March 6, 1962 L. J. ERCK ETAL 3,024,101

UPDRAFT TRAVELING GRATE PELLETIZING FURNACE

Filed May 25, 1956 9 Sheets-Sheet 1

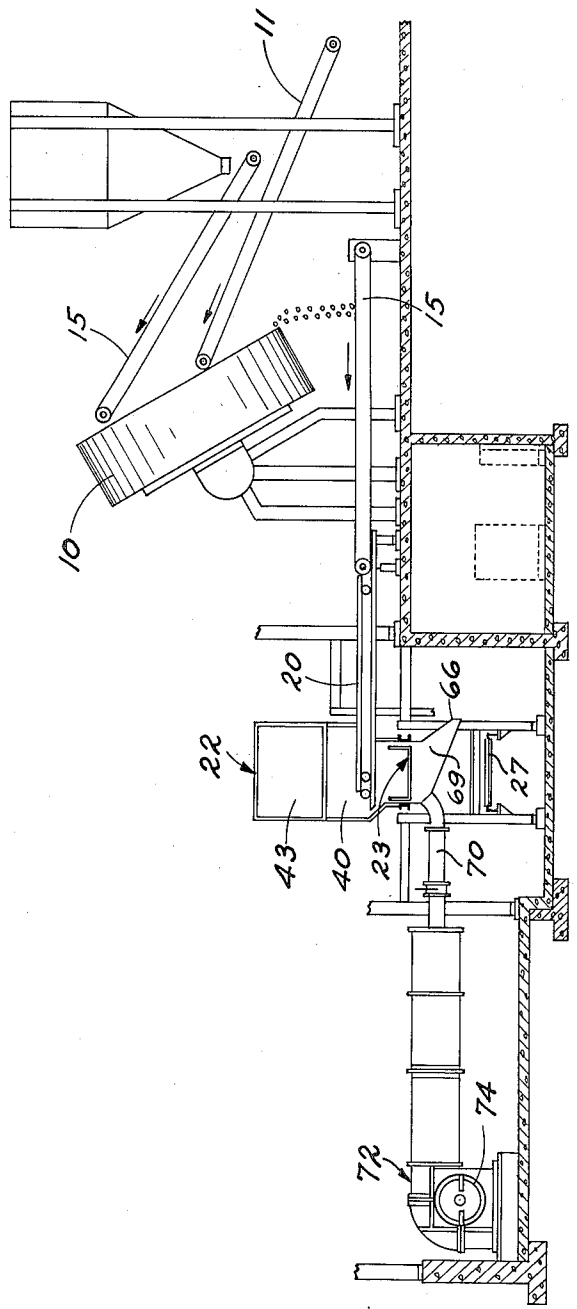


Fig. 1

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March 6, 1962 L. J. ERCK ETAL 3,024,101

UPDRAFT TRAVELING GRATE PELLETIZING FURNACE

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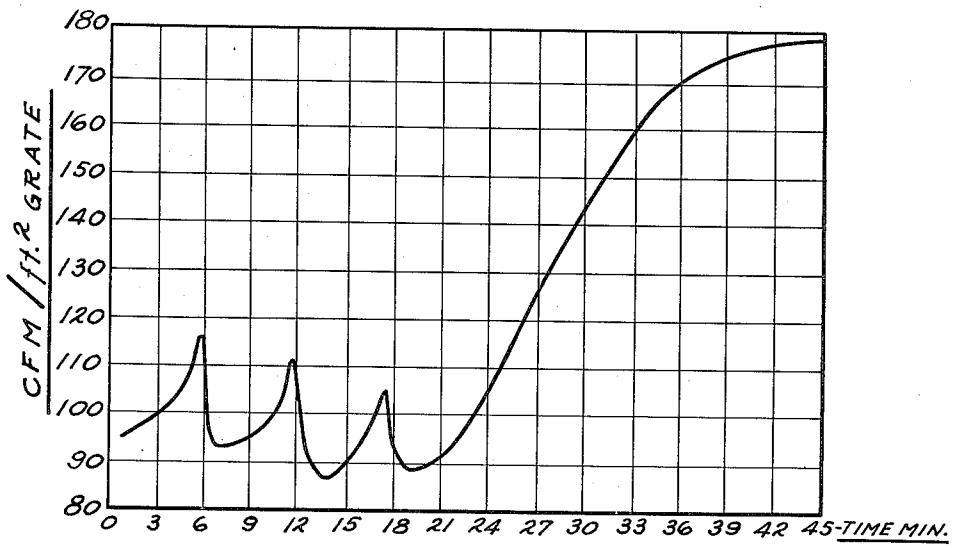


Fig. 3

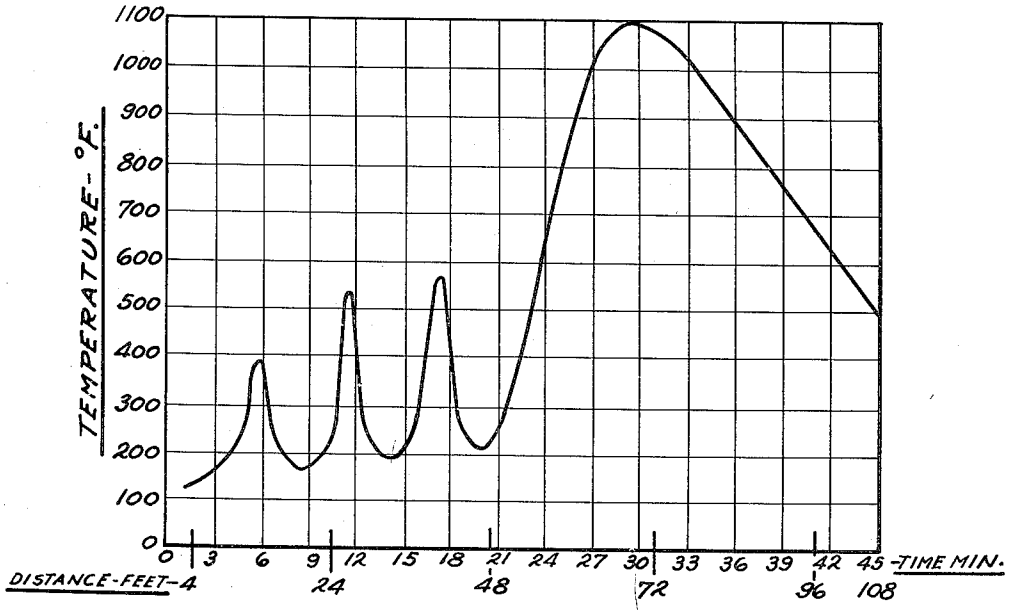


Fig. 2

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UPDRAFT TRAVELING GRATE PELLETIZING FURNACE

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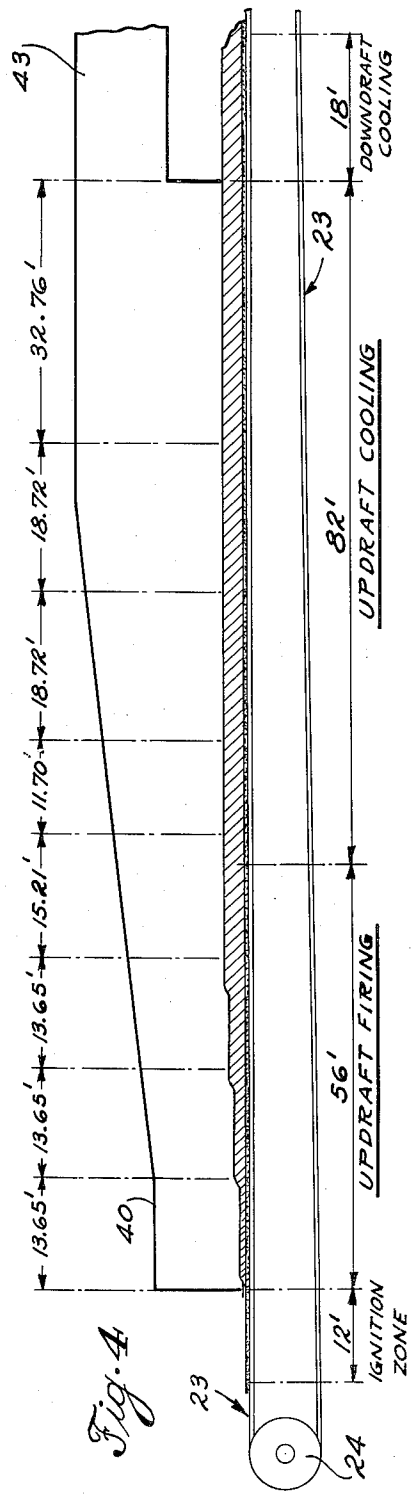


Fig. 4

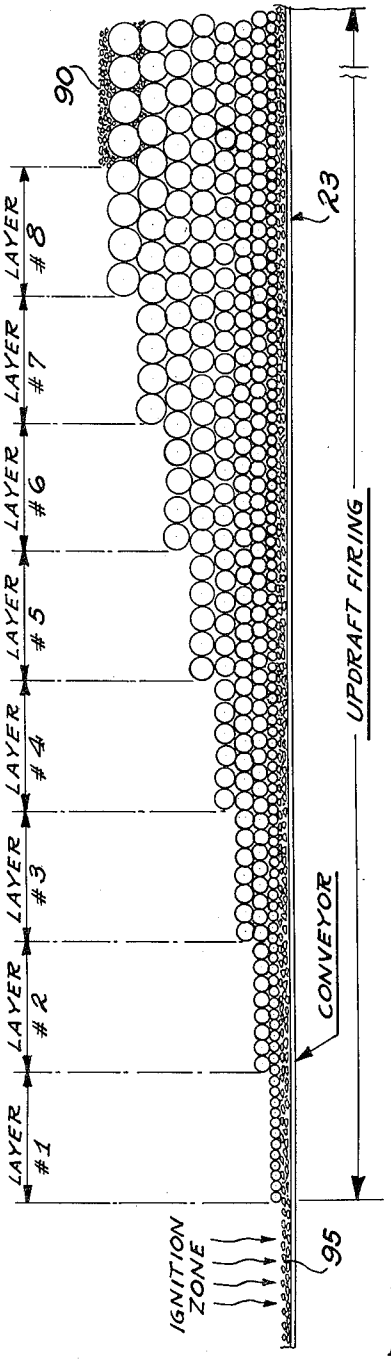


Fig. 5

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UPDRAFT TRAVELING GRATE PELLETIZING FURNACE

Filed May 25, 1956 9 Sheets-Sheet 4

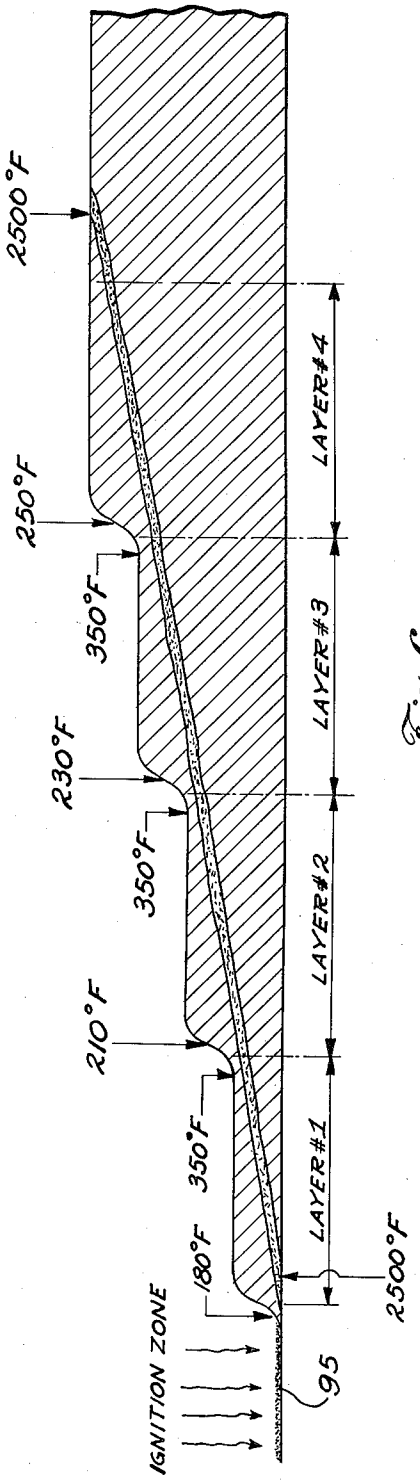


Fig. 6

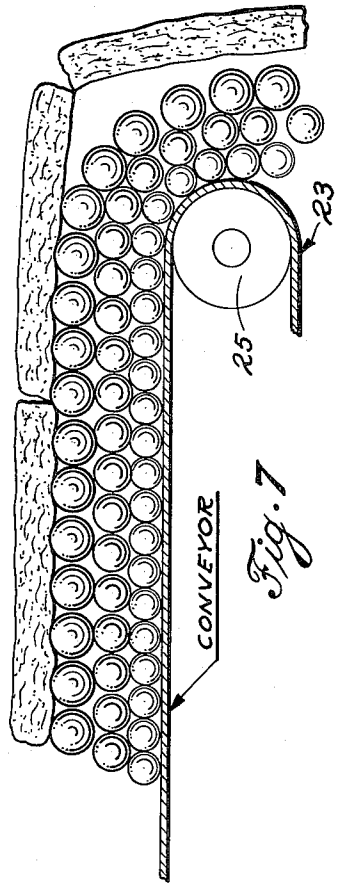


Fig. 7

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UPDRAFT TRAVELING GRATE PELLETIZING FURNACE

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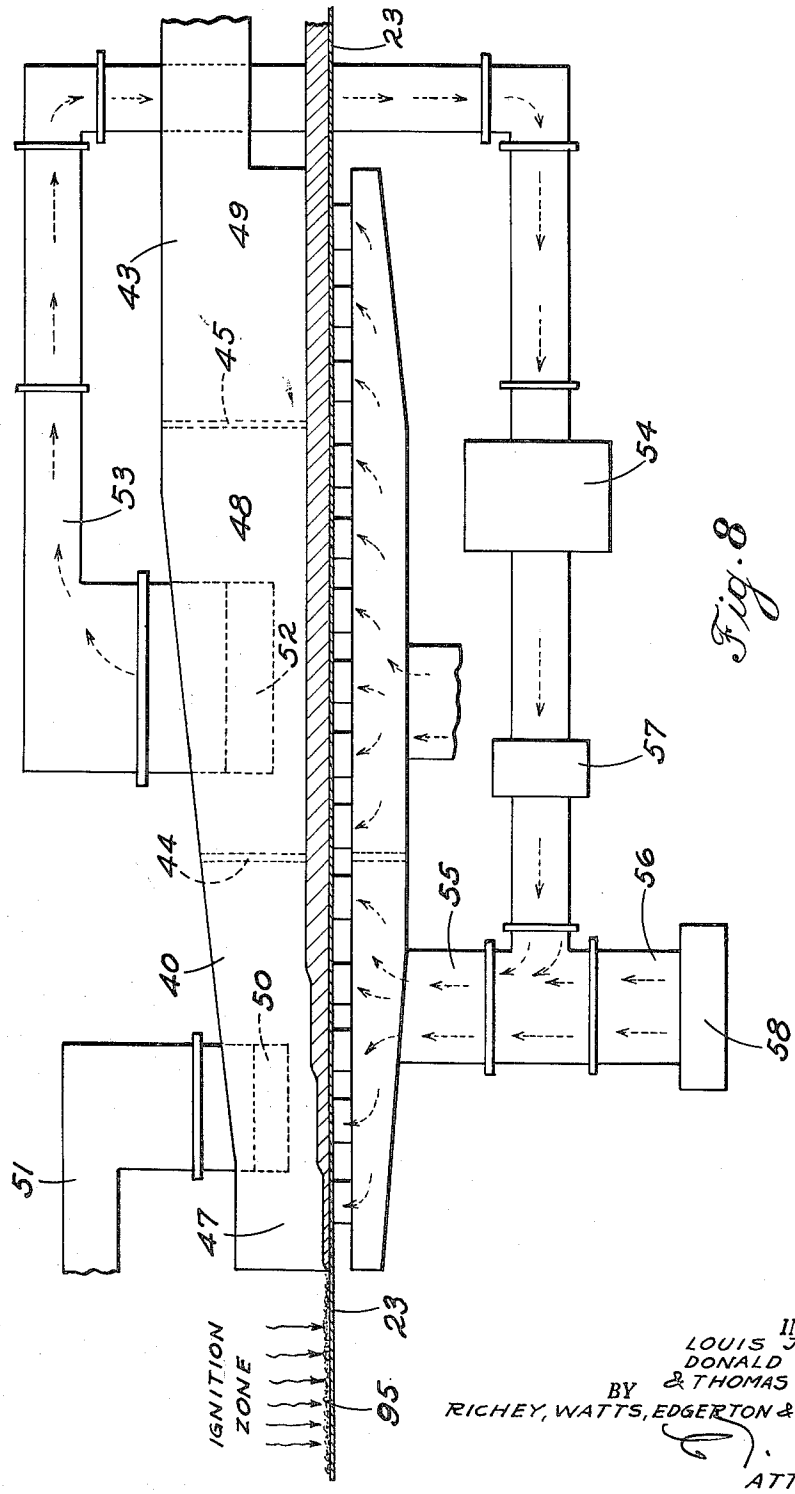


Fig. 8

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UPDRAFT TRAVELING GRATE PELLETIZING FURNACE

Filed May 25, 1956 9 Sheets-Sheet 6

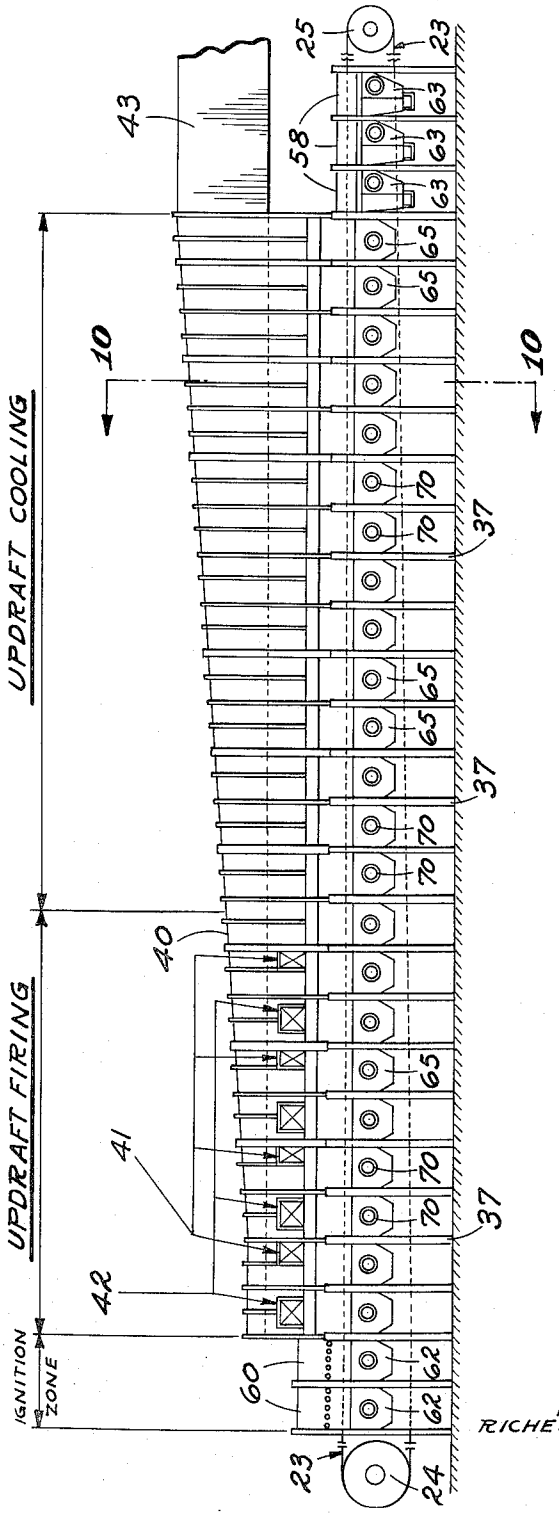


Fig. 9

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UPDRAFT TRAVELING GRATE PELLETIZING FURNACE

Filed May 25, 1956 9 Sheets-Sheet 7

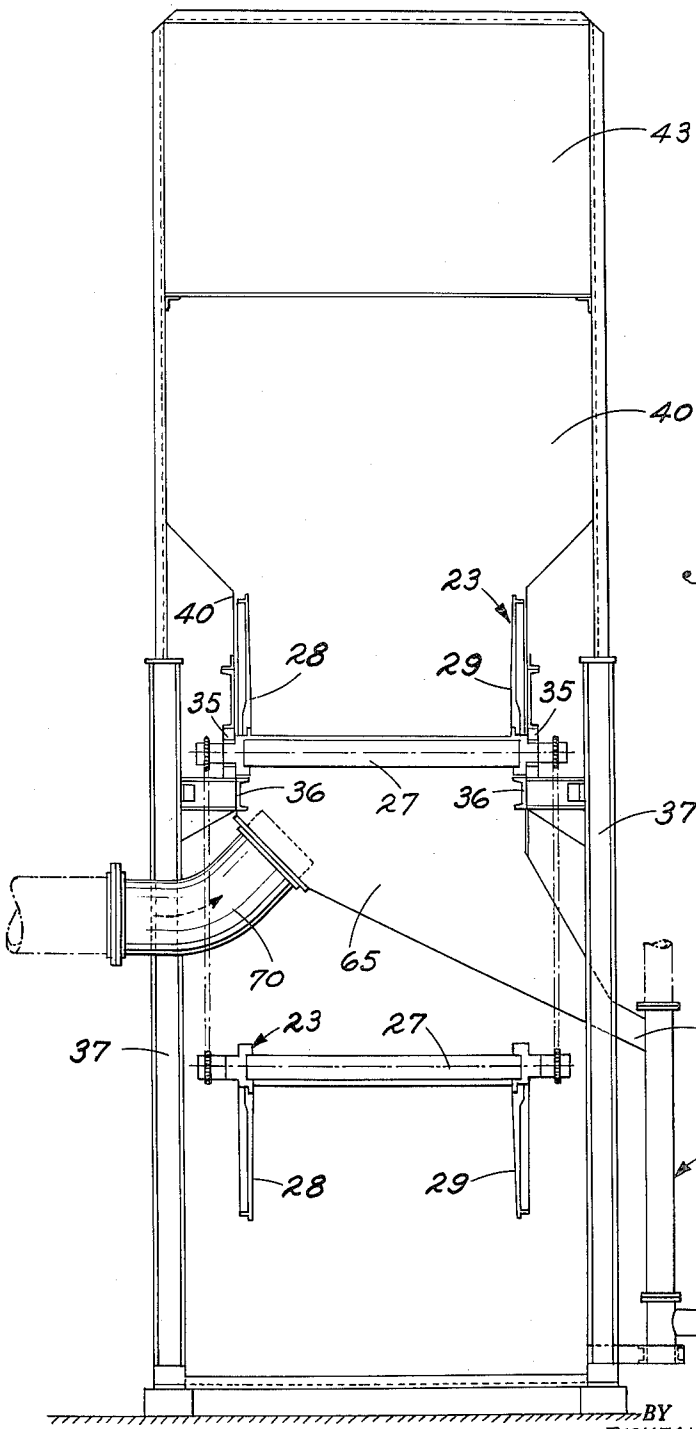


Fig. 10

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UPDRAFT TRAVELING GRATE PELLETIZING FURNACE

Filed May 25, 1956 9 Sheets-Sheet 8

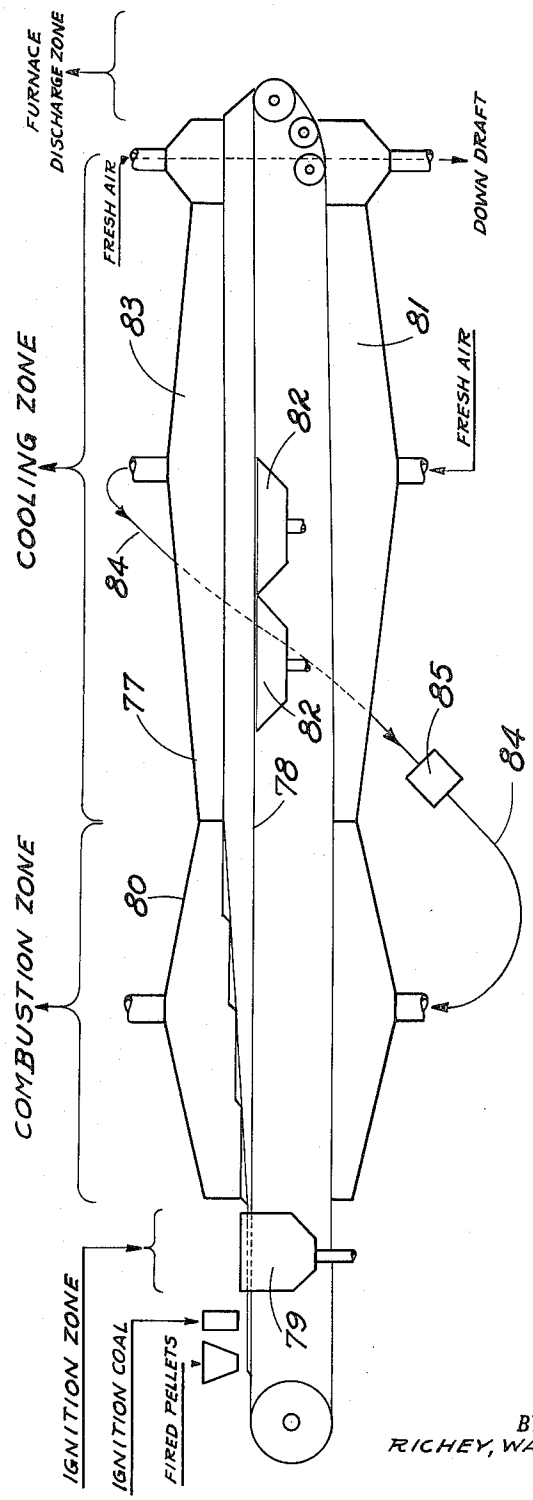


Fig. 11

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UPDRAFT TRAVELING GRATE PELLETIZING FURNACE

Filed May 25, 1956 9 Sheets-Sheet 9

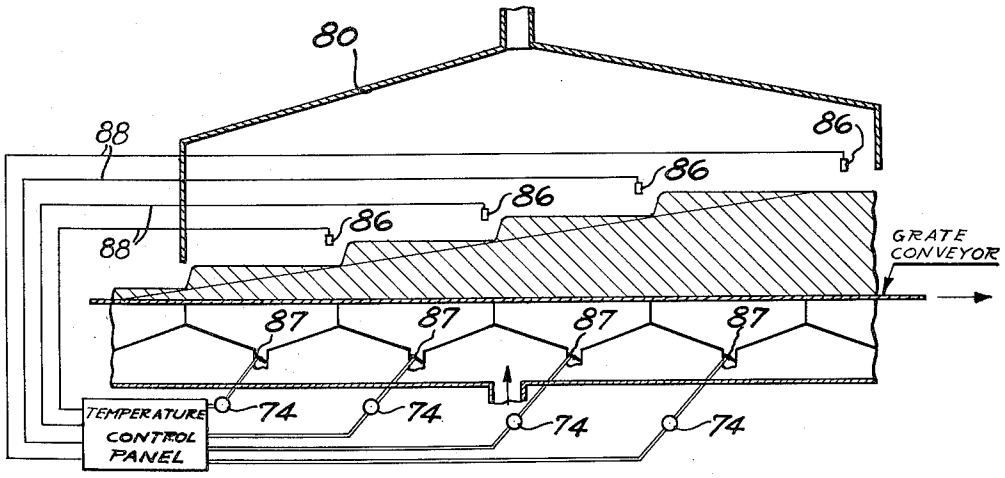


Fig. 12

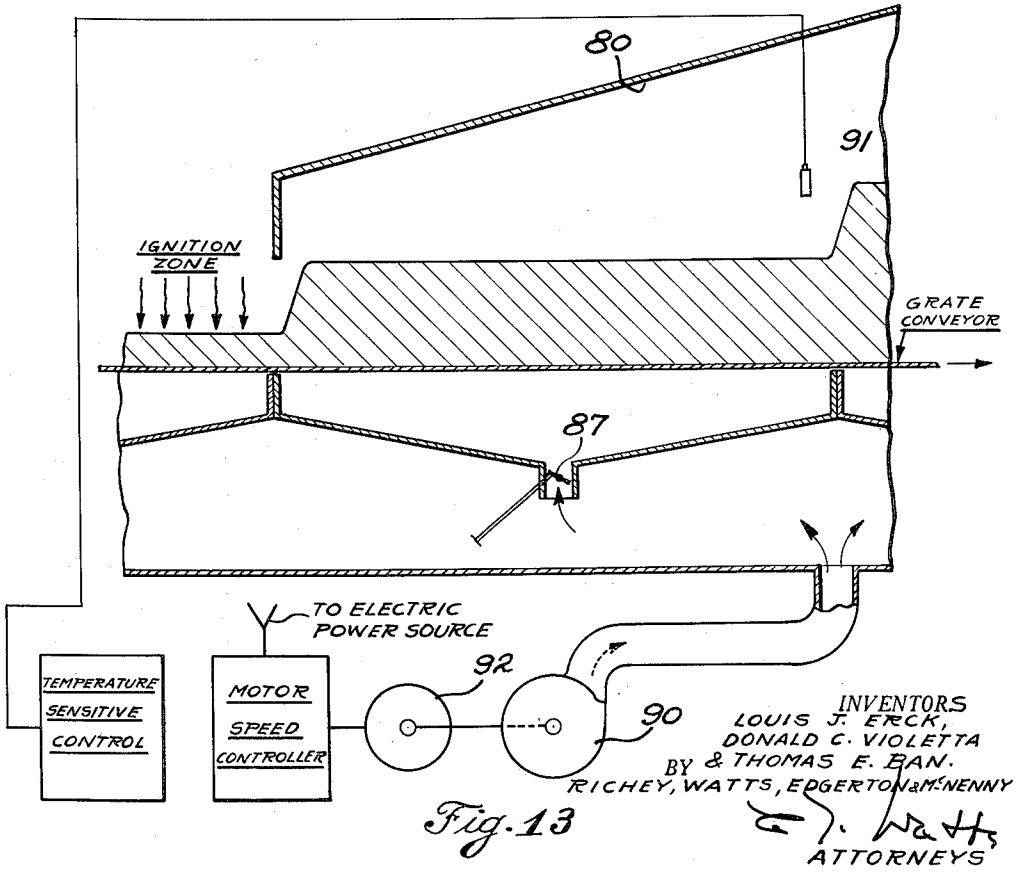


Fig. 13

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United States Patent Office 3,024,101 Patented Mar. 6, 1962

3,024,101
UPDRAFT TRAVELING GRATE PELLETIZING FURNACE

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Filed May 25, 1956, Ser. No. 587,393
13 Claims. (Cl. 75—5)

The present invention relates generally to the art of iron-ore beneficiation and is more particularly concerned with a novel method of agglomerating finely-divided iron ores and with new apparatus implementing the said novel method.

The iron-ore mining industry in this country turned its attention some years ago to the problem of beneficiating horizontal ores because the principal sources of high grade ores were being rapidly depleted. The virtually inexhaustible supply of lower grade iron formations averaging about 30% to 40% iron in finely-textured rocks of the taconite and jasper types occurring in the Mesaba and Marquette ranges has offered a special incentive to the industry to develop some means for economic recovery of the iron values of these formations. It has been estimated that marginal ores of this type aggregate in the Minnesota and Michigan iron-mining areas a total of 70,000,000,000 tons compared to an aggregate of about 4,000,000,000 tons of the higher grade ore which was originally present there.

The advantages to be gained through the development of a commercially feasible means for upgrading marginal domestic ores consequently are spectacular. Furthermore, they are not limited to the interests owning or operating iron-ore mines and mining facilities in this country, but are important to the country as a whole. The costs of bringing foreign ores to this country for reduction are comparatively high, making the cost of iron and steel and everything made by or with them correspondingly greater. Moreover, national self-sufficiency as to the most important natural resource will be lost to this country if these domestic ore horizons cannot be successfully developed.

Since the upgrading of lean ores may, in theory, be carried to the point that relatively high grade iron oxide is produced, there is an additional advantage of potentially great commercial significance to be gained through the development of any feasible procedure for concentrating these ores. Thus, instead of offering steel mills ores of 51.5% iron (natural), it is a practical possibility to furnish ores of 66% iron (natural) for their furnaces. This would materially reduce the cost of furnace operation because of the higher yields of metal, and it would increase metal production facilities without the enlargement of any existing equipment or addition of any new furnaces.

With the advantages to be gained being so great and with the consequences of failure being so disastrous, there have naturally been many determined efforts made to develop such a process, and large sums of money have been expended in this direction. As a result, the technology of iron ore beneficiation has been advanced long distances in various directions and phases in the past fifteen years since the problem entered its acute stage. However, only very recently have there been commercial operations involving marginal ores and prior to the present invention, these operations were limited to magnetic ores.

New techniques and tools have been devised to overcome the special difficulties in mining taconite and jasper. In actual practice, these techniques and apparatus have established themselves as satisfactory for commercial use,

being effective, rapid and economical by comparison with current open-pit and shaft-mining operations.

Similarly, new techniques and machines have been developed for commercial use in the extraction of the ore values from the gangues of marginal ores. The procedure of froth flotation has been refined, and chemical research has yielded frothing agents which have improved the yields in flotation operations to the point where they are commercially acceptable. In addition, some new tools have been developed, and some older ones have been adapted for the extraction of fine, specular iron oxides from mixtures of predominantly siliceous material. Thus, the so-called heavy-media process in current use predominantly on the Mesabi range may involve the use of the cyclone, the Hardinge separator and the Akins classifier.

As for the particular processes and procedures employed, those disclosed and claimed in copending application Serial No. 206,448, filed January 17, 1951, now Patent No. 2,744,627, in the name of Louis J. Erck, give special promise of rapidly and consistently producing premium ore products and have the advantage of being usable in a conventional Hardinge machine. They also offer the important advantage of enabling the use of relatively inexpensive materials as the separating media. Thus, ferrosilicon can be replaced with magnetite, under certain circumstances, to improve the economy or to simplify the separating process.

The finely-divided ore values recovered from low grade or horizontal deposits cannot be charged into a commercial reduction furnace because their particle size is typically minus 60 mesh. Therefore, some type of agglomerating operation is essential to their utility. Sintering processes and conventional sintering machines have been employed in various ways in a number of efforts to produce a satisfactory agglomerate from these fines, but the results have been unsatisfactory to the point where the art generally has turned to pelletizing as a logical approach. The tendency for this ore to pack in a sintering operation is such that normal operation of the sintering machine is not consistently possible. Furthermore, sintering machines are of low capacity so that their use would either be too expensive or time-consuming.

Prior to the present invention to the best of our knowledge, the problems associated with the production from these ore fines of ball products suitable as furnace charge have not been totally overcome. These problems break down into two general categories according to the two general stages of the balling procedure, i.e., the forming of the green ball from the ore fines and the firing or burning of the green ball to provide it with the physical characteristics necessary to see it through the handling, shipping and charging operations incident to its use as furnace charge.

In the first stage, good results in large-scale operations have been consistently obtained through the use of the process and the apparatus disclosed and claimed in our copending application Serial No. 580,423, filed February 15, 1956. Also, the process disclosed and claimed in copending application Serial No. 346,786, filed April 3, 1953, now Patent No. 2,799,572, in the names of Grover J. Holt and Louis J. Erck, offers special advantages in this use. The combination of the teachings of these two disclosures, furthermore, produces consistently superior results and represents a development in the art which stands out far in advance of the field and apparently meets and disposes of all the problems and difficulties in the prior art relating to the production of green balls of good physical characteristics.

Accordingly, the final link in the chain of this development is the firing of the pellets, and it is at this obstacle that the art has arrived and has been impeded in its prog-

ress for some time. These have all had important shortcomings and derelictions which have been generally recognized and tolerated in commercial operations because they represented the best that the art afforded. In particular, the conventional shaft furnace or kiln has inherent operating deficiencies and traveling grate-type furnaces operating on the down-draft principle also have restricted capacity and relatively high thermal requirements. Also, grate bar maintenance is a significant cost factor in these latter furnaces due to the high temperatures to which the grates are subjected in pelletizing operations, i.e., 2000° F. or higher.

In accordance with the present invention, it is, for the first time, to the best of our knowledge, possible to control closely green ball firing conditions and to eliminate other serious shortcomings and derelictions of methods and apparatus of the prior art devised for the production of acceptable blast furnace pellets. Thus, this control may be essentially automatic, but whether automatic or manual it can be exercised throughout the period of operation of the furnace without sacrifice of product yield. Actually, in accordance with this invention, yields of acceptable pellets will average consistently higher than the prior art has been able to secure through the use of hematite or hematite-magnetite mixture, and the best firing methods and apparatus heretofore known. In other words, this invention enables, for the first time, the economic production on a commercial scale of pellets of hematite of quality rivaling that of magnetite pellets.

Another important new advantage of the present invention concerns apparatus capacity, it being possible to fire with consistently good results green balls in bed depths twice to three times those recommended in the prior art. In fact, from the standpoint of firing characteristics, there is theoretically no limit upon bed depth, but as a practical matter, the design considerations will prevent the building and operation of a furnace large enough to fire beds five to ten times conventional depths.

Still another advantage of this invention is the heat-exchange efficiency obtainable in the ordinary practice of this invention, there being effective use of heat in the pellet bed during the combustion period and there being in addition a feature of substantial heat recovery from the effluent gases.

A further advantage of this invention is that it provides a process which can be carried out continuously with wide variations in the nature of the green balls. Thus, the chemical characteristics of the balls may vary from essentially pure hematite iron to essentially pure magnetite iron without either overfiring or underfiring the pellets and without either diminishing pellet yields or inordinately increasing the fuel costs. Likewise, variations in the physical characteristics of the pellets will not affect the efficiency of the firing operation in the usual practice of this invention.

Still further, the use of solid fuel in the bed of green balls is unusually efficient in accordance with this invention, being graduated according to the location of a given layer of green balls in the bed and according to the mass of each green ball. As an additional advantage, no solid fuel is necessary outside the bed during the firing operation and only in the brief period during which the base layer is heated at the outset of the operation is it necessary to employ any external fuel to carry out the process.

Another advantage of this process is that a portion of the product may be clinkered where there is a particular use for coalesced indurated pellets. The remainder of the pellet product, however, will be in the form of discrete pellets at the time of discharge from the furnace of this invention, making separation of the clinkers simple and easy. A related advantage is that pellets of a wide variety of sizes for varying requirements may be made at one time in this apparatus.

A further important advantage of this invention is that the capacity expressed as long tons per square foot per day can be unusually high by prior art standards. Furthermore, while it was necessary in accordance with the prior art traveling grate practice to reduce to relatively low levels the moisture content of green balls prior to firing them, this is not essential in carrying out the operations of this invention.

By virtue of our invention, it is possible to use coke breeze or coarse coal in its natural structure, by contrast with the prior art practices which required special, finely-divided coal. However, we prefer to use fuels of the high fixed-carbon class of which anthracite coal is representative.

The method of our invention, broadly described, comprises the steps of converting finely-divided, raw, iron-ore concentrates which consist mainly of hematite or magnetite into green balls, i.e. substantially spheroidal compacts which are relatively smooth and hard, establishing on a traveling grate a porous bed of incandescent solid material, distributing the green balls and solid fuel on the porous incandescent bed in overlying gas-pervious layers, flowing gases through said porous incandescent bed and upwardly through the overlying charge of green balls and solid fuel, and thereby igniting and burning the said fuel and firing the green balls.

In one of its apparatus aspects, the present invention, in general, comprises in a green ball-firing furnace having a traveling grate and means for delivering streams of gas into the green ball charge on the grate, the combination of means for regulating the volume of the gas streams and means for sensing the rate of combustion of the charge operatively associated with the gas delivery means to control the flow of gas into the green ball charge and to maintain the charge combustion rate within predetermined limits.

In another of its apparatus aspects, the present invention, as applied to a green ball-firing furnace having a traveling grate and a plurality of wind boxes along the grate travel course, comprises in general the combination of heat recovery means including a hood for collecting gases emerging from the charge at elevated temperatures and a duct communicating with the wind boxes and the hood for introducing collected gases into the charge.

These methods and apparatus of this invention are described in detail below for the benefit of those skilled in the art, reference being had to the drawings accompanying and forming a part of this specification, in which:

FIG. 1 is an end elevational view, partly in section, of pelletizing apparatus embodying this invention in assembly with green balls making and rerolling apparatus and transfer means for delivering green balls into the pelletizing furnace;

FIG. 2 is a chart bearing a curve indicating the relationship between exhaust gas temperature and time or furnace length in typical operation of apparatus of this invention;

FIG. 3 is a chart bearing a curve representing the flow of air at different times or locations in the furnace length bed resistance to air flow being constant;

FIG. 4 is a diagrammatic view of the apparatus of this invention indicating the manner in which the green ball charge is delivered into the traveling grate and the way in which the charge is treated in respect to gas currents in the four zones of the furnace;

FIG. 5 is an enlarged diagrammatic view showing the structure of a green ball bed of this invention from the outset of the charging operation until the final layer is applied to the top of the bed;

FIG. 6 is another diagrammatic view similar to FIG. 5, but indicating the progress of the combustion zone upwardly through the bed of green balls and pellets and showing the temperature variations as measured in the hot gases approximately 12 inches above the bed;

FIG. 7 is an enlarged diagrammatic view indicating the

structure of a special form of pellet bed at the time of its discharge from the furnace;

FIG. 8 is a diagrammatic view of apparatus of this invention illustrating the collection of several effluent gas fractions and the recirculation and the filtration of one of these fractions in accordance with preferred practice;

FIG. 9 is a fragmentary, side elevational view of a pelletizing furnace embodying this invention;

FIG. 10 is a fragmentary, section elevational view taken on line 10—10 of FIG. 9;

FIG. 11 is a schematic, side elevation of another pelletizing furnace embodying this invention in a preferred form;

FIG. 12 is a diagrammatic view of the combustion zone portion of the FIG. 11 furnace, showing the location of the temperature-sensing means and indicating the manner in which combustion is controlled; and

FIG. 13 is an enlarged, fragmentary, diagrammatic view of FIG. 11 furnace equipped with an alternative type of combustion control system.

With reference to FIG. 1, a preferred arrangement of apparatus for the commercial practice of our invention includes a balling device such as a balling disc 10 into which ore fines obtained from a froth floatation process or other commercial separation processes are introduced by conveyor 11 with an adequate amount of water suitably in the form of a fine spray. Additives, such as limestone and bentonite clay in finely-divided form, are also introduced into the balling disc, all in accordance with the teachings of our copending application Serial No. 580,423, filed February 15, 1956, and application Serial No. 346,786, filed April 3, 1953. Green balls rolling from the lip of disc 10 are fuel-coated and ready for firing, having been rerolled in disc 10 with finely-divided coal delivered into the reroll zone of the disc by conveyor 15. These rerolled green balls are carried by belt 20 from the disc into pelletizing furnace 22. Depending upon the size of the operation and the number of green ball layers to be established in the firing bed, there may be two or more green ball lines of this type, preferably arranged in parallel relation.

As shown in FIGS. 1, 9, and 10, furnace 22 comprises an endless conveyor 23 which is driven by a suitable motor means (not shown) through a travel course around cylinders 24 and 25 disposed outside the two ends of the furnace. Conveyor 23 has grate bars 27 which provide a floor for the establishment of pellet beds and with a series of opposed side walls 28 and 29 extending at right angles to the grate bars to support the pellet bed in its travel. In preferred form, the grate bars and side walls extend around the entire length of the conveyor, but the side walls are articulated in short length so that the grate can be free running in its travel around its closed course.

The travel course is defined by a pair of rails 35 which are supported by a plurality of opposed beams 36 carried by columns 37 arranged in two opposed series on opposite sides of the conveyor 23.

A hood 40 is disposed along the course of the traveling grate, enclosing that portion of the grate in the pellet-firing and cooling zones of the furnace. The hood has lower portions extending downwardly on opposite sides of the side walls of the grate to a point adjacent to grate bars 27 and has observation ports 41 and access doors 42 at intervals along its length, as indicated in FIG. 9. The hood communicates with a duct 43 which serves to carry off gases emerging from the pellet bed and hood and duct are provided with partitions 44 and 45 (FIG. 8) which divide this gas-handling system into three separate zones 47, 48, and 49, each of which is provided with a separate outlet for the collected gases. In zone 47, moisture-laden gases evolved as a result of the combustion of the solid fuel in the pellet bed are collected through the hood and duct assembly and exhausted through port 50 and conduit 51. Middle zone 48 serves to collect gases which are substantially free from combustion products and moisture but are at elevated temperature, exhausting them through opening 52 and a conduit 53 equipped with a filter 54. Conduit 53 exhausts into gas-delivery line 55 serving the combustion zone of the furnace and is connected to a source of air by means of a conduit 56. Fan 57 downstream from filter 54 in conduit 53 draws gases through this filter which serves to remove dirt from the gases and thereby protect the impellers of fan 57 and also eliminate the danger of clogging the bed of wet green pellets in the ignition zone of the furnace. A fan 58 is disposed in conduit 56 to supplement the output of fan 57 with fresh air and it will be understood that when an excess of preheated air is delivered by fan 57, conduit 56 may be used to vent the excess air to the atmosphere. In the lower end of the furnace where the pellet bed is subjected to updraft cooling, as will be subsequent described, gases collected in the hood and duct assembly are exhausted from the system through the open end of the duct 43 by suitable stack means (not shown).

At the discharge end of the traveling grate, wind boxes 58 are provided as shown in FIG. 9, this being the downdraft cooling zone of the furnace. Suitable connections to a source of air under pressure and at ordinary temperatures are made into boxes 58 for the establishment of downdrafts through the bed.

Similarlly, at the other extremity of the furnace in the ignition zone and just in advance of the first green ball-charging station, burner boxes 60 are disposed over the conveyor for the application of gas flames or hot gases to solid material provided at this point on the grate to create an incandescent bed for subsequent bed ignition, as will be described. Ducts 62 and 63, respectively, are located under the upper level of conveyor 23 in the ignition zone and the downdraft cooling zone to receive gases flowing from the grate downwardly at each of these stages. These gases are exhausted from the system by any suitable means.

Through the length of the furnace between the ignition zone and the discharge zone, a series of wind boxes 65 are disposed between the upper and lower levels of the traveling grate assembly. The upper end of each of these boxes is open to the full width of the bed as determined by the spacing of side walls 28 and 29, while the lower end portion 66 of each box 65 is restricted for discharge through a relatively small opening into a dust-collecting line 68, as illustrated in FIG. 10. Air is delivered into 65 by a plurality of separate pipes 70 which are directed for discharge of air upwardly through the upper end of these boxes and into the traveling grate and the charge carried thereon. Blower means in the form of a plurality of separate fans 72 (one shown) are provided to supply regulated quantities of air at the required pressures for the firing operation. The operation of fans 72 and the volume of air delivered into the pellet bed traveling through the furnace may be manually regulated, but in accordance with the preferred practice of the present invention, this is automatically accomplished by means of the types illustrated in FIGS. 12 and 13.

Furnace 77 of FIG. 11 is in general similar to furnace 22, being an updraft traveling grate designed for continuous operation under automatic control. Thus the driving, supporting and sealing means may be essentially the same in each instance and may be like the corresponding components of conventional sintering machines. The air delivery and gas exhaust systems, however, are different in these two furnaces and our present preference is the FIG. 11 arrangement.

Traveling grate 78 of furnace 77 extends over a course running from right to left as seen in FIG. 11 along which are disposed several stations or zones. Thus, fired pellets are loaded continuously on grate 78 at the first station and ignition coal is deposited more or less uniformly on the resulting burned pellet bed to be carried by the

grate through ignition furnace 79 (ignition zone) wherein propane gas flames burn the fuel and heat said pellets to incandescence. Green ball charge is then deposited in four stages on the grate in the combustion zone of the furnace, induration being effected by the upward delivery of heated air through the grates under conditions of automatic control as indicated in FIGS. 12 and 13 and described in detail below. Gases emerging from the pellet bed in the combustion zone are collected in hood 80 and exhausted from the system.

When induration is complete, as indicated by the zone line in FIGS. 11, 12, and 13, the cooling operation is begun by reason of the advancement of grate 78 carrying the indurated pellets into the cooling zone. Fresh air is delivered into the grate charge at this station by means of a windbox duct 81 and windboxes 82 and the resulting heated air emerging from the top of the indurated charge is collected by hood 83 and then conducted into the windbox duct serving the combustion zone windboxes, a conduit 84 being provided for this purpose and a filter 85 being disposed in the conduit to clean this heated air prior to its introduction into the combustion zone. The grate charge is next conveyed into a downdraft cooling zone in which fresh air is delivered downwardly into the top of the indurated charge and exhausted from the system through a duct disposed from the bottom of the grate, this air normally being of such low heating value that recuperation or heating recovery from it is not feasible. The thus cooled indurated charge is next carried into the furnace discharge zone and dumped from the traveling grate on to suitable conveyors or into shipping or storage vessels.

The combustion control system of FIG. 12 as applied to the combustion zone of furnace 77 comprises four thermopile units 86 located in hood 80 at points substantially uniformly spaced above the respective green ball layers of the furnace charge bed. Four motors 74 for operating dampers 87 of the windboxes are electrically conected to the respective thermopiles through controller circuits 88. The rate of delivery of air into the combustion zone duct may be substantially constant or it may be regulated by suitable automatic control means according to the rate of flow of air from the windboxes into the traveling grate. Thus as illustrated in FIG. 13 blower fan 90 is controlled by thermopile 91 in hood 80 in cooperation with a controller circuit which regulates the speed of fan motor 92.

The controller circuits which we prefer for use in these assemblies are exemplified by the Minneapolis Honeywell Electroline Control System (see Minneapolis Honeywell Catalog No. 1531). Thus such a circuit includes an Electr-O-Line relay, Electronik proportional controllers, and an electric proportional control motor. Thermopiles 86 are connected to their respective proportional controllers so that when temperature sensed by a thermopile varies from a predetermined temperature, the circuit including that thermopile is "lined-out" and the said relay with its automatic reset feature will cause the final control element, i.e. the damper 87 controlled by this particular circuit to assume the correct position through the operation of its motor 74 to maintain control in a predetermined temperature range.

The normal operations of these FIGS. 12 and 13 systems are indicated in FIGS. 2 and 3, wherein it is apparent that blowing rates are related to bed temperatures over the major part of the resident period of an increment of furnace bed or charge. When combustion is completed the blowing rate is increased to effect rapid cooling of the charge in preparation for removing the indurated pellets from the furnace. Another characteristic of this operation is the reduction in blowing rate with each successive charge, this being due to the tendency for bed resistance to build higher at deeper bed depth and to increase with each charge.

Operation of the FIG. 1 apparatus is carried out in a similar manner. Thus, prior to the delivery of the first green balls into the furnace, a layer 95 of suitable material, such as indurated pellets, solid fuel, or both, is deposited on grate 23 and is brought to incandescence by direct application of a flame or by combustion of the solid fuel. With the grate traveling continuously along its course at a predetermined rate, layer or bed 95, as it reaches temperature, is carried continuously into the first green ball charging station. Subsequent charging operations are consequently continuous and at fixed rate, but with the possibility that charging ratios may be altered at any time that it is desired to modify the constituency of the bed as to pellet size, distribution or fuel form or ratio.

In the first green ball charging stage, balls prepared by the procedure described above in the apparatus illustrated in FIG. 1 are delivered onto the incandescent bed continuously and at a predetermined rate to establish a primary layer. These balls may, as indicated above, be of magnetite or hematite or mixtures thereof and suitably compounded for physical characteristics desired in the final burned pellets as well as in green ball form. Normally, it is preferable to charge relatively small diameter green balls into the furnace at the first station, but the present invention contemplates the charging of green balls of any desired or suitable size in this phase of the process, as well as in subsequent bed-building steps.

As shown in FIG. 5, as the grate moves along its course, a second charge of green balls is made, forming a second layer of balls of slightly larger size than those in the base layer. Further travel of the conveyor through the firing zone of the furnace involves the establishment of successive layers of balls of gradually increasing size until in the operation illustrated a total of eight distinct layers have been established on top of the original ignition layer 95.

Throughout the period that the grate is traveling through the successive ball-charging stations, an updraft of a mixture of ambient fresh air and filtered, warm furnace air may be delivered into the lower part of the grate and into the bed laying thereon in the form of a number of separate streams. Windboxes 65, fans 72 and pipes 70 connecting them to the windboxes provide the air pressures required beneath the pellet bed to cause streams of air to flow through the grate to accomplish the firing result required. FIG. 2 illustrates the condition as it may be typically established and maintained in the operation of a furnace of this type where the volume of the air delivered into the pellet bed as it travels along the furnace grate course is shown to increase at approximately the point where firing of the bed is completed. Lower blowing rates are employed while combustion is taking place in the bed than subsequent to that time because of the danger of not firing the bed thoroughly at high blowing rates which strip heat from the pellet bed.

Referring to FIG. 6, a four-level bed is established in accordance with this invention so as to take full advantage of the heat recoveries possible in the bed and to use the successive pellet charges as means for controlling the temperatures within the bed. Stepwise, additions of green balls along the course of the grate travel also provide the advantages indicated above of maintaining uniform firing conditions in all portions of the bed so that beds of virtually any desired depth within the limits of machine design may be produced with satisfactory indurated pellets resulting. As this diagram shows, combustion begins in the bed almost as soon as the green balls are deposited at the first charging station on incandescent layer 95. The rate of combustion of the solid fuel associated with the green balls as a coating or as an admixture in the bed is indicated as being substantially a straight line function of the grate travel rate, but those skilled in the art will understand that satisfactory results may

be obtained consistently when these ratios are varied. One of the important things is that conditions as to moisture in the bed are controlled to prevent "mushing" of the green balls of the upper layers due to cooling of gases rising through the bed and condensation of their moisture burden. Accordingly, when the first layer of green balls is burned close to the upper surface and the uppermost part of this bed shows a temperature of approximately 350° F. indicating elimination of moisture, a second layer of green balls is placed upon the substantially fired first layer, dropping the temperature of the surface to about 210° F. and indicating that the heat rising through the bed from the combustion zone is being used to evaporate the moisture from the green balls of the second charge. In further travel upwardly through the bed of the combustion zone and with further travel of the conveyor, the surface of the second charge zone shows an increase to 350° F. with the elimination of the last of the moisture. A repetition of the charging operation to produce a third layer of green balls brings the resulting surface temperature down to about 230° F. in a typical operation with a subsequent rise to 350° F. as the combustion zone again approaches the top of the bed. A fourth charging stage has the same effects, but thereafter the bed is fired out as the conveyor continues along its course and no further change is made with the result that eventually the combustion zone reaches the top of the last charge and the bed surface is at a temperature of 2500° F. From this point onward, the effort is in the direction of cooling the charge in preparation for its removal from the furnace. The combustion zone appears at the surface of the charge relatively early in the firing zone and cooling of the bed takes place continuously substantially from that time. Actually, updraft cooling is begun almost as soon as the charge has burned through, and this is followed by a relatively short period of downdraft cooling to approximately room temperature.

All bed temperatures stated herein and indicated in the drawings are actually temperatures of the hot gases twelve inches above the portion of the bed specified.

When the combustion zone breaks through the top of the bed so that all of the fuel in the bed is exhausted and the gases emerging from the bed are free from both moisture and combustion products, recovery of the sensible heat in these gases is a practical possibility. Thus, in accordance with this invention, gases of this type collected through the middle portion of the length of the furnace, as indicated in FIG. 8, are withdrawn from duct compartment 48 separately from the cooler gases of compartment 49, and the contaminated gases in compartment 47, and filtered and reintroduced into the pellet bed in the combustion zone. As is shown, it may be desirable to supplement these gases with fresh air as make up and this may be regulated through control over the operation of fan 58.

In charging green balls into the traveling grate as stated above, they may be provided with coatings of sufficient solid fuel to meet their heating needs in the firing operation. Alternatively, they may be admixed in the bed with solid fuel in the required amount, being charged together therewith or being added separately to establish the desired ratio and bed constituency. Furthermore, by virtue of the heat recoveries possible in accordance with this invention, the ratio of fuel may be diminished in successive layers of the bed so that the ratio of fuel to pellet bulk will vary from rich to lean from the bottom of the bed to the top of the pellet bed.

In accordance with our preferred practice of this invention, when anthracite coal or similar high carbon-content solid fuel is employed and is added separately to the green ball bed, the amounts and particles sizes of this fuel are regulated so that fuel distribution through the bed is substantially uniform and each void in the bed is filled to approximately one-third of its total volume. Also, the green balls will be charged onto the grate so that between about 35% and about 55% of the resulting bed volume, excepting the separately added solid fuel, will represent voids. Thus the total void volume is diminished by the solid fuel by approximately one-third in our usual practice, but it will be understood that satisfactory results can be consistently obtained when the quantity of fuel is between about one-fifth and one-third of the total bed void volume, i.e. between approximately one-fifteenth and one-sixth of the aggregate volume of the green ball bed. However, it is important that the bed be pervious to gases and this requires that the amount of fuel be limited and that its distribution be such that no substantial proportion of the bed voids be eliminated with the result that the bed is effectively plugged. Additions of substantially more solid fuel than the limits stated above may be offset in their deleterious effects upon bed firing by increased blowing rates but this remedy will normally involve an economic disadvantage because of increased power requirements and possibly also because of lost heat values of the fuel.

Having thus described this invention in such full, clear, concise and exact terms as to enable any person skilled in the art to which it pertains to make and use the same, and having set forth the best mode contemplated of carrying out this invention, we state that the subject matter which we regard as being our invention is particularly pointed out and distinctly claimed in what is claimed, it being understood that equivalents or modifications of, or substitutions for, parts of the above specifically described embodiments of the invention may be made without departing from the scope of the invention as set forth in what is claimed.

What is claimed is:

1. The method of agglomerating finely-divided, raw, iron-ore concentrates in which the major portion of the iron is present in the form of a compound selected from the group consisting of hematite and magnetite which comprises the steps of forming green balls of said concentrates of various sizes, distributing said green balls and solid fuel on a grate as a bed of graduated green ball size with the largest green balls at the top of the bed, and flowing gases at elevated temperatures upwardly through the said bed and thereby igniting and burning the said fuel and firing the green balls.

2. The method set forth in claim 1 in which the solid fuel is sufficient to fill about one-third of the voids between the green balls.

3. The method set forth in claim 1 in which the voids between the green balls constitute between about 35% and about 55% of the total bed volume and the solid fuel is sufficient to fill about one-third of the total volume of the voids.

4. The method of agglomerating finely-divided, raw, iron-ore concentrates in which the major portion of the iron is present in the form of a compound selected from the group consisting of hematite and magnetite which comprises the steps of forming green balls of said concentrates of various sizes, distributing said green balls and solid fuel on a grate in a series of layers in which the green balls are graduated as to size between layers, and flowing gases at elevated temperatures through the resulting bed from the smaller green ball-size layer to the larger green ball-size layer and thereby igniting and burning the said fuel and firing said green balls.

5. The method of agglomerating finely-divided, raw, iron-ore concentrates in which the major portion of the iron is present in the form of a compound selected from the group consisting of hematite and magnetite which comprises the steps of forming green balls of said concentrates of different sizes ranging between about ¼" and about ½" in diameter, forming a plurality of layers of said green balls and anthracite coal on a porous bed of incandescent solid material on a grate, the size of the balls

being smallest in the lowermost layer and increasing in size in the layers thereabove, flowing gases at elevated temperatures upwardly through the layers of green balls and said coal and thereby drying the green ball layers in sequence, and igniting and burning the said coal and firing the lowermost green ball layer before uppermost green ball layer has been dried.

6. The method of agglomerating finely-divided, raw, iron-ore concentrates in which the major portion of the iron is present in the form of a compound selected from the group consisting of hematite and magnetite which comprises the steps of forming green balls of said concentrates of various sizes between about ¼" and about ½" in diameter, coating said balls with finely divided anthracite coal, forming a series of relatively shallow layers of said green balls, with the size of the balls increasing from the bottom layer to the top layer, heating and removing substantially all the moisture from the green balls of each layer in sequence, from bottom to top, and flowing gases at elevated temperatures upwardly through the resulting multi-layer bed of green balls thereby firing the green balls in sequence according to their location in the layered green ball bed so that as the lowermost layer is being fired the uppermost layer is being dried.

7. The method of agglomerating finely-divided, raw, iron-ore concentrates in which the major portion of the iron is present in the form of a compound selected from the group consisting of hematite and magnetite which comprises the steps of forming green balls of said concentrates of several different sizes, successively charging said green balls into a furnace to establish a plurality of layers graduated as to green ball size from a minimum of about ¼" in diameter in the lowest layer to about ½" in diameter in the top layer, incorporating high fixed-carbon content solid fuel in the bed in amount sufficient to fire all the green balls, igniting the fuel in the lower portion of the furnace charge, delivering a plurality of air streams upwardly into the bottom of the green ball bed and carrying the resulting combustion zone upwardly through the successive layers of green balls, and regulating the volume and velocity of flow of the air streams to control the rate of combustion of fuel in the bed in such a manner that the moisture is driven from the balls on one layer before another layer is applied thereto.

8. The method of agglomerating finely-divided, raw, iron-ore concentrates in which the major portion of the iron is in the form of hematite or magnetite comprising the steps of forming green balls of said concentrates of substantially uniform size between about ¼ inch and about ½ inch, providing on a grate a layer of indurated pellets, heating the indurated pellets to incandescence, providing a coating of finely-divided anthracite coal on said green balls, depositing the coal-coated green balls on the incandescent pellets to a bed depth of about eight inches, flowing air upwardly through the incandescent pellet layer and through the overlying green ball bed and igniting and burning the coal on the green balls, depositing additional anthracite coal-coated green balls to a bed depth of about eight inches on the first green ball bed when the zone of combustion approaches the top of the first said bed, continuing air flow upwardly through the grate charge, and depositing a third bed of anthracite coal-coated green balls of about eight inches depth when the zone of combustion has approached the top of the second green ball bed, and depositing a fourth anthracite coal-coated green ball bed about eight inches deep on top of the third green ball bed when the combustion zone has approached the top of the third said bed, continuing the upward flow of air through the grate charge until the combustion zone breaks through the top of the fourth bed, and then substantially increasing the volume of air flow through the bed to improve thermal efficiency.

9. The method of making iron ore pellets suitable for use in a blast furnace which comprises the steps of forming green balls by rolling finely divided, moist, raw iron ore concentrates in which the major portion of the iron is present as a compound selected from the group consisting of hematite and magnetite, forming a continuous layer of indurated iron ore pellets on an endless, continuously traveling grate, heating pellets in said layer to incandescence by moving said layer past a flame contacting the upper surface thereof, moving said layer into a closed combustion chamber and depositing at least one layer of said green balls and finely divided fuel on said incandescent pellets, flowing gases up through said pellets and green balls and burning said fuel in said chamber, cooling the burned green balls in a closed cooling chamber by flowing gases up through the burned green balls, and collecting gases in the cooling chamber ranging in temperature between about 800° F. and 2500° F. and directing said gases upwardly through the grate and materials thereon in the combustion chamber.

10. The method set forth in claim 9 in which a plurality of superimposed layers of green balls and finely divided fuel are successively formed on said layer of pellets.

11. The method of making iron ore pellets suitable for use in a blast furnace which comprises the steps of forming green balls by rolling finely divided, moist, raw iron ore concentrates in which the major portion of the iron is present as a compound selected from the group consisting of hematite and magnetite and coating said green balls with finely divided solid fuel, forming a continuous layer of indurated iron ore pellets on an endless, continuously traveling grate, heating the pellets in the upper portion of said layer to incandescence by moving said pellets past a flame contacting the upper surface thereof, moving the thus heated pellets into a closed combustion chamber and depositing at least one layer of said fuel coated green balls on said incandescent pellets, flowing gases up through said pellets and balls and burning the fuel on said green balls in said chamber, cooling the thus burned green balls in a closed cooling chamber by flowing gas up through the burned green balls, collecting gases from the cooling chamber ranging in temperature between about 800° F. and 2500° F., adding fresh air thereto and directing said mixed gases upwardly through the grate and materials thereon in the combustion chamber.

12. The method of making iron ore pellets suitable for use in a blast furnace which comprises the steps of forming green balls by rolling finely divided, moist, raw iron ore concentrates in which the major portion of the iron is present as a compound selected from the group consisting of hematite and magnetite, forming a continuous layer of indurated iron ore pellets on an endless, continuously traveling grate, heating pellets in the upper portion of said layer to incandescence by moving said layer past a flame contacting the upper surface thereof, moving said layer into a closed chamber having first, second and third zones, depositing at least one layer of said green balls and finely divided fuel on said incandescent pellets, flowing gases up through said pellets and green balls and igniting said fuel on said green balls in said first zone, removing and discarding moisture ladened gases from said first zone, burning said fuel and passing gases up through the green ball layer in the second zone, cooling the burned green balls in the third zone by flowing air up through the burned green balls, and collecting gases from the third zone ranging in temperature between about 800° F. and 2500° F. and directing said gases upwardly through the grate and materials thereon in the first and second zones.

13. In a pellet firing furnace the combination of an endless traveling grate, means forming a closed chamber about and along the grate and having first, second and third zones, conduit means to remove moisture ladened gases from above the grate in said first zone, conduit

means to remove highly heated gases from above the grate in the said second zone and discharge them into the first said zone below the grate, means to introduce fresh air into said highly heated gases just prior to their entry into said first zone, means to admit fresh air into said second and third zones beneath said grate, and means including temperature sensitive means in the upper part of said first zone for regulating the volume of gases discharged into said first zone.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,024,101 March 6, 1962

Louis J. Erck et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 6, line 28, for "Similarlly" read -- Similarly --; line 40, for "Through" read -- Throughout --; column 14, line 5, for "1,280,281" read -- 1,280,221 --.

Signed and sealed this 3rd day of July 1962.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents