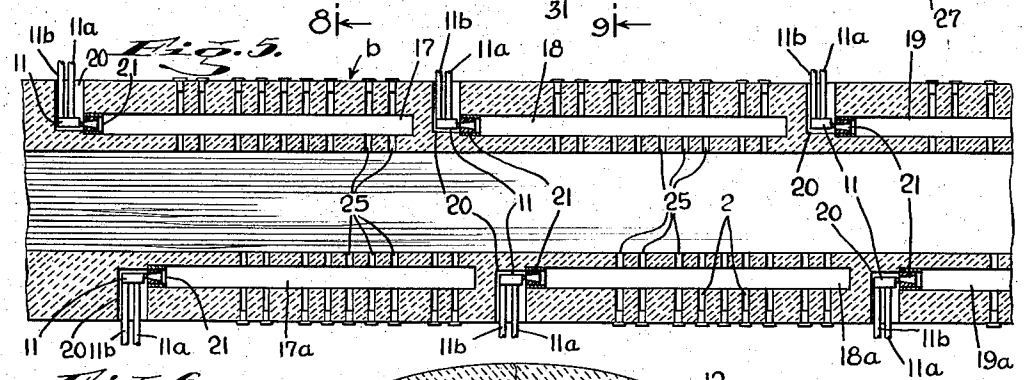
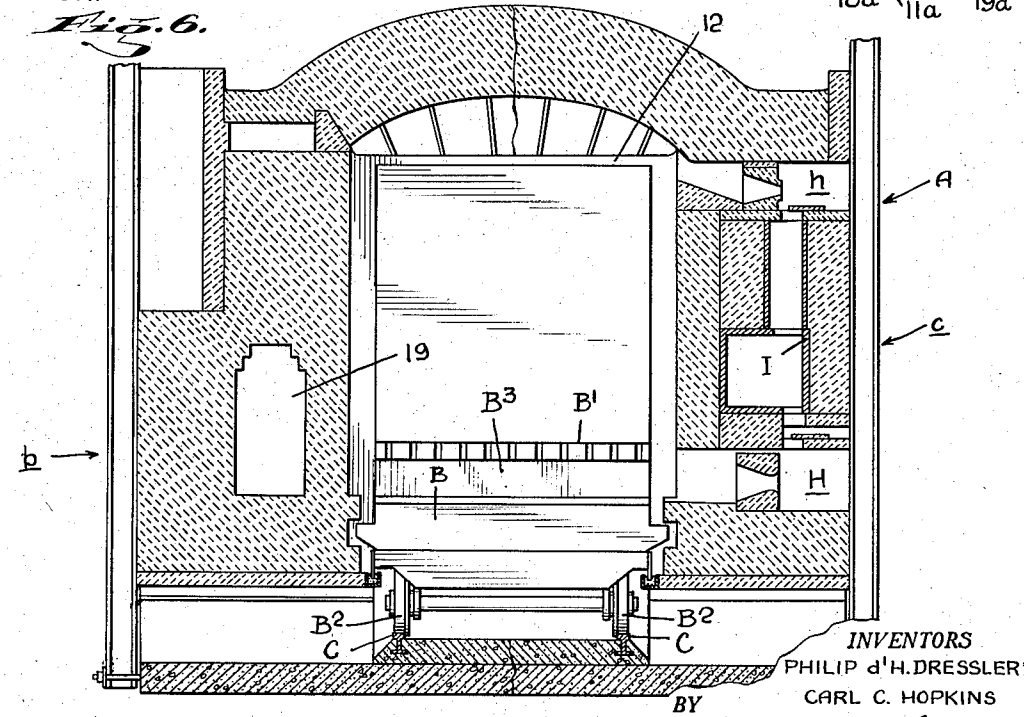


Fig. 6.



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Fig. 7.

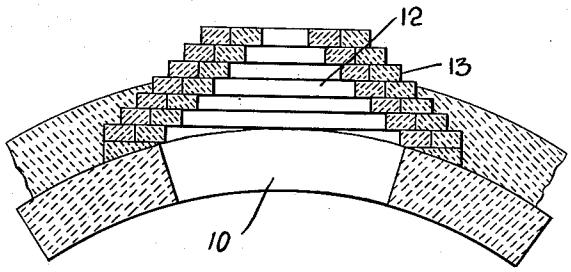


Fig. 8.

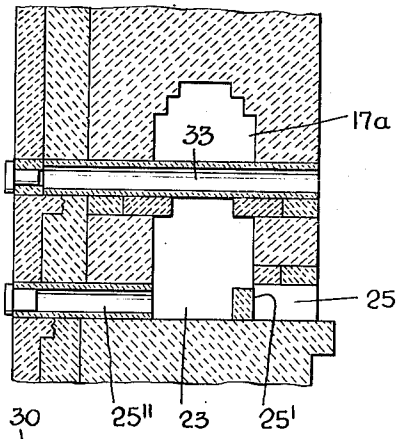
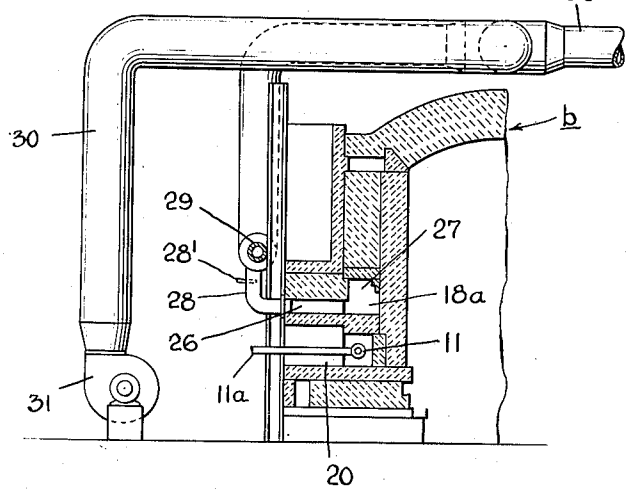


Fig. 9.



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2,567,556

METHOD AND APPARATUS FOR REGULATING THE OPERATION OF AN OPEN-FIRE TUNNEL KILN

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Application June 2, 1949, Serial No. 96,722

16 Claims. (Cl. 25—142)

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The general object of the present invention is to provide an improved method of, and improved apparatus for controlling the operation of an open-fire tunnel kiln of the usual type in which fuel is burned in a high temperature or firing section of the kiln chamber which is intermediate the ends of the kiln and from which heating gases pass through the kiln chamber to an outlet or outlets adjacent the entrance end of the kiln chamber. As material to be heated is moved through the kiln chamber from its entrance end to its exit end, the material absorbs heat from and cools the hot gases passing through the kiln chamber towards its entrance end from the high temperature or firing section of the kiln. In consequence, the kiln temperature tends to progressively increase from the entrance end of the kiln chamber to its high temperature section. Such progressive increase is practically desirable in many cases, but is objectionable in some cases.

One major object of the present invention is to provide a simple and effective method of and apparatus for retarding or preventing the usual temperature increase in a portion of the kiln chamber intermediate the entrance end and the high temperature section of the kiln. In some uses of open-fire kilns such retardation or prevention of the usual temperature increase is practically essential, or at least highly deirable. Thus for example, in the manufacture of silica bricks, the latter are subjected to a so-called quartz-inversion action at a temperature of about 1050° F., and it is practically desirable, if not essential, that during a period in which the quartz-inversion action occurs, and which is usually not less than fifteen hours, and not more than twenty-four hours, the temperature of the bricks should very slowly increase from about 1000° F. to about 1100° F. At the end of said period, a rapid increase in the temperature of the silica bricks is not objectionable, but during said period, a rapid temperature change is undesirable, and a small decrease from a brick temperature above 1050° F. to a brick temperature below 1050° F., will ruin or seriously injure the bricks.

A second major object of the present invention is to provide a practical method of maintaining an oxidizing atmosphere of suitable temperature and composition in an oxidation portion of an open-fire tunnel kiln of such length, relative to the rate of ware movement through the kiln, that each ware piece will be in contact with said oxidizing atmosphere for the period needed for the substantially complete oxidation of the oxidizable constituents of the wares.

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The maintenance of a substantially constant, optimum oxidation temperature in an elongated oxidation zone portion of an open-fire kiln is of especial practical importance in the continuous oxidation and firing of bricks, building blocks and other articles made from natural clays containing oxidizable material, and commonly designated heavy clay wares, and also in the manufacture from such clays of articles not so designated. The practically desirable oxidation temperature varies with conditions of which the character of the ware material is only one.

The ware oxidizing process is a combustion process which is necessarily slow because it requires the necessarily slow passage of combustion air into the ware bodies through their pores or capillary passages, and the necessarily slow outflow from the wares through said pores or passages of the gases of combustion formed. In practice, the oxidation process thus requires the maintenance of the wares at an elevated oxidizing temperature while enveloped in an oxidizing atmosphere for a suitably prolonged oxidizing period.

The range of oxidation temperatures which may be employed in the use of the present invention in producing ceramic wares of various forms, dimensions, structural characteristics and compositions, extends from about 900° F. to about 1700° F. Thus in the production of articles such as flower pots from surface clays of such character that the maximum maturing temperature is about 1650° F.–1700° F., the desirable oxidation temperature is about 900° F., while in the production of brick like bodies from certain clays so highly refractory that the ware maturing temperature is about 2300° F., the desirable oxidation temperature attained may be about 1700° F. In most uses of the present invention, however, we expect the desirable oxidation temperature to be considerably higher than 900° F., and considerably lower than 1700° F. In general, the optimum oxidation temperature maintained in any particular use of the invention will be approximately the maximum temperature permitting adequate oxidation of the particular wares produced without risk of having the normal oxidation action prematurely interrupted or hampered by the partial or complete closure of the ware pores or capillary passages. Such pore or capillary passage closure may result from the constriction of said pores or passages as the firing of the wares proceeds. It may also result, in the production of glazed wares, from the melting of the glaze coating material or some constituents thereof.

If the wares are heated above a suitable oxidizing temperature before their oxidation is completed, the proper completion of the oxidation action at the higher temperature becomes practically impossible, and the wares will be injuriously affected. When the wares are heated to a temperature at which the pores of the ware contract, or close as a result of the melting of a glaze coating, the inflow of air into the wares from the surrounding kiln atmosphere is slowed down. In such cases, further oxidation is effected in an undesirable manner by the reaction of the pyrites and carbonaceous material with oxygen contained in the ware material and desirably retained therein in its original form. Such delayed high temperature oxidation results in the formation of objectionable "black cores" in the ware, and in the formation of gases in the wares which cannot escape freely from the interior of the wares, and produce the undesirable ware expansion or bloating effects commonly referred to as "swell-bellies."

In general, the minimum required length of the oxidation period with any particular oxidation temperature, is dependent on the physical and chemical characteristics of the ware forming clay, and particularly on the porosity of the clay and on the character and amount of the clay constituents to be oxidized in the oxidation zone. Those contituents comprise pyrites and organic substances. The latter are commonly assumed to have resulted from the incorporation of vegetable and animal matter in beds of clay and shale forming materials. The organic substances are commonly referred to as carbonaceous material and are wholly or mainly in the form of carbohydrates, and as previously indicated, their oxidation temperatures may vary from about 900° F. to about 1700° F.

The oxidation of the pyrites constituent of heavy clay wares, involves the conversion of FeS_2 into FeS and SO_2, as the wares are heated in an oxygen containing atmosphere to a temperature of not less than about 900° F. On further heating of the wares to a temperature of about 1450° F., the iron sulphide FeS is converted into iron oxide Fe_2O_3 and sulphur dioxide. As the sulphide dioxide formed escapes from the wares into the enveloping atmosphere, it is converted into sulphur trioxide.

In the preferred mode of use of the present invention the wares will be maintained at some suitably predetermined, substantially constant oxidation temperature throughout the major portion of the oxidation period. Generally speaking, an increase in the oxidation temperature means a decrease in the duration of the oxidation period, and is practically desirable for that reason, as it permits a reduction in the length, and hence in the cost, of the kiln required for a given kiln output. The selection in any case of the duration of the oxidation period, and the approximately constant oxidizing temperature desirably maintained in a major portion of the oxidizing zone, should take into account the form, as well as the composition of the ware pieces, the lengths and diameters of ware pores or capillary passages and the character of the glazing material used when the wares produced are glazed. The oxidizing temperature maintained in the production of glazed wares may well be lower than it would be in production of unglazed wares of the same character and composition. The temperature at which the melting of glaze material may seal ware pores is usually between 1500° F. and 1600° F., but may

sometimes be as low as, or lower than 1400° F. In practice the required oxidation period is prolonged in some cases, as a result of the smoothing or slicking of more or less of the external ware surface. For example, when wares such as bricks or building blocks, are formed by the extrusion of elongated bars and the severance of the bars into short sections, the ware surfaces in sliding contact with the walls of the extrusion channel are smoothed and the outer ends of the pores extending to the smoothed surface are thereby closed in whole or in part. In such case, a large portion of the oxidizing air passing into the ware in the oxidation process must enter the ware pieces through their cut end surfaces.

In the practical use of the invention, moreover, the oxidizing temperature maintained may well depend in some cases, on the dimensions and other physical characteristics of the kiln, and on the kiln temperatures and the speed of ware travel through the kiln, found necessary to the production of a ware output of satisfactory volume and ware quality.

In its preferred form, the improved continuous tunnel kiln in which we oxidize and fire heavy clay wares, comprises an initial preheating section, an oxidation section, a firing section, a rapid cooling section and a final cooling section arranged in series in the order named between the inlet and exit ends of the kiln. In respect to most of its structural features and operating characteristics, our improved tunnel kiln need not differ significantly from known open-fire continuous kilns heretofore used in firing ceramic wares. Our improved kiln differs, however, from all prior kilns known to us, in respect to its provisions for supplying heat and oxidizing air to the oxidation zone of the kiln.

We have discovered that it is practically feasible to maintain suitable temperature and oxidizing conditions in the oxidizing zone of a continuous, open-fire, tunnel kiln by passing heating gases and air into the lower portion of said zone and by injecting air into the upper portion of the kiln adjacent the adjacent ends of the oxidizing and high temperature zones, in streams suitably directed and distributed to dilute, cool and depress the stream of products of combustion entering the oxidation zone from the furnace zone. In preferred forms of the invention, all or a substantial portion of the air needed to cool and dilute with oxidizing air the gases passing into the oxidation zone from the firing zone, is in the form of downwardly directed ribbon-like jets discharged into the kiln through transverse slots formed in the crown of adjacent end portions of the oxidation and furnace zones of the kiln, whereby said jets depress and rapidly admix with and cool and dilute the highly heated gases passing into the oxidation zone from the furnace zone.

In the preferred form of the invention, the oxidizing air supplied through the kiln roof slots is supplemented by air passed into the lower portion of the oxidation zone through the distributed outlet ports of fire boxes alongside the lower portion of the oxidation zone. The air thus passed into the lower portion of the oxidation zone is admixed with and cools and dilutes products of the combustion of fuel burned in the fire boxes. Advantageously the air thus passed into the oxidation zone through the roof slots is air which has been heated in cooling the ware in the cooling zone of the kiln A.

The various features of novelty which characterize our invention are pointed out with particularity in the claims annexed to and forming a

part of this specification. For a better understanding of the invention, however, its advantages and specific objects attained with its use, reference should be had to the accompanying drawing and descriptive matter in which we have illustrated and described a preferred embodiment of the invention.

Of the drawings:

Fig. 1 is a longitudinal sectional elevation of a continuous tunnel kiln;

Fig. 2 is a horizontal section taken on the line 2—2 of Fig. 1;

Fig. 3 is a graph illustrating the variation in ware temperature along the length of the kiln;

Fig. 4 is an elevation partly broken away and in section of the oxidation zone portion of the kiln shown in Figs. 1 and 2;

Fig. 5 is a plan section on the line 5—5 of Fig. 4;

Fig. 6 is a section on the broken line 6—6 of Fig. 2;

Fig. 7 is a partial section on the line 7—7 of Fig. 4;

Fig. 8 is a partial section on the line 8—8 of Fig. 4; and

Fig. 9 is a partial section on the line 9—9 of Fig. 4.

In the accompanying drawings we have illustrated a continuous, open-fire, tunnel kiln A, which embodies a preferred apparatus form of the present invention. The kiln A comprises preheating, oxidation, furnace or high temperature, and cooling sections *a*, *b*, *c* and *d*, respectively, extending in the order named from the entrance end A′ to the exit A^2 of the kiln. The wares treated in the kiln are moved through the latter on a movable hearth, customarily formed by the refractory platforms or ware supporting bodies B′ of a train of cars B, and forming the bottom wall of the kiln chamber. As cars move slowly through the kiln, at the entrance end A′ of the kiln cars are added one at a time to the rear end of the train, and at the exit end A^2 of the kiln cars are separated one at a time from the front end of the train. The car wheels B^2 run on track rails C.

The variations in the temperature of each piece of ware as that ware piece is progressively advanced from the kiln inlet end A′ to its outlet end A^2, in one successful commercial use of our invention, is shown by the temperature graph or curve D of Fig. 3. In Fig. 3, the curve points 1 and 5 show the ware temperatures at the entrance and exit ends of the kiln, respectively, and the points 2, 3 and 4 show the ware temperatures at the outlet ends of the kiln sections *a*, *b* and *c*, respectively. Except for the substantially horizontal portion of the curve D between its oxidation points *e* and *f*, the temperature curve D is generally characteristic of the operation of a continuous open-fire kiln, and indeed of practically all commercial continuous tunnel kilns whether of the open-fire or muffle heating type. In general all such kilns, as heretofore constructed and operated, are alike in that the ware temperature progressively increases from the entrance end of the kiln to a portion of the kiln in which the ware attains its maximum temperature E. Ordinarily, and as shown, the maximum temperature E is attained in the end portion of the high temperature kiln section *c* adjacent the cooling section *d*. Between the high temperature point E and exit temperature point 5, the temperature decreases at an average rate greater than the average rate of temperature increase between the points 1 and E.

The generally progressive increase in the temperature between the points 1 and E and the progressive decrease in the temperature from the point E to the point 5, are characteristic of the normal operation of the usual continuous tunnel kiln, and are natural results of the desirable regenerative heating and cooling actions which occur in continuous tunnel kilns. The maintenance of the required high temperatures in the furnace section C of the kiln, requires the supply of heating gases to that section of the kiln in substantial volume, and at a temperature necessarily higher than the temperature of the ware to be heated. The heating gases withdrawn from that kiln section carry away from the latter a large portion of the total amount of heat supplied to the kiln.

The hot heating gases withdrawn from the high temperature kiln section *c* move longitudinally through the kiln chamber from the section *c* to a point or points adjacent the entrance end of the kiln, at which the heating gases are withdrawn to a stack or exhaust connection. As the heating gases move from the high temperature kiln section *c* toward the inlet end of the kiln, the temperature of the gases would progressively decrease and the temperature of the wares would progressively increase, but for the special provisions made by us to retard or interrupt such progressive temperature changes in an oxidizing zone portion of the kiln. Those provisions fully described hereinafter include the introduction of cooling gases into an upper portion of the kiln, adjacent the connected ends of the kiln sections *b* and *c*, and include burners located in the preheating portion of the kiln and supplying some of the heat required to bring the wares up to their maximum temperature, and thereby producing local variations in the rate of ware heating at different points along the length of the kiln.

In the cooling section of a continuous tunnel kiln, the normal cooling action involves the transfer of heat from the wares being cooled to air which is passed into the kiln for cooling purpose, and is thus heated up as the wares cool down. A portion of the cooling air thus heated is customarily used as a combustion air in connection with fuel burners. Ordinarily more cooling air is supplied to the kiln than is needed for combustion purposes, and the excess heated cooling air is passed from the cooling zone to waste, or is used for some useful purpose as in preheating the wares passing from the entrance end of the kiln to its high temperature section.

As previously pointed out, the variation in the temperature of wares moving through the kiln A, and shown by the curve D, is typical in character of the operation of a continuous tunnel kiln, except for the horizontal portion of the temperature curve between the points *e* and *f* and the nearly horizontal portion of the curve D between the points *f* and 3. A ware temperature of about 1350° F. in the portion of the oxidation section of the kiln shown by the portion of the curve E between the points *e* and *f*, has been found to be practically ideal in the commercial use of the kiln A in oxidizing glaze coated, heavy clay products formed from certain clays containing a relatively large amount of pyrites and having a substantial carbonaceous content. The oxidation of the oxidizable constituents of the wares is a slow process because it is a combustion process and

involves the movement of sufficient oxygen into each ware piece through its pores for the combustion reaction, and requires the outflow through the ware pores of the CO^2 and other combustion products of the reaction.

In the particular commercial installation of the kiln A to which reference has been made, the oxidizing kiln section *b* is slightly more than sixty-two feet in length, the horizontal distance between the entrance and exit ends of the kiln is slightly greater than two hundred seventy feet, and the normal rate of kiln car movement through the kiln is such that the time required for the movement of each piece of ware through the oxidation kiln section *b* is about 21 hours, and the time required for the movement of each ware piece between the kiln points to which the temperature points *e* and *f* pertain, is about thirteen and one-half hours.

The ware temperature indicated by the flat portion of the curve D between its points *e* and *f*, is about 1350° F. as the curve D indicates, and is critical in that it is approximately the minimum temperature at which the combustion of the oxidizable constituents of the wares fired will not be unduly slow, and is about the maximum temperature at which the burning out of the oxidizable constituents of the wares will not be prevented, or seriously affected by the melting of one or more of the constituents of the ordinary glazed coating material applied to building tiles and blocks. The melting of glaze constituents close or choke the pore ends at the surface of the wares at which the melting occurs. As we explain later, it is readily possible to increase the length of the portion of the kiln in which an oxidizing atmosphere of approximately constant temperature and composition is maintained, when the ware composition and dimensions or other conditions of operation make this desirable. As we explain later, the portion of the kiln A in which a substantially constant oxidizing temperature and atmosphere is maintained, may be materially increased without any change in the kiln structure, with the possible exception of the addition of one or two air inlets into the kiln adjacent the junction of the sections *b* and *c*.

Our invention is characterized by the method and the apparatus provisions which we employ to maintain suitable and substantially constant temperature and composition conditions in a suitably prolonged oxidizing portion of the kiln between its entrance end and the portion of the kiln in which the ware temperature first increases to a suitable predetermined oxidizing temperature.

In respect to the structure of the portions of the kiln at the opposite ends of, and immediately adjacent the portion of the kiln in which oxidation is effected, the kiln A may, and in fact does follow well-known and approved prior art practice. For the purpose of the present invention, it is practically important that the wares passing into the oxidizing portion of the kiln should be uniformly heated, i. e., that ware temperatures at all points in a vertical plane transverse to the kiln at which the plane intersects the wares stacked on a kiln car, should be substantially equal. The preheating action of the kiln A may be speeded up, and the desired preheating uniformity insured by the use of exhaust and recirculating provisions of the character disclosed in the Phillips patent, 2,081,954 of June 1, 1937. The general purpose of such provisions is to neutralize longitudinal flow tendencies in the portion of the kiln adjacent its entrance end, which, if not neutralized, would result in higher temperatures adjacent the roof than adjacent the bottom of the kiln chamber. The neutralizing provisions preferably included in the kiln A, comprise a recirculating fan F and an exhaust fan (not shown) which withdraws heating gases from the lower entrance end portion of the kiln. The fan F also withdraws gases from the lower entrance end portion of the kiln, but returns those gases to the kiln through nozzles G discharging jets directed toward the exit end of the kiln into the upper portion of the kiln chamber.

The high temperature section of the kiln A comprises a set of lower burners H and a smaller set of upper burners *h*, each set being distributed along the length of the kiln section *c'*. Each of the burners H and *h* is supplied with fluid fuel, oil or gas under pressure by suitable piping, not shown, and discharges a horizontal jet of fuel into the kiln chamber effective to aspirate the necessary combustion air supplied through longitudinal ducts or chanels I in the side walls of the kiln, and preheated in the kiln cooling section *d*, generally as disclosed in the Dressler Patent 1,744,453 of January 21, 1930.

The cooling section *d* of the kiln may well be, and as shown is generally similar to the cooling zone section of the kiln disclosed in the Talbot Patent 1,804,657 of May 12, 1931. A characteristic feature of the Talbot patent is the forced recirculation of air supplied to the cooling section of the kiln for cooling purposes, and the use of air thus heated, as combustion air. The recirculating provisions preferably included in the kiln A comprise a recirculation fan K, which serves the important purpose of passing some of the air withdrawn from the cooling section of the kiln into the oxidation section *b* of the kiln chamber through the pipe 15. A second recirculation fan (not shown) may advantageously be associated with the cooling section *d* of the kiln A. Hot air passes directly from the cooling section of the kiln A into ducts I.

The described sections *a*, *c*, and *d* of the kiln A embody suitable forms of construction and arrangement for the purposes of the invention, and are preferred constructions for such use. However, the present invention may be used with advantage in continuous tunnel kilns comprising preheating, furnace and cooling sections, including none of the special features of the abovementioned Phillips, Dressler and Talbot patents.

The means which we have devised and use to maintain the desired atmospheric temperature and composition conditions in the oxidation section of the kiln, comprise means for discharging jets of heated air into adjacent upper portions of the kiln sections *b* and *c* through roof inlets 10, and means including fuel burners 11 for discharging products of combustion admixed with air into the lower portion of the oxidation kiln section *b* at points distributed along the length of the latter.

As shown, each roof air inlet 10 is in the form of an elongated arc shaped slot in the crown portion of the kiln wall and extending transversely to the length of the kiln. In the particular kiln structure illustrated, each slot is about two and one-half feet long at its lower end and is about two and one-half inches wide. The upper end of each slot opens into a corresponding chamber 12 of tapering form surrounded by a brickwork wall 13 extending upward from the kiln roof and having a central opening at its upper end which

receives the outlet or discharge nozzle end portion of a corresponding pipe 14. The pipes 14 are branches of a sheet metal pipe 15 into which the previously mentioned fan K discharges air drawn from, and heated in, the cooling section of the kiln. As diagrammatically shown in Fig. 1, each branch pipe 14 is provided with a slide damper 14' by which the amount of air discharged into the kiln through that branch pipe may be individually regulated. As shown, there are four roof inlets 10 distributed along approximately the half length of the kiln section *b* adjacent the kiln section *c*, and three inlets 10 distributed along the portion of the kiln section *c* adjacent the section *b*, the spacing of the different inlets 10 along the length of the kiln being shown in Fig. 1. In the particular kiln installation illustrated, the wide or ribbon-like downwardly directed air jets discharged into the upper portion of the kiln chamber through the three last mentioned roof inlets 10 have been found effective to adequately dilute and cool the products of combustion moving into the oxidation section *b* from the high temperature section.

As is made apparent by the temperature curve D, the temperature of the air passing into the kiln through each inlet 10 is necessarily some hundreds of degrees below the average gas temperature maintained in the oxidation section *b* in the major portion of which the ware is maintained at an approximately constant temperature of about 1350° F. In addition to their cooling and diluting action, the wide, downwardly directed jets of hot air discharged into the upper portion of the kiln through the roof inlets 10, form baffles or barriers which neutralize the tendency to the flow of an overly large portion of the gases from the furnace section *c* into the upper portion of the oxidation section *b*, and which thereby increase the portion of the gases entering the section *b* at lower levels. The tendency to an undesirably large longitudinal gas flow in the upper portion of the kiln is also opposed by transverse roof baffles 16 distributed along the length of the kiln.

As shown, there are three burners 11 at each side of the lower portion of the kiln chamber in the oxidizing section *b*. Each of the burners 11 discharges into an elongated fire box, there being three fire boxes 17, 18 and 19 in end to end relation at one side of the kiln chamber, and three generally similar fire boxes 17*a*, 18*a* and 19*a* at the opposite side of the kiln chamber.

Each of the burner chambers is in effect an elongated duct formed in the lower portion of the corresponding side wall of the furnace. Each burner 11 is located in a corresponding burner chamber 20 formed in the kiln side wall at the end of the associated fire box nearest to the entrance end of the kiln. Each burner discharges into the corresponding fire box through the orifice in a burner block 21 forming a part of the end wall of the corresponding fire box chamber. Each burner 11 is supplied with fluid fuel which may be either oil or gas, through a branch 11*a* of a fuel supply distribution pipe system, and combustion air may be supplied to each burner 11, through a branch 11*b* of the distribution system which supplies combustion air to the previously mentioned burners in the furnace section of the kiln.

As shown, the fuel and air supplied to each fire box through the corresponding burner block 21 is received in an initial combustion space 23 which is separated by a horizontal partition wall 24 from the portion of the fire box above the space 23. The wall 24 extends away from the head end of the fire box for a distance of about three or four feet. The end of the space 23 remote from the head end of the fire box is open. Each fire box is provided with a plurality of horizontal outlet ports 25 in its side wall adjacent the kiln chamber. The outlets are arranged at such a level that the jets discharged into the outlets pass directly into transverse channels B^3 formed in the masonry body portion of the kiln cars B. The outflow through each outlet port 25 may be cut off or variably throttled by a slide brick damper 25' in the fire box. Each slide brick 25' may be adjusted by a bar extended into the fire box through an opening 25'' in alignment with the corresponding port 25 and formed in the outer wall of the fire box. Each opening 25'' is normally closed by a plug or closure which may be removed when necessary for inspection purposes, or to permit slide brick adjustments.

The combustion products discharged from each fire box through its outlets 25 are admixed with air supplied to the fire box. As shown dilution air is supplied to each fire box through a wall passage 26 above the burner chamber 20, and opening into the portion 27 of the fire box which is parallel to the end above the partition wall 24. Each of the three dilution air inlets 26 at each side of the kiln, receives air through a corresponding branch 28 from a horizontal sheet metal pipe 29 external to the kiln and alongside the latter. As shown, the air supply connection 28 to each chamber 27 is provided with a slide damper 28' through which the flow of air into the corresponding chamber 27 may be independently regulated. As diagrammatically shown, each of the two pipes 29 at the opposite sides of the oxidation zone, receives air through a corresponding branch 30' of the outlet pipe 30 of a fan or blower 31 provided to pass dilution air into the various fire boxes 17—19*a*. The fan 31 draws air from the atmosphere, and the air which it passes into the fire boxes suitably reduces the temperature of the mixture of air and products of combustion passed into the lower portion of the kiln section *b* through the fire box outlets 25.

In consequence, of the tendency of the kiln atmosphere to be substantially higher at the top of the kiln chamber than at the bottom of the chamber, it is practically desirable that the gases passing into the lower portion of the kiln section *b* from the fire boxes 17—19*a* through their respective outlets 25, should be at a temperature appreciably above the average kiln atmosphere temperature in the adjacent portion of the kiln. It is also desirable, that the temperature of the gases in the intermediate fire boxes 18 and 18*a* should be higher than the temperatures in the fire boxes 17 and 17*a* which are nearer to the entrance end of the kiln and lower than the temperature in the fire boxes 19 and 19*a*, which are more remote from the entrance end of the kiln. In practice, the gas temperature may well be about 1900° F., in the fire boxes 17 and 17*a*, and about 1750° F. in the fire boxes 18 and 18*a*, and about 1600° F. in the fire boxes 19 and 19*a*. As will be recognized by those skilled in the art, the kiln and ware heating effects of the gases passing into the kiln chamber from each of the fire boxes depends upon the amount as well as the temperature of the gas passing into the kiln chamber, and may be regulated by adjustment of the slide brick dampers 25'.

The relatively cool air supplied through the roof inlets and the relatively hot air and gas mix-

ture supplied through the fire box outlets 25, coact in maintaining the constant oxidizing zone temperature of about 1400° F.

For use in determining what damper and fuel supply valve adjustments are required, openings may be formed, as is customary, at suitably distributed points in the furnace wall to receive thermocouples permanently mounted in the furnace structure. In addition, openings such as the openings 33 shown in Fig. 3 may be formed in the side walls of the kiln to facilitate measurements of the temperature of the wares stacked on the slowly moving kiln cars.

A desirable feature of the fire box arrangement illustrated is the introduction of the fuel and combustion air as well as the dilution air into the end of each fire box adjacent the entrance end of the kiln so that in consequence, the gas flow in each fire box is in the same direction as the movement of the wares through the kiln. Heretofore, in kilns having heating arrangements including elongated fire boxes at sides of the kiln chambers, it has been the universal custom, so far as we are aware, to so pass fuel and combustion air into the fire boxes that the direction of gas flow in each box is counter to the direction of the ware movement in the adjacent kiln chamber. We have discovered that by making the general direction of heating gas movement in each fire box parallel to the direction of ware travel we can obtain a better heat distribution than is obtainable when the direction of such heating gas movement is counter to the direction of ware movement.

We believe that the advantage just mentioned is explained, in part at least, by the piling up of the heating gases in the end portion of each fire box remote from the fire box burner. Such piling up is attended by an increase in the static pressure of the gas in the end of each fire box remote from the kiln inlet end A'. In consequence, the outflow of heating gas through each fire box port 24 is greater at the fire box end remote from the inlet end of the kiln than at the end of the fire box nearer to the kiln inlet A'. When the direction of gas movement in each fire box is counter to the direction of ware movement in the kiln chamber, there is a hump in the temperature of the kiln adjacent the end of each fire box nearest to the entrance end of the kiln. This results in undesirably sudden ware temperature increases which are avoided with our arrangement, in which the heating gas flow in each fire box is parallel to the direction of ware movement through the kiln.

We believe that the operation of the apparatus illustrated and the preferred mode of practicing the invention will be apparent from the foregoing description and the accompanying drawings without further explanations. It is noted, however, that in considering kiln temperature conditions, it is convenient to treat the kiln chamber as comprising four longitudinal zones, namely, an initial heating zone, a constant temperature oxidizing zone, a final heating zone, and a cooling zone, and that these zones need not be, and as shown, are not co-extensive with the four kiln sections, *a*, *b*, *c*, and *d*. Thus the left hand end of the constant temperature oxidizing zone indicated by the point *e* in Fig. 3, is displaced to the right from the point 2 which indicates the junction of the kiln sections *a* and *b*. The point *f* of Fig. 3, which indicates the right hand end of the constant temperature zone, is at the left of the point 3 which indicates the junction between the oxidizing kiln section *b* and the furnace or high temperature kiln section *c*. Furthermore, the kiln temperature at the point 4 which indicates the junction of the furnace kiln sections *c* and cooling section *d*, is displaced to the right from the high temperature point E of the furnace section *c*. In the longitudinal portion of the kiln chamber between the points *e* and 4 the wares are substantially cooled.

It is to be noted, moreover, that while the points 2, 3 and 4 of Fig. 3 represents the junctions of structurally different sections of the kiln, and are fixed points of the kiln structure, the temperature zone separating points *e*, *f* and E are subject to adjustment longitudinally of the kiln by changes in operating conditions, such as may be produced by adjustment of the dampers 14', 25' and 28'. It is also to be noted that the exact temperature of the ware on a kiln car entering, at A', the kiln may vary from the temperature of the external atmosphere to a temperature which may be 100° or more above the temperature of the external atmosphere, depending upon operating conditions, and particularly on the temperature of the body of the kiln car when loaded with wares, and the time interval between the loading of the car and the introduction of the loaded car into the kiln.

While the operation of the particular kiln installation illustrated and herein before referred to has been highly satisfactory with the kiln output for which the kiln was designed, we now believe that the inclusion in the kiln of an additional pair of fire boxes similar to the existing fire boxes and between the entrance end of the kiln and the fire boxes 17 and 17*a*, would make possible a substantial increase in the kiln output with no reduction in the quality of oxidized wares produced in the kiln.

As will be apparent, the kiln illustrated particularly, if provided with an additional pair of fire boxes adjacent the entrance end of the kiln as just described, could be used in the production of silica brick without change other than adjustments of burners, fire box outlets and air inlets as required to maintain a quartz-inversion zone temperature of about 1050° F. during a period of from about 15 to about 24 hours. In such use of the kiln it is not necessary to maintain an oxidizing atmosphere in any portion of the kiln, and the air introduced into the kiln through the fire boxes and roof inlets as hereinbefore described, might be replaced in some cases, at least, by spent heating gases withdrawn from the kiln adjacent its entrance end.

While in accordance with the provisions of the statutes, we have illustrated and described the best form of embodiment of our invention now known to us, it will be apparent to those skilled in the art that changes may be made in the form of the apparatus disclosed without departing from the spirit of our invention as set forth in the appended claims, and that in some cases certain features of our invention may be used to advantage without a corresponding use of other features.

Having now described our invention, what we claim as new and desire to secure by Letters Patent is:

1. In heating and oxidizing ceramic wares in an open-fire continuous tunnel kiln comprising initial heating, oxidizing, final heating and cooling zones or kiln chamber sections through which the wares successively pass as they are moved through the kiln chamber from its entrance end

to its exit end, the method which consists in heating the wares from about atmospheric temperature to a substantially higher oxidizing temperature and then further heating the wares to a temperature higher than said oxidizing temperature by the combustion of fuel, effected mainly in said final heating zone, and by moving gaseous products of combustion thereby formed out of the final heating zone into and through the oxidizing zone and thence into the initial heating zone and through a major portion, at least, of the last mentioned zone, and continuously maintaining an oxidizing atmosphere and temperature in said oxidizing zone and opposing the tendency of said gaseous products of combustion to increase the temperature in the last mentioned zone by injecting downwardly directed jets of gaseous material at a temperature substantially below said constant temperature into an upper portion of the kiln chamber adjacent the adjacent ends of said oxidizing and final heating zones and by passing a gaseous material normally at a temperature substantially above said oxidizing temperature, into the lower portion of said oxidizing zone at points distributed along the length of the kiln, said gaseous material including sufficient oxygen to effect oxidation of the wares.

2. A method as specified in claim 1, including the additional step of recirculating the gases in the preheating zone to uniformly heat the wares passing from the preheating zone into the oxidation zone.

3. A method as specified in claim 1, in which the mixture of air and gaseous products of combustion passed into the lower portion of the oxidizing zone is formed in elongated combustion spaces at the sides of the kiln into each of which fuel and air for the combustion of the fuel and for the dilution of the products of combustion formed, are passed at the end thereof nearest the entrance end of the kiln and in which the air and products of combustion mixture pass from said space into the kiln chamber in streams transverse to the length of the kiln and distributed along the length of the space.

4. A method as specified in claim 3, in which the temperature of the mixture of air and gaseous products passed into the oxidizing zone from the spaces relatively near to the entrance end of the kiln is higher than the temperature of the mixture passed into the oxidizing zone from the spaces more remote from the entrance end of the kiln.

5. A method as specified in claim 1, in which atmospheric conditions in said oxidizing zone are regulated by varying the relative amounts of heated air in the different downwardly directed jets.

6. A method as specified in claim 1, in which temperature and atmospheric conditions in the oxidizing zone are regulated by regulating the relative amounts of mixture of products of combustion and air passed into the lower portion of said zone at different points distributed along the length of the kiln.

7. In a continuous open-fire tunnel kiln comprising an elongated kiln chamber including preheating, oxidizing, heating and cooling sections arranged in series in the order stated between the entrance and exit ends of the kiln, and including combustion means discharging products of combustion into said heating section as required to thereby supply the major portion of the kiln heat requirement and means for withdrawing heating gases from the preheating section and thereby drawing products of combustion out of the heating section and through the oxidizing section into the preheating section, apparatus for maintaining an oxidizing atmosphere in said oxidizing section at an oxidizing temperature lower than the temperature of the heating gases drawn out of the heating section and higher than the temperature in the preheating section comprising air moving means associated with air heating means and with kiln roof openings for discharging downwardly directed jets of air into the upper portion of the oxidizing section at a temperature intermediate the temperature of the atmosphere and said oxidizing temperature, and means including combustion chambers with air and fuel inlets and discharge outlets at the sides of the oxidizing kiln section for discharging jets of gaseous products of combustion admixed with air into the lower portion of said oxidizing section at a temperature above said oxidizing temperature.

8. The improved tunnel kiln apparatus as specified in claim 7, in which said roof inlets have lower discharge portions elongated in a direction transverse to the length of the kiln.

9. In a continuous open-fire tunnel kiln comprising an elongated kiln chamber including preheating, oxidizing, heating and cooling sections arranged in series in the order stated between the entrance and exit ends of the kiln, and including combustion means discharging products of combustion into said heating section as required to thereby supply the major portion of the kiln heat requirement and means for withdrawing heating gases from the preheating section and thereby drawing products of combustion out of the heating section and through the oxidizing section and thence into the preheating section, the improved means for maintaining an oxidizing atmosphere in said oxidizing section at a temperature substantially lower than the temperature of the gases brought into the oxidizing section from the heating section of the kiln, which comprises means for discharging downwardly directed jets of heated air at a temperature intermediate the temperature of the atmosphere and the temperature of said heating gases, into the upper portion of said oxidizing zone, and comprises combustion chambers alongside the oxidizing section of the kiln chamber and formed with outlets opening to said chamber at points distributed along the length of the latter and means for passing fuel and air in excess of the amount required for the combustion of the fuel into said combustion chambers.

10. In a continuous, open-fire tunnel kiln comprising an elongated kiln chamber including preheating and cooling sections adjacent the entrance and exit ends of the kiln, respectively, and comprising fuel burners discharging heating gases into a heating section of the kiln intermediate the two first mentioned kiln sections, means for withdrawing heating gases from the preheating zone and thereby drawing heating gases out of said heating section into the preheating section, and means for providing a local heating effect in the lower portion of the kiln intermediate said heating section and the entrance end of the kiln comprising a plurality of elongated horizontal combustion chambers at each side of the kiln chamber in a portion thereof intermediate the said preheating and heating sections of the kiln and each formed with a plurality of discharge outlets opening to the kiln chamber at points along the length of the

latter and means for passing fuel and air for the combustion of the fuel into the end portion of each chamber nearest to the entrance end of the kiln, whereby the gaseous flow in said chambers is in the same direction as the movement through the kiln chamber of the wares heated therein.

11. In a continuous open-fire tunnel kiln comprising an elongated kiln chamber including preheating, oxidizing, heating and cooling sections arranged in series in the order stated between the entrance and exit ends of the kiln, and including combustion means discharging products of combustion into said heatings section as required to thereby supply the major portion of the kiln heat requirement, means for withdrawing heating gases from the preheating section and thereby drawing products of combustion out of the heating section and into and through the oxidizing section and thence into the preheating section, and means for passing cooling air into the cooling section, the improvement comprising means for maintaining an approximately uniform temperature in said oxidizing zone from one end to the other including a plurality of air inlets formed in the kiln roof at intervals along a portion of the kiln including adjacent end portions of said oxidizing and heating section, each inlet being formed with a narrow lower end portion elongated in a horizontal direction transverse to the length of the kiln, and means for discharging wide downwardly directed jets of heated air into the kiln through said inlets to thereby form gaseous baffles which reduce the portion of the gases flowing from the furnace section into the upper portion of the oxidizing section and increase the portion of the last mentioned gases flowing into the oxidizing section at lower levels, the last mentioned means comprising a fan having an inlet connected to said cooling section and having an outlet, a conduit having one end connected to said fan outlet and having outlet branches separately connected to said roof inlets and means for separately regulating the air flow through the different conduit branches.

12. In continuously heating material moving through an open-fire tunnel kiln from its entrance end to its exit end mainly by the combustion of fuel in a high temperature section of the kiln and by the passage of heating gases out of said section through an elongated kiln chamber zone between said section and the entrance end of the kiln, the method which consists in retarding the rate of temperature increase in said zone by introducing cooling gases into an upper portion of said kiln adjacent the adjacent ends of said zone and high temperature section of the kiln at a temperature substantially lower than that of the heating gases passing into said zone from said section, so as to thereby cool the heating gases and lower their path of travel, and by passing heating gases into the lower portion of said zone at points distributed longitudinally of the kiln through said zone said upper portion of the kiln being more remote from the entrance end of the kiln than some, at least, of said points.

13. A method as specified in claim 12, in which the said points at which heating gases are introduced into a lower portion of a said elongated zone are distributed along substantially the entire length of said zone.

14. A method as specified in claim 12, in which the temperature of the heating gases passed into the oxidizing zone at points relatively near to the entrance end of the kiln is higher than the temperature of the heating gases passed into said zone at points more remote from the entrance end of the kiln.

15. In a continuous open-fire tunnel kiln comprising an elongated kiln chamber including a preheating section, an intermediate section, a high temperature section, and a cooling section arranged in the order stated between the entrance and exit ends of the kiln and including combustion means discharging hot products of combustion into said high temperature section as required to thereby supply the major portion of the kiln heat requirement and means for withdrawing heating gases from the preheating section and thereby drawing products of combustion out of the heating section and through said intermediate section into the preheating section, the improvement comprising apparatus for retarding the progressive increase in the temperature at points in said intermediate section at progressively greater distances from the entrance end of the kiln which the heating gases passing into said intermediate section from said high temperature section tend to produce, comprising means for introducing cooling gases into the upper portion of the kiln chamber adjacent the adjacent ends of said intermediate and high temperature kiln sections and means for passing heating gases into the lower portion of said intermediate section of the kiln.

16. An improvement as specified in claim 15, in which the means for passing heating gases into the lower portion of the intermediate section are adapted to supply said heating gases at higher temperatures at points relatively near to, than at points more remote from the preheating section of the kiln.

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