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(54) **Starved-air combustor.**

(57) The present invention relates to a starved-air combustor of the type capable of consuming non-conventional fuels such as the byproducts of wood, pulp, and paper mills, and household and commercial refuse. Prior art starved-air combustors have not been entirely satisfactory in entirely consuming the combustible elements of the fuel at high throughput without producing air pollution. While the pollution problem can be solved to a degree by the utilization of scrubbers and other antipollution devices, such mechanisms are very expensive and their cost may militate against the use of alternative energy sources. The disclosed starved-air combustor includes a combustion chamber which is divided into a plurality of combustion chamber zones with separate overfire and underfire airflows being individually provided for each zone. Fuel is fed to the combustor in selectable constant weight batches and the supply of underfire air is proportional to the rate at which an auger rotates to convey the fuel through the combustor. Overfire air is supplied to each combustion zone in an inverse relationship to the variance of a sensed temperature within the zone from a predetermined temperature.

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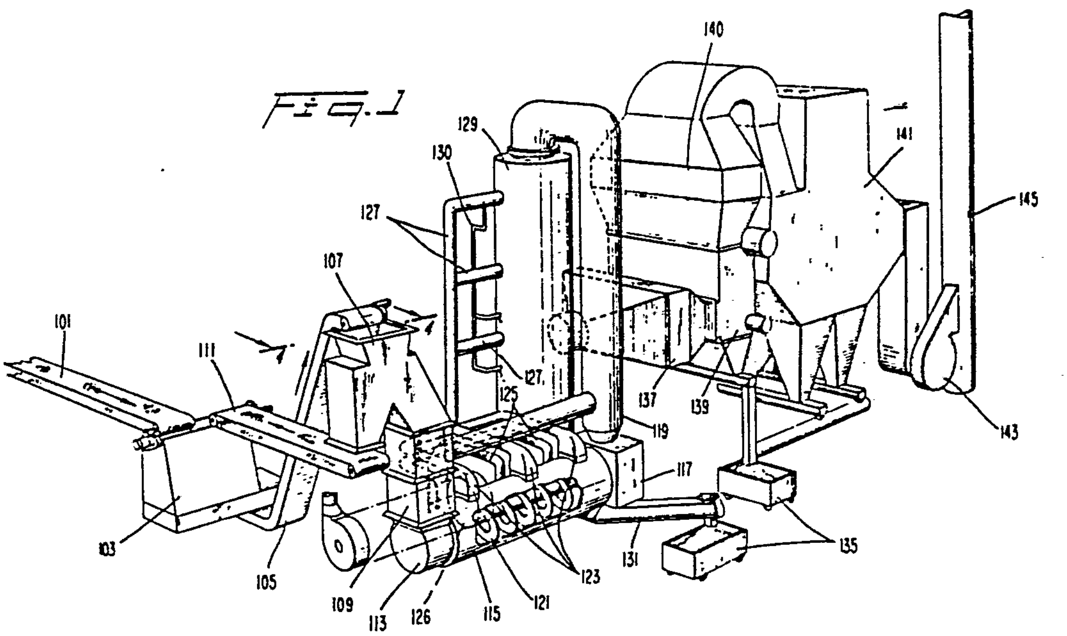
Fig. 1



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STARVED-AIR COMBUSTOR

BACKGROUND OF THE INVENTION

In the last century, much of the world's energy needs have been fulfilled by hydrocarbon fuels which provides a convenient, plentiful, and inexpensive energy source. The current rising costs of such fuels and concerns over the adequacy of their supply in the future has made them a less desirable energy source and has led to an intense investigation of alternative sources of energy. The ideal alternative energy source is a fuel which is renewable, inexpensive, and plentiful, with examples of such fuels being the byproducts of wood, pulp, and paper mills, and household and commercial refuse.

The use of alternative energy sources is not problem-free, however, since there is a concern over the contents of the emissions from the combustion of such fuels as well as the environmental ramifications of acquiring and transporting the fuel and disposing of the residue of combustion.

One promising prior art device for using such alternative energy sources while maintaining a high degree of environmental quality is the starved-air combustor wherein the air supplied for combustion is controlled in order to control temperature conditions and the rates of combustion are controlled to consume the fuel entirely. Such starved-air combustors are capable of burning various types of fuel and producing significant amounts of heat which can be employed for any number of purposes including the production of process steam for use in manufacturing and in the generation of electricity.

Starved-air combustors, as previously known and operated, have not been entirely satisfactory in both entirely consuming the combustible elements of the fuel at high throughput while not producing noxious emissions. This problem results, in part, from the use of such starved-air combustors to burn a wide variety of fuels some of which may be non-homogeneous, e.g., household or commercial refuse. It has not been possible in the previously known starved-air combustors to tailor in a real time manner the combustion processes to the type of fuel being combusted in order to maximize the efficiency of the combustor while minimizing the generation of air pollutants. While the pollution problem can be solved to a degree by the utilization of scrubbers and other antipollution devices, such mechanisms are very expensive and their cost may militate against the use of alternative energy sources.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a starved-air combustor capable of efficiently utilizing many different types and quantities of fuel.

Another object of the invention is to provide a starved-air combustor which does not release noxious pollutants into the atmosphere.

Yet another object of this invention is to provide a starved-air combustor which is capable of combusting to a very high degree the percentage of all combustible materials provided to it as fuel.

Still another object of the invention is to provide a starved-air combustor including a control system for selectively controlling the quantity of hot combustion gases produced thereby in accordance with the demand for heat produced by the starved-air combustor.

Yet another object of this invention is to provide a starved-air combustor wherein the combustion chamber is divided into a plurality of combustion zones and includes a control system which controls independently the injection of air into each of the combustion zones.

Another object of this invention is to provide a starved-air combustor wherein the air supplied to each combustion zone includes overfire air supplied above the fuel in the combustion zone and underfire air supplied beneath the fuel in the combustion zone and wherein the amount of overfire air supplied is dependent upon the temperature in the combustion zone and the amount of underfire air supplied is dependent upon the rate that fuel is being conveyed through the combustion chamber.

To achieve these objects, and in accordance with the purpose of the invention, as embodied and broadly described herein, the starved-air combustor comprises: a combustion chamber having an inlet end for receiving fuel, the combustion chamber for combusting the fuel to produce a quantity of heat (hot combustion gases) related to the rate of combustion; means for conveying the fuel through the combustion chamber at a variable rate; means for supplying a variable airflow to the combustion chamber; and means for controlling the rate of the conveying means and the quantity of air supplied by the supplying means to increase the quantity of hot combustion gases produced by the system responsive to an increase in the heat demand and to decrease the quantity of hot combustion gases produced by the system responsive to a decrease in the heat demand.

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate an embodiment of the invention and, together with the description, serve to explain the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an illustration of the starved-air combustor system of the instant invention connected between a fuel supply system and a system which produces process steam from the heat produced by the starved-air combustor system.

Figure 2 is a graph illustrating the relationship between temperature in the combustion chamber and the afterburner of the starved-air combustor system as related to the amount of air supplied to the combustion chamber and to the afterburner.

Figure 3 is a graph illustrating the control of the fuel flow for three given weights of fuel and a range of auger rotation rate.

Figure 4 is a cross-sectional view taken along lines 4-4 of a means for feeding variable quantities of fuel to the combustion chamber in a batch mode illustrated in Figure 1.

Figure 5 is a timing diagram explaining the operation of feeding means of Figure 4.

Figure 6 is a longitudinal cross-sectional view of the combustion chamber of the starved-air combustor system of Figure 1 taken along the line 6-6.

Figure 6A is a schematic view of an alternative embodiment of the means for exhausting combustion gases from the combustion chamber.

Figure 7 is a transverse cross-sectional view of the combustion chamber of the starved-air combustor system of Figure 1 taken along the lines 7-7.

Figure 8 is a schematic logic circuit diagram illustrating the control system for supplying overfire air and underfire air to the combustion chamber and air to the afterburner of the starved-air combustor system.

Figure 9 schematically illustrates the logic of the control circuit for relating the angular rate of the auger to the quantity of fuel conveyed through the combustion chamber of the starved-air combustor system.

Figure 10 schematically illustrates the control circuit for controlling the quantity of underfire air supplied to the combustion chamber of the starved-air combustor system.

Figure 11 schematically illustrates the control circuit for controlling the overfire air supply to the combustion zones in the combustion chamber of the starved-air combustor system.

Figure 12 is a top view of the hot gas recycle apparatus of the instant invention.

Figure 13 is a side view of the hot gas recycle apparatus of Figure. 12.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 illustrates an embodiment of the starved-air combustor according to the present invention coupled between a refuse feeder system and a steam generation system. As embodied herein, the refuse supply comprises a supply conveyor 101 for conveying fuel, in this instance refuse, from a receiving building (not shown) and one or more storage silos (not shown). The receiving building and storage silos are to insure that an adequate supply of fuel can be supplied to the combustor in order to permit the combustor to run at peak efficiency. In the illustrated embodiment, it is contemplated that the supply conveyor 101 would supply fuel to the fuel surge and recirculation bin 103 at a rate of at least fifteen tons per hour and that the capacity of the combustor system would range from 150 to 500 pounds per minute.

The fuel surge and recirculation bin 103 comprises an additional means for insuring that a constant and adequate supply of fuel is available to the combustor. The bin 103 could, for example, contain at least 10 minutes capacity of fuel, i.e., approximately 25 tons, which is received at the top of the bin 103 and supplied through the bottom of the bin 103 to the feed conveyor 105. Feed conveyor 105 supplies the fuel to a splitter valve 107 which may either direct the fuel into the feed and weigh bin 109 or, when the feed and weigh bin 109 is filled to capacity, to the return conveyor 111 for return to the fuel surge and recirculation bin 103. The feed and weigh bin 109 is calibrated to supply a constant weight of fuel at the inlet end 113 of a refractory lined combustor 115 at such time that the first flight of an auger 121 within the chamber 115 has been rotated into a fuel-receiving position. Within the starved-air combustor 115 there is provided a well-known oil igniter (not shown) in the input end 113 of the combustion chamber 115 to serve as a means for initially igniting the fuel upon start up of the starved-air combustor.

The auger preferably is rotatable, water-cooled horizontal shaft supporting a spiral flight of decreasing pitch from the input end of the auger to the output end. It is contemplated in the instant system that the speed of the auger would range from .3 to 1 rpm.

An appropriate oil igniter would comprise an oil burner having its flame extending into the input end of the combustor 115 to heat and to ignite the initial load of fuel supplied by the feed and weigh bin 109. It is contemplated that such an oil igniter would be capable of burning oil fuel at a rate of approximately six gallons per hour at two pounds per square inch pressure.

The combustor 115 has an output end 117 connected to a conduit 119 which feeds the top of an afterburner 129. The combustor 115 also includes air supply means 123 for supplying underfire air and conduits 125 for supplying overfire air. This air is provided by a fan 126 (shown in phantom) which also supplies air through conduits 127 to the afterburner 129. Alternatively, a separate fan or fans may be provided to supply underfire air, overfire air, and air to the afterburner 129. A small air distributor 130 is connected to the upper conduit 127 to supply air into the afterburner 129 through special injectors located both at and below the midpoint of the afterburner 129.

Afterburner 129 is provided, in part, as a secondary combustor chamber which mixes the air supplied by the conduits 127 with the gaseous and entrained solid particle output of the combustor from the outlet end 117 to combust all combustible material in the gaseous output and, in part, to separate suspended ash and non-combustible solids from the hot non-combustible gas. Both the non-combustible material from the afterburner 129 and the combustion residue from the combustor 115 are fed through conduit 131 to an ash collector 135. The hot non-combustible gas is discharged into a superheater 137 from which it is supplied to a waste heat boiler 139 to produce, in this case, process steam. An electrostatic precipitator 141 removes any additional solids from the now cooler non-combustible gas exiting from the waste heat boiler 139 through an economizer 140 and the solid material is conveyed to an ash cart 135. From the precipitator 141, the non-combustible gas is drawn by a fan 143 and expelled from stack 145. Upon entering into the fan the temperature of the gas is approximately 300 to 400 degrees Fahrenheit and the fan 143 is of sufficient strength to exert a negative pressure in the system within the combustor 115, the afterburner 129, superheater 137, waste heat boiler 139, economizer 140, and precipitator 141.

One of the principal advantages of a starved-air combustion system is that gasification or partial oxidation of solid fuels can be made to occur at moderate temperatures (1300° - 1800°F). The significant beneficial effects of this include elimination of slagging or fusing of the fuel and ash particles, exposing the combustor structure to only moderate temperature in non-oxidizing conditions, and reducing the formation of nitrogen oxides.

Thr principal control difficulty in the prior art starved-air combustor systems lies in maintaining temperature levels through the combustor, i.e., within the pile of fuel material and the gas space above it in the combustion chamber, while also optimizing the performance of the combustor system, i.e., mass of solid material gasified per unit of time and unit of area of grate surface. Temperature control is achieved by regulating the airflow into the combustion chamber to achieve the proper air/fuel ratio.

Figure 2 is a plot of temperature after reaction of fuel and air at different proportions and, as the terminology suggests, a starved-air combustor chamber operates at a negative percentage of excess air compared to the chemically correct amount in the temperature region indicated in Figure 2. Thus, to increase the operating temperature within the combustion chamber of a starved-air combustor, it is necessary to increase the airflow into the combustion chamber.

Also evident from Figure 2 is that the temperature within the afterburner responds to an increased airflow in the opposite manner as does the combustion chamber. Thus, to increase the temperature in the afterburner it is necessary to reduce the air supply thereto.

One problem in regulating the temperature within the combustion chamber is that the fuel bend and the injection of air into it are not necessarily homogeneous and the schedule of events leading to complete gasification or oxidation is not uniformly identical for all particles of the fuel. Local air/fuel ratio increases from average can cause radical temperature increases within the combustion chambers. Some of these pertubations in temperature are unavoidable because, as will hereinafter be explained, the air is injected into the combustion chamber from discrete parts through the refractory lining of the chamber and the fuel particles are obviously discrete solid particles thereby causing non-homogeneous air/fuel mixtures where the injected air directly impacts upon the fuel particles. These conditions are only temporary, however, because the auger within the combustion chamber removes and tumbles fuel so that the non-homogeneous conditions do not last long enough to cause slagging of the non-combustible material. The major difficulty arises in correctly relating the volumes the underfire air (the air supplied beneath the fuel in the combustion chamber) and the overfire air, (air supplied above the fuel in the combustion chamber) used in partially combusting or gasifying the solid fuel and the fuel gas to the rate of fuel flow within the combustion chamber.

The prior art attempted to solve the slagging and temperature control problems by different types of control systems. In one type of control system, the underfire air was uniformly supplied beneath the bed of fuel in the combustion chamber and the overfire air was supplied in multiple zones above the fuel bed. No means was provided for regulating the amount of fuel fed to the combustion chamber and all of the controls of the underfire air and the overfire air were manual. Some of the drawbacks of this arrangement were that it did not provide for altered zoning of the underfire air to accommodate changes in fuel moisture content and reactivity, and the possibility that uncontrolled variable fuel feed could lead to undesired oscillations in the operating properties in the combustion chamber.

It has also been attempted, in the prior art, to provide a combustion chamber wherein no overfire air is provided but where the underfire air was separated into three different zones with independent control of the airflow into each zone. This approach suffers from the inability to balance properly the reaction sequence in the fuel bed and the reaction sequence in the evolved combustion gases especially during changes of fuel feed rate. When the fuel feed was interrupted temporarily or when the rate of fuel feed was decreased because of reduction of fuel density, the severe local temperature aberrations occurred because of an increase in the air/fuel ratio. When the airflow rate was decreased, the gasification rate and efficiency of the starved-air combustor decreased.

The present invention, as will hereinafter be described, avoids the problems of the prior art starved-air combustor systems and provides a starved-air combustor of greater efficiency by providing a feed system for feeding fuel into the combustion chamber in constant weight batches, an air supply system for feeding both underfire and overfire air in a zoned manner, and a control system for regulating underfire airflow in accordance with the rate of fuel flow through the combustion chamber and overfire air flow in accordance with the temperatures in the combustion zone The feed system charges a fixed (operator-set) weight of fuel (M) for each rotation or partial rotation of the auger within the combustion chamber. This means that the fuel weight flow rate (m_f) is adjústed by changing the auger rotation rate (W_{aug}). The proportion of underfire air (m_u) to fuel weight flow rate is operator-set, as a function of auger rotation rate W_{aug}, while overfire flow rates (m_o) are controlled according to the gas temperature of the combustion zones T_i. Thus, fuel flow and underfire air are keyed to the auger's speed by $m_u = K \cdot M \cdot W_{aug}$ so that after M and the constants for each zone K_i are set, then underfire air/fuel flow ratios are constant. If auger speed drops, m_u is automatically decreased in proportion. Similarly, if M is decreased, m_u is also decreased. Thus, the response of the starved-air combustor system to changes in heat demand is through auger speed.

This approach insures that the flow of fuel through the fuel bed in the combustion chamber is of uniform size and is provided with the same air/fuel ratio for each batch of fuel that is fed into the combustion chamber.

Figure 3 is a graph relating fuel feed rates to auger speed. If, for example, the nominal maximum fuel feed rate and auger speed is 15 tons of fuel per minute and .9 revolutions of the auger per minute, then the line A relates decreases in the fuel feed rate to decreases in the auger speed for a constant fuel batch weight MI. It has been determined that if the auger is rotated at too slow a rate, e.g., less than .4 rpm, clinkering and slagging may occur within the combustion chamber. Thus, as the auger speed approaches .4 rpm with the fuel batch weight of MI, or the fuel feed rate is 8 tons per hour or less, then it is more efficient to operate along performance curve B with a fuel batch weight of M2 less than MI than performance curve A. Similarly, a change to operating curve C with a fuel batch weight of M3 less than M2 should be effected when fuel is being fed at a rate of 5 or fewer tons per hour or auger speed approaches .4 rpm.

As stated above, the starved-air combustor system of the instant invention includes means for feeding selectable weights of fuel into the inlet end 113 of the combustion chamber 115 in a batch mode. Such a feeding means is illustrated in Figure 4. The feeding means comprises a chute 201 positioned beneath the fuel feed conveyor 105 such that fuel conveyed by the conveyor 105 drops off into the chute 201. From the chute 201, the fuel can either pass into a combustor feed path 203 of the feeding means or a return path 205 to the return conveyor 111 for return to the surge and recirculation bin 103 as previously explained. A splitter valve 207 is rotatable in the neck of the chute 201 to guide the received fuel to the combustor feed path 203 or to the return path 205.

The combustor feed path 205 leads to a chute 209 for guiding the fuel directed to the combustion chamber 115 into a weigh bin 211. A cover valve 213 is provided at the inlet of the chute 209 and is rotatable to either permit the fuel to pass from the chute 209 and into weigh bin 211 when the cover valve is in an open or downward position or to prevent additional fuel from entering chute 209 and weigh bin 211 when the cover valve 213 is in a closed or, as illustrated in Figure 4, a horizontal position. The cover valve 213 provides an airtight seal with the sides of the chute 209 such that when the cover valve 213 is closed, outside air is prevented from entering chute 209 and weigh bin 211. The cover valve 213 could alternatively be a slidable valve having an inward (closed) position and an outward (open) position.

The weigh bin 211 is connected to the chute 209 via a flexible coupling 215 so that the weight of the weigh bin 211 and any fuel contained therein is not supported by the chute 209, but, as will hereinafter be explained, is supported by means of one or more weigh cells 223 connected between a stationary support member 221 and support arms 225 extending from the exterior of the weigh bin 211.

Release valve 217 is not opened, i.e., rotated to extend into the lower chute portion 219 of the feeding means, until the weigh cells 223 indicate that a predetermined weight of fuel has been accumulated in weigh bin 211 and an auger position sensor 227 has determined that the auger 121 has been rotated into the proper feed orientation. The lower chute portion 229 is coupled to the weigh bin 211 by means of a flexible, airtight seal 218 so as not to support the weigh bin 211 but merely to guide the fuel into the inlet end 113 of the combustion chamber 115 while simultaneously preventing ambient air from entering the combustion chamber 115. As stated above, the feeding means includes weighing means which, as embodied herein, comprise one or more weigh cells 223 coupled, as above-described, between stationary support members 221 and support arms 225 connected to the weigh bin 211.

One skilled in the art will readily recognize that each weigh cell 223 comprises any one of a number of means whereby a particular weight can be selected, the weight of the weigh bin including fuel received and contained therein determined, and an output signal generated when the measured weight of the weigh bin exceeds a selected weight. As an example, the weigh cell 223 could comprise a variable resistor for generating a voltage signal with a level proportional to the weight of the fuel in the bin 211. A voltage threshold detector senses the voltage levels and actuates a microswitch when the sensed voltage exceeds a threshold voltage corresponding to a selected weight. The output of the microswitch is employed within suitable logic circuitry, as will be hereinafter explained, to actuate splitter valve 207, cover valve 213, and release valve 217 to feed the conveyor with fuel in a proper manner.

Figure 4 also illustrates, in block diagram form, functional logic circuits that are needed to control the feeding means to feed fuel either into the combustor 115 or to the return conveyor 111. Figure 5 is a timing diagram to be read in conjunction with the block diagram of Figure 4 for complete understanding of the operation of the logic circuits.

In normal operation, during the combustion chamber feed mode, the splitter valve 207 will be positioned as indicated by the solid lines in Figure 4. The cover valve 213 will be in its open, or downward position, and the release valve 217 will be in the closed position as shown in Figure 4. Fuel will be dropping from feed conveyor 105 through the feed path 203 and the upper chute 209 into the weigh bin 211. This will gradually cause an increase in the weight of the fuel in the weigh bin 211 and, when the preselected weight of a batch or charge of fuel has been accumulated in the weigh bin 211, then the weigh cells 223 will cause bin full signals to be supplied to the feed control circuit 231. This is illustrated in Figure 5 as a change of the bin full signal from a low value to a high value.

When the preselected weight has been accumulated in the weigh bin 211, it is necessary to rotate the splitter valve 207 into the orientation shown by the dotted lines in Figure 4 and to close the cover valve 213. This is performed under the control feed control circuit 231 by supplying an appropriate output to cover valve control 233 and to splitter valve control 235. Once the splitter valve 207 has been rotated into its recirculation position and the cover valve 213 rotated into its air-sealing position, then the feeding means will not change state until the auger position sensor 227 determines that the auger 121 has been rotated into an orientation such that the area 151 is of its proper feed volume. When this orientation of the auger 121 is reached, the auger position sensor 227 supplies a pulse as shown in Figure 5, to the feed control circuit 231.

There are many ways of implementing the auger position sensor 227, for example, a small magnetic flux producing element could be attached to the auger such that it would be rotated into alignment with a flux sensor when the auger has been rotated into the feed orientation. When the feed control circuit has received the auger position pulse and is also still receiving the bin full signal at a high level, the feed control circuit 231 will signal the release valve control 227 to rotate the release valve 217 to its downward orientation in order to permit the fuel contained within the weigh bin 211 to pass through lower chute 219 into the first area 151 of combustion chamber 115.

The feed control circuit 231 will produce a restore pulse, after a suitable delay to provide time for the fuel to be discharged from the weigh bin 211, that is supplied to the auger position sensor 227, release valve control 229, cover valve control 233, and splitter valve control 235 to control the feeding means in a manner to permit the accumulation of a subsequent charge or batch of fuel in the weigh bin 211. As explained above, this feeding orientation comprises: first, closing release valve 217; second, opening the cover valve 213; and third, rotating splitter valve 207 into the orientation illustrated by the solid lines in Figure 4. The weigh cells 223 will automatically reset the microswitch because after the discharge of the fuel from weigh bin 211 the weigh cells 223 will no longer indicate that a preselected fuel weight has been accumulated in weight bin 211.

Figure 6 illustrates an embodiment of the combustion chamber 115 of the starved-air combustor system. As shown in Figure 6, the starved-air combustor system includes means for conveying the fuel through a combustion chamber at a variable rate. As embodied herein, the conveying means comprises screw conveyor or auger 121 extending the length of the combustion chamber and being rotated by the auger motor and speed control 251. The auger motor and speed control 251 is capable of rotating the auger at rates of, for example, from .3 to 1.0 rpm under manual control.

The fuel bed 253 is of its greatest depth at the inlet end

113 of the combustion chamber and is conveyed from the inlet end 113 to the outlet end 117. During its travel through the combustion chamber, the fuel bed 253 gradually decreases in size as its contents are combusted and combustion gases evolved. The auger 121 is positioned off-center within the combustion chamber 115 in order to provide a gas mixing zone above the fuel bed 253. In the mixing zone, the evolved gases are mixed with overfire air supplied by air supply means 125 (figure 1) for further combustion. Conduits 123 supply underfire air to the combustion chamber beneath the bed of fuel 253 such that the underfire air, when at an elevated temperature, contributes to the ignition of the fuel in the fuel bed 253 by heating and drying the fuel.

The starved-air combustor system further comprises means for supplying a variable airflow to the combustion chamber 115. The physical structure for accomplishing this is illustred in Figure 6 and, as embodied therein the walls of the combustion chamber 115 include underfire air plenums 255 each coupled to one of the air supply conduits 123. Air passes from the plenums 255 through pipes 256 (Figure 7) embedded in a refractory layer 257 and terminating in a plurality of ports or injectors 259 communicating with the combustion chamber 115 beneath the bed of fuel 253. The plenums 255 are separated from each other by stops or gaskets 261 to define multiple underfire combustion zones Z1, Z2, and Z3.

Similarly, overfire air is supplied to the combustion chamber 115 by means of plenums 263 (Figure 7) communicating with the overfire air supply means 125. The plenums are divided into a plurality of zones (in this case, three) and the air within each zone is injected into the combustion chamber 115 through ports or injectors 267 which extend through the layer of refractory material 257 lining the interior surface of the combustion chamber 115. As illustrated in Figure 6, the zones of the overfire air and the zones of the underfire air may coincide and form combustion zones Z1, Z2, and Z3. A temperature sensor 271 (Figure 7) is inserted through the refractory material 257 into the gas phase flame areas of each of teh temperature zones to sense the temperature in the overfire area of the zone.

Overfire and underfire air injectors may be used in each zone Z1, Z2 and Z3 or, alternatively, certain zones may be provided with either overfire or underfire air injectors, as desired.

With reference to Figure 7, the rotation of the auger (not shown) within combustion chamber 115 results in the fuel bed 253 being oriented as shown. Underfire air from supply 123 is supplied to plenum 255 from which it is ignited beneath the fuel bed 253 by means of pipes 256 terminating in injectors 259. The pipes 256 are embedded in the refractory lining 257 of the combustion chamber 115.

Underfire air received by one of the plenums 263 from supply 125 is injected above the fuel bed 253 through ports 267. The temperature sensor 271 for one of the overfire air zones is provided above the fuel bed 253 and it is contemplated that a thermocouple capable of withstanding the high combustion chamber temperatures could be employed as sensor 271.

The starved-air combustor of the instant invention further comprises means for controlling the rate of the fuel conveying means or auger 121 and the volume of the airflow supplied into the zones Z1, Z2, and Z3 to increase or to decrease the quantity of heat produced in the form of hot combustion gases. The means for controlling the rate of the conveying means and the airflow supplied by the supplying means to increase the quantity of hot, combustion gases (heat) produced by the system responsive to an increase in the quantity of hot, combustion gases (heat) produced by the system responsive to a decrease in the heat demand, as embodied herein, is illustrated in Figure 8 as comprising an underfire air system, an overfire air system, and an afterburner air system. The afterburner air system is not a feature of the present invention and will not be discussed in detail.

As illustrated in Figure 8, the combustor 115 receives underfire air in three zones: primary (p) corresponding to zone 1, secondary (s) corresponding to zone 2, and tertiary (t) corresponding to zone 3. Controllers 301, 303, and 305 control the injection of underfire air from air supply line 307 into the p, s, and t zones. These three zones are set to initial values to apportion the air supplied by the air supply line 307 to the previously discussed supplier 123 but, as explained above, if there is a change in heat demand then the speed of the auger will be changed necessitating corresponding changes in the supply of air to the p, s and t zones by the controllers 301, 303, and 305, respectively. The change in auger speed as determined by the auger motor and speed control 251 (Figure 6) are supplied to multiplier 309 along with a signal indicating the weight of each batch of fuel supplied to the combustion chamber. This weight is represented by the quantity M and could, for example, be an output of the previously explained weigh cells 223. The output of multiplier 309 is a signal K_u which is supplied as an input to each of the controllers 301, 303, and 305 to alter the airflow into their associated underfire zones.

The overfire air system is, as previously explained, temperature dependent and thus the signal T_p is an output of temperature sensor 271 (Figure 7) which monitors the temperature in combustion zone Z1 or the primary zone. The controller 313 compares the instantaneous temperature within the primary zone to a desired temperature and properly alters the airflow from air supply line 319 to the primary zone in the combustion chamber. Similarly, controllers 315, and 317 receive the temperature indications T_s and T_t, respectively, from the temperature sensors to 271 in their associated combustion zones. Any change in the temperatures in their associated zone from the desired temperature will cause the controllers 315 and 317 to alter the airflow from air supply line 319 into the secondary and tertiary zones in the manner illustrated in Figure 2.

Figure 9 illustrates, in greater detail, the circuit for controlling the flow of fuel into the combustor 115. The mass of each fuel batch or charge is supplied to the multiplier 309 where it is multiplied by the change in auger rotation rate W_{aug}. The output of the multiplier 309 is the change in fuel feed m_f which must be accommodated by the underfire air control system.

Figure 9 illustrates, in greater detail, the underfire air control system. The controllers 301, 303, and 305 are initially set with a constant indicating the air distribution into the primary, secondary, and tertiary zones. The controllers 301, 303, and 305 each receive, as an input, the change in fuel flow through the combustion chamber and each generate output signals to adjust accordingly the airflow into the primary, secondary, and tertiary zones. As an example, the output of controller 301 is a signal corresponding to the new airflow into the primary zone of the combustion chamber. This is supplied to an adder 321 which receives as its other input the output of flow transmitter 323 indicating the amount of air currently flowing into the primary zone from the air supply line 307. If there is a difference between the newly determined amount and the current airflow into the primary zone then a signal representing that difference is supplied to valve control circuit 325 to open or close a flow control device 327, e.g., a valve. The output of the flow control device 327 is the air supplied to the primary zone (Z1 in Fig. 6) through the appropriate air conduit 123 (Fig. 6). If the heat demand is increased, then the flow control device 327 will cause a greater airflow into the primary zone of the combustion chamber. Conversely, if the heat demand is decreased, the output of the adder 321 will be a negative difference and will cause valve control circuit 325 to control the flow control device 327 in a manner to restrict airflow into the primary zone of the combustion chamber. Figure 10 also illustrates the circuits required to control airflow into the secondary and tertiary zones in the combustion chamber but these will not be explained since they operate in the same manner as the circuit for controlling airflow into the primary zone.

Figure 11 illustrates an embodiment of a circuit for controlling the flow of overfire air into the primary, secondary, and tertiary zones. Initially, the controllers 313, 315, and 317, are set to values corresponding to the desired temperature in the primary, secondary, and tertiary zones, respectively, within the combustion chamber. The controller 313, as explained above, receives a signal T_p corresponding to the actual temperature within the primary zone and will generate an appropriate output signal representing the difference between the desired primary zone temperature and the actual primary zone temperature. This is supplied to the adder circuit 329 which receives as another input a signal corresponding to the current flow of overfire air into the primary zone. The difference between the two signals is determined and passed to valve control circuit 333 which appropriately opens or closes the flow control device, such as a valve 335, to either increase or to decrease the temperature within the primary zone. This will cause a change in the temperature in the primary zone which will be supplied to the controller 313. When the proper temperature has been reached in the primary zone, then the adding circuit 329 will no longer signal the valve control circuit 333 to adjust the flow control device 335.

The starved-air combustor further includes means (see Figure 6) for controlling the exhausting of the evolved gases from the combustion chamber to exhaust selectively the evolved gases entirely through the conduit 409 or proportionally through the conduit 401 and the conduit 409. As embodied herein, the controlling means comprises a manually-positionable damper 403 located at the intersection of the conduit 401 and the duct 119 and having a length sufficient to seal completely the intersection of the conduit 401 and the duct 119 when the damper 403 is positioned in a vertical position and to restrict partially the commication of conduit 409 with the duct 119 when the damper is rotated in the horizontal position. As illustrated in Figure 6, the damper has been positioned to permit exhaustion of the gases through both the conduit 401 and the conduit 409 to enable the selective balancing of co-current and countercurrent flow of combustion gases in the combustion chamber 115.

Figure 6A illustrates an alternate embodiment of the first and second exhausting means and the controlling means. As illustrated in Figure 6A, the first means and the second means comprise first and second conduits 411 and 413, respectively, which intersect at the location of the damper 415. The damper is selectively positionable to control the flow of exhaust gases through the conduit 411 or the conduit 413 into the exhaust gas collector or duct 119. As was the case with the embodiment illustrated in Figure 6, the overfire air and underfire air supplied to the combustion chamber together with the draft of the fan 143 (Fig. 1) causes an inherent flow of combustion gases from the combusting fuel in the fuel bed 253 out of the combustion chamber 115.

The instant starved-air combustor further comprises means for receiving the hot, combustion gases from the combustion chamber and for further combusting any combustible material entrained in the combustion gases to produce hot, non-combustible gases. As embodied herein, this receiving and combusting means comprises afterburner 129 (Figure 1) connected to the outlet end 117 of the combustion chamber 115 by means of duct 119. The instant exhaust gas recycle device is operable with many different types of afterburners.

The output of the afterburner 129 is a gas having a temperature between 1500-2000°F. This gas is supplied, as previously explained, to superheater 137 but, as contemplated in the instant invention, a portion of this gas is also supplied to a means for selectively mixing the gas with selected amounts of air to heat the air and for supplying the mixture to the underfire air inlet 123 of plenum 255 for injection into the combustion chamber through the injectors 259 embedded the layer of refractory material 257.

This mixing and supplying means is illustrated in Figures 12 and 13 and, as embodied herein, comprises a mixing chamber having a central inlet 521 for receiving the hot gases from the discharge of the afterburner 129. Surrounding the inlet 521 are radial vanes 523 rotatable around axes 525 to permit selected amounts of air to enter the mixing chamber. As shown in Figure 12, the vanes 523 are in their fully closed position and, therefore, would not permit the entry of air into the mixing chamber.

Surrounding the ends of the radial vanes 523 is a ring actuator 527 concentrically rotatable about the inlet 521. Rotation of the ring actuator 527 controls the opening and closing of the radial vanes 523 by appropriate links 528 which cause the vanes 523 to rotate upon rotary displacement of the actuator 527 to control the entry of air into the mixing chamber. The mixing chamber further includes an outlet 530 for discharging the mixed combustion gases received through inlet 521 and air received through the openings through the vanes 523. A fan 529 provides the appropriate negative pressure to pull air into the mixing chamber. The inlet 123 into the first plenum 255 is connected to the output side of fan 529 such that the mixture of air and combustion gases is supplied to the plenum 255.

Figure 13 is a side view of the mixing chamber broken-away along line 532. The side view of the vanes 523 illustrates them in a partially open position to permit air to enter the mixing chamber 531. A fixed set of radial vanes 533 is provided within the mixing chamber 531 to reverse the flow of the air and combustion gas in the chamber 531 to insure a complete mixture of the air and the gas.

The starved-air combustor further includes means for sensing the temperature of the mixture of air and non-combustible gas and for controlling the amount of air mixed with the non-combustible gas to maintain a preselected temperature range for the mixture. As embodied herein, the sensing and controlling means comprises a sensor unit 535, for example, a thermacouple, connected to temperature control circuit 537. The temperature sensor 535 produces an output signal having a magnitude reflecting the temperature of the gas exhausted from the outlet 530 of the mixing chamber 531. If the magnitude of the output signal is within the range of magnitudes corresponding to a range of acceptable temperatures for the mixture of air and gas, then temperature control circuit 537 will permit the status of the mixing chamber 531 to remain unchanged. If, however, the magnitude of the output signal of temperature sensor 535 indicates that the temperature of the mixture discharged through outlet 530 is not within the preselected range, temperature control circuit 537 supplies an appropriate outlet signal to ring actuator control 539 to control the rotation of ring actuator 527 to either further open or further close the vanes 523. If the temperature of the discharged mixture is too low, then too much air is entering the mixing chamber 531 and the ring actuator control will cause the ring actuator 527 to rotate in the direction to cause the vanes 523 to close and permit less air to enter the mixing chamber 531. If, however, the temperature of the mixture discharged through outlet 530 is too high, as sensed by temperature sensor 535, then the ring actuator control 539 will cause the ring actuator 527 to rotate in the direction to open the vanes 523 of the mixing chamber 531. If the temperature of the discharged mixture exceeds a certain boundary temperature, then temperature control circuit 537 will signal gas control 541 to rotate valve 543 within the gas inlet 521 to block the entry of gas into the mixing chamber 531.

In summary, the instant combustion gas recycle apparatus receives hot gases (1500-2400°F) from the afterburner in the starved-air combustor system of the instant invention. The top of the mixing chamber 531 has automatically controlled radial vanes 523 which open and close to modulate the amount of air drawn into the mixing chamber 531 to maintain a preset mixed gas temperature upon discharge from outlet 530 of the mixing chamber 531. The orientation of the vanes 523 is such as to impact a strong swirl to the air as it enters the box whereby the combustion gas and the air mix by sheer-generated turbulence with the inner core of air being hotter and the areas surrounding the walls of the mixing chamber 531 being cooler. With this flow pattern, a refractory lining of the mixing chamber is not required although such a refractory lining could be provided. A plurality of fixed, radial vanes 533 within the mixing chamber 531 reverses the direction of flow to further enhance mixing. The mixed gas and air exits through outlet 530 of the mixing chamber 531.

From outlet 123, the mixture is supplied as underfire air to the first plenum 255 of the combustion chamber 115 to be injected into the fuel duct connected to plenum 255 to heat and to dry the fuel in the bed 253 as an aid to combustion.

CLAIMS

1. A starved-air combustor system for producing a variable quantity of heat responsive to a demand for said heat, said combustor system comprising: a combustion chamber having an inlet end for receiving said fuel, said combustion chamber for combusting said fuel to produce a quantity of heat related to the rate of combustion; means for conveying said fuel through said combustion chamber at a variable rate; means for supplying a variable quantity of air to said combustion chamber; and means for controlling the rate of said conveying means and the quantity of fuel supplied by said supplying means to increase the quantity of heat produced by said system responsive to an increase in said heat demand and to decrease the quantity of heat produced by said system responsive to a decrease in said heat demand.

2. A starved-air combustor system according to Claim 1, including means for feeding selectable weights of fuel into said inlet end of said conveyor in a batch mode.

3. A starved-air combustor system according to Claim 2, wherein said combustor chamber is cylindrical and includes an outlet end for discharging combustion residue produced by said combustion and wherein said conveying means comprises: a rotatable screw conveyor in said combustion chamber for conveying said constant weight batches of fuel from said inlet end of said combustion chamber to said outlet end of said combustion chamber and for conveying said combustion residue toward said outlet end of said combustion chamber; and means for rotating said rotatable screw conveyor at a variable rate directly proportional to said heat demand to control the flow of said fuel through said combustion chamber.

4. A starved-air combustor system according to Claim 1, 2 or 3, wherein said combustion chamber has an outlet end for discharging said hot combustion gases, said combustion chamber being divided into a plurality of combustion zones serially spaced from said inlet end to said outlet end, and a plurality of air supply means singularly associated with each of said combustion zones for independently supplying to said associated combustion zone a variable airflow.

5. A starved-air combustor system according to Claim 4, wherein said air supplying means comprises at least one overfire air injector associated with at least one of said plurality of zones for injecting air above the fuel in said associated combustion chamber zone,

a temperature sensor associated with said at least one of said combustion chamber zones for determining the temperature in said associated combustion chamber zone, and an overfire air controller for controlling the quantity of air injected into said at least one of said combustor zones by said at least one overfire air injector in response to the temperature in said associated zone as determined by said associated temperature sensor.

6. A starved-air combustor system according to Claim 4 or 5, wherein said air supply means includes at least one underfire air injector associated with at least one of said combustion chamber zones for injecting air into said associated zone beneath said fuel in said associated zone, and an underfire air controller for controlling the quantity of air injected into said last-mentioned at least one of said zones by said at least one underfire air injector in direct proportion to said flow of fuel through said conbustion chamber.

7. A starved-air combustor system according to Claim 5 or 6 wherein said at least one overfire air injector comprises a set of overfire air injectors associated with each of said combustor chamber zones and said overfire air controller controls the quantity of air injected into each of said combustor zones by said set of overfire air injectors.

8. A starved-air combustor system according to Claims 5, 6 or 7, wherein said at least one underfire air injector comprises a set of underfire air injectors associated with each of said combustor chamber zones and said underfire air controller controls the quantity of air injected into each of said combustor zones by said set of underfire air injectors.

9. A starved-air combustor comprising: a cylindrical combustion chamber having an inlet end for receiving fuel and an outlet end for discharging combustion gases and combustion residue, said combustion chamber for combusting said received fuel to produce said combustion gases and said combustion residue; a rotatable screw conveyor in said combustion chamber for conveying said fuel from said inlet end toward said outlet end, said screw conveyor comprising a cylindrical axle extending along the length of said chamber and a spiral flight concentrically connected to said axle, said spiral flight and said cylindrical axle defining in said combustion chamber a plurality of spaces around said cylindrical axle, a first of said spaces located beneath said inlet end of said

cylindrical combustion chamber; and means for selectively feeding predetermined weights of said fuel into said first space through said inlet end.

10. A starved-air combustor according to Claim 9, including means for sensing the orientation of said screw conveyor in said cylindrical combustion chamber and wherein said feeding of said fuel into said first space is responsive to the rotation of said screw conveyor into a predetermined orientation in said combustion chamber.

11. A starved-air combustor comprising: a combustion chamber having an inlet end for receiving fuel, said combustion chamber for combusting said received fuel to produce hot, combustion gases and combustion residue, said combustion chamber including an outlet end for discharging said combustion residue; means for conveying said fuel through said combustion chamber from said inlet end toward said outlet end; first means communicating with said combustion chamber proximate said inlet end of said combustion chamber for exhausting said hot, combustion gases from said combustion chamber; second means communicating with said combustion chamber proximate said outlet end of said combustion chamber for exhausting said hot, combustion gases from said combustion chamber; and means for controlling the exhausting of said combustion gases from said combustion chamber to exhaust selectively said evolved gases entirely through said seocnd means or proportionately through said first means and said second means.

12. A starved-air combustor comprising: a combustion chamber having an inlet end for receiving fuel, said combustion chamber for combusting said received fuel to produce hot combustion gases and a combustion residue, said combustion chamber further including an outlet end for discharging said combustion gases; means in said combustion chamber for conveying received fuel from said inlet end towards said outlet end; a plenum adjacent to said combustion chamber and communicating with said chamber through at least one aperture located beneath said fuel in said combustion chamber; means for receiving said hot, combustion gases from said combustion chamber and for further combusting any combustible material entrained in said combustion gases to produce a hot, non-combustible gas; means for selectively mixing a portion of said non-combustible gas with selected amounts of air to heat said air and for supplying said mixture to said plenum for injection into

said combustion chamber through said at least one aperture to heat and to dry said fuel in said chamber; and means for sensing the temperature of said mixture of air and non-combustible gases and for controlling the amount of air mixed with said non-combustible gas to maintain a preselected temperature range for said mixture.

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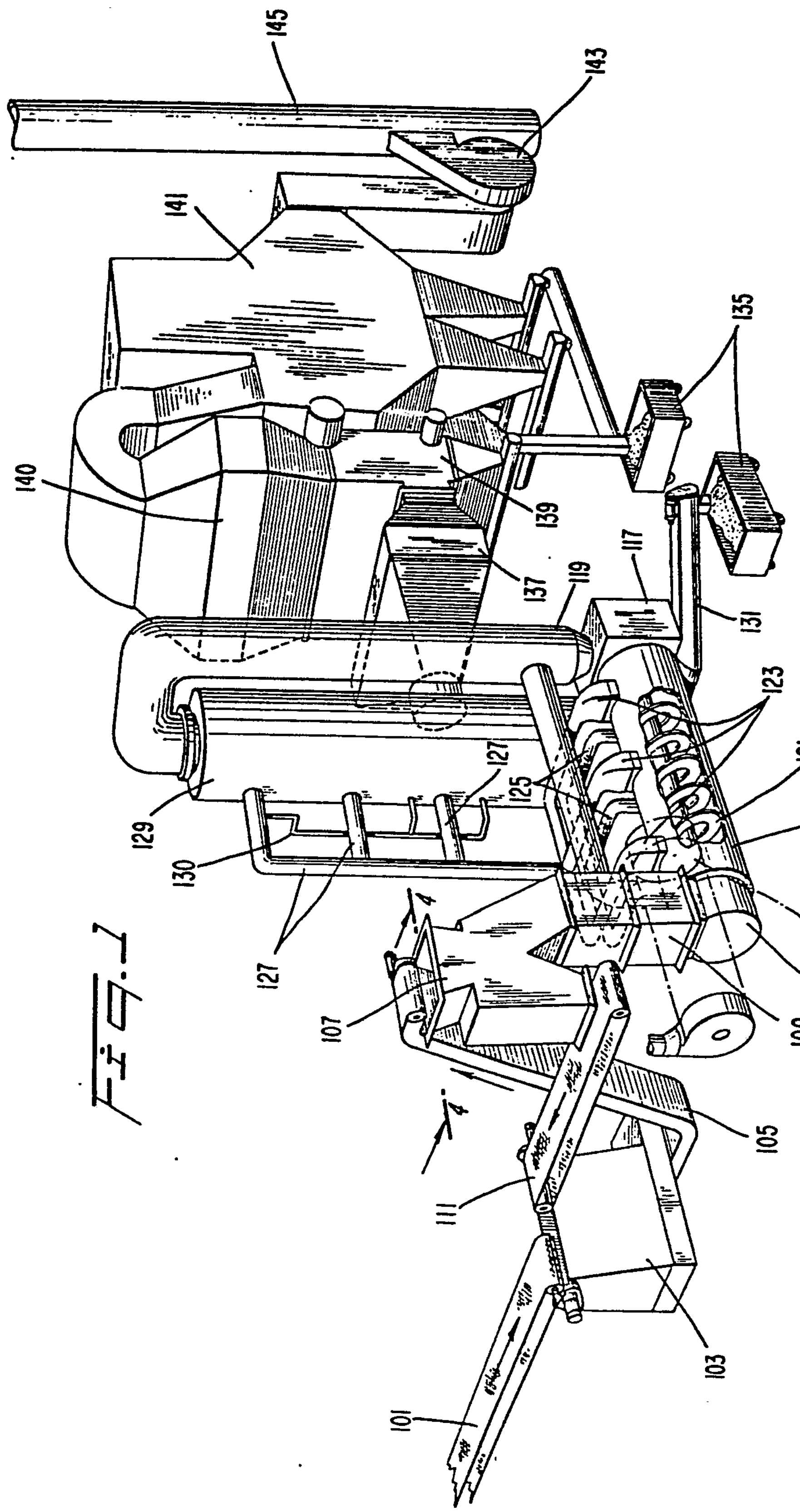

FIG. 1

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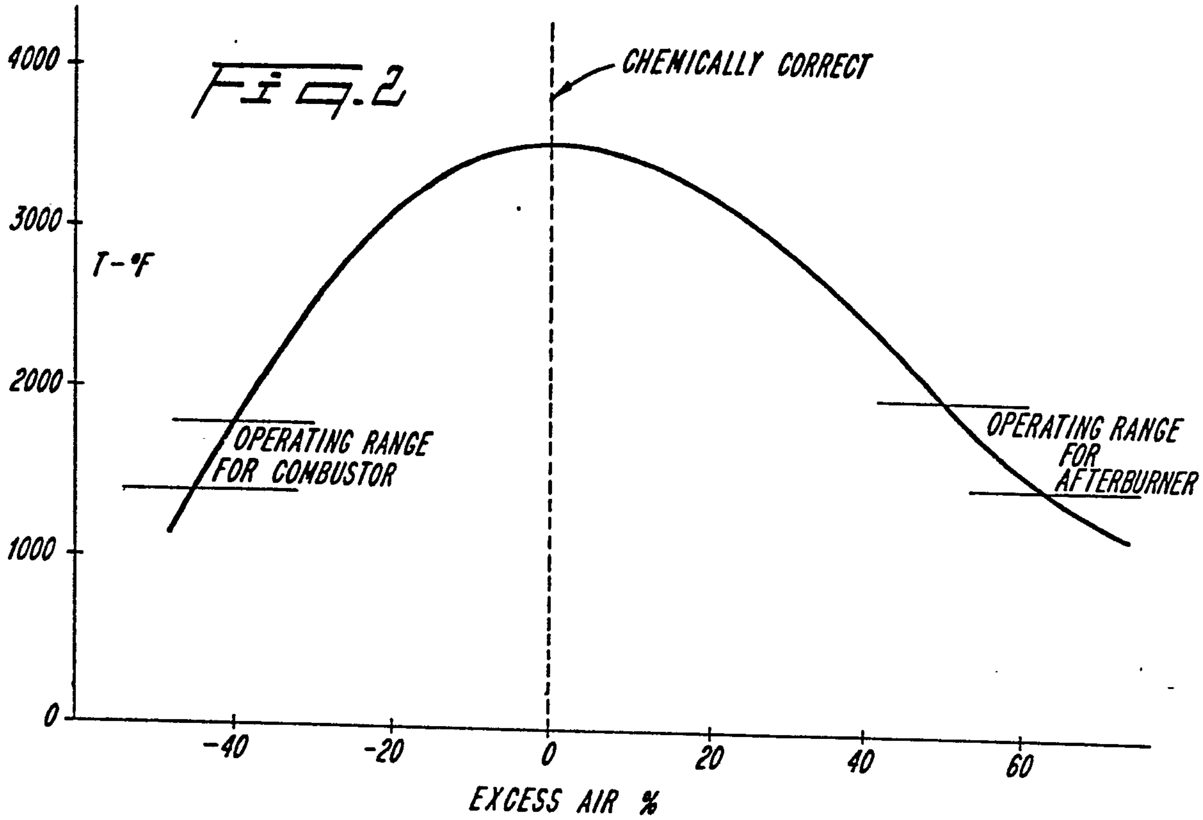


Fig. 2

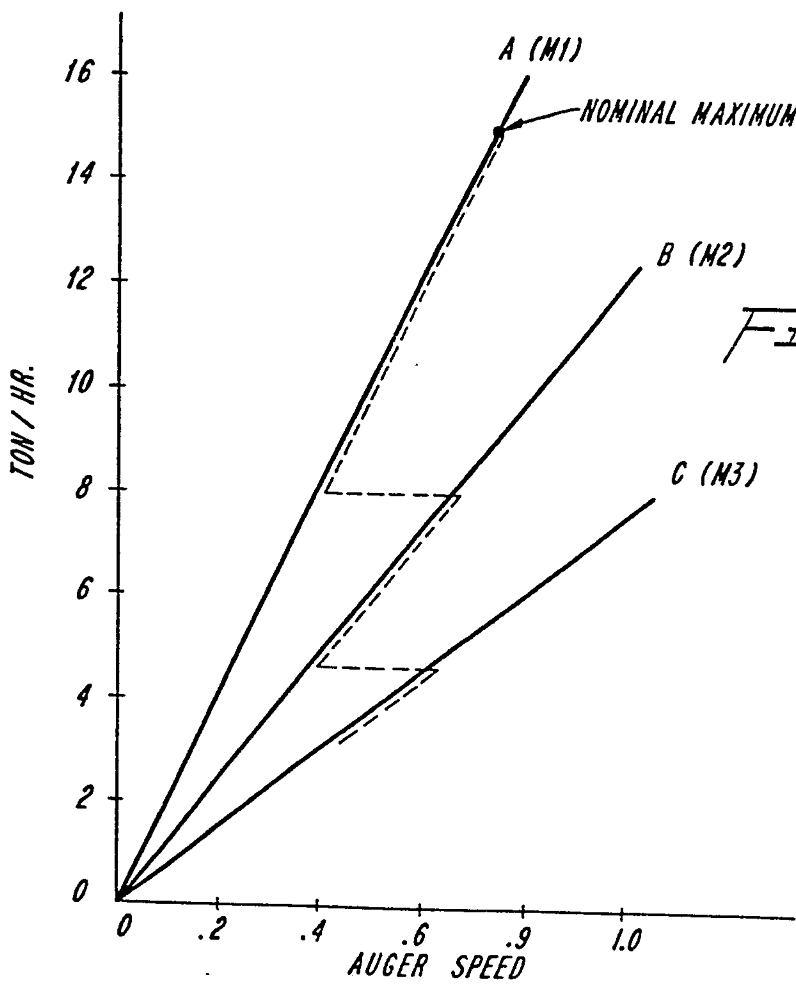
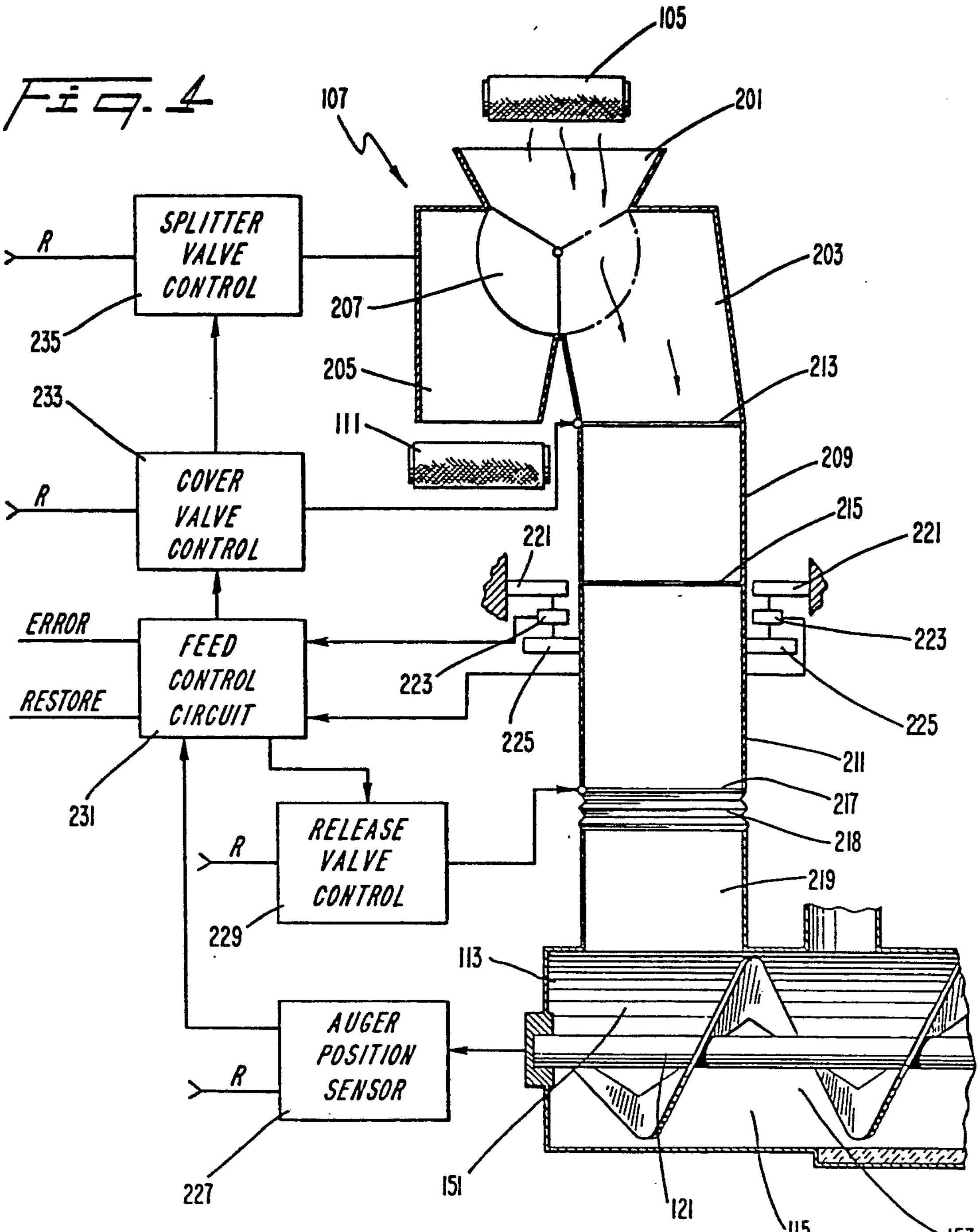


Fig. 3

Fig. 4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SPLITTER VALVE CONTROL
R
235
233
COVER VALVE CONTROL
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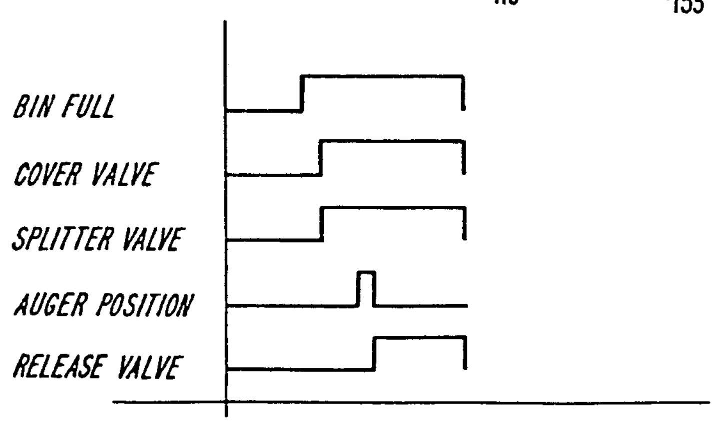
ERROR
RESTORE
FEED CONTROL CIRCUIT
231
RELEASE VALVE CONTROL
R
229
AUGER POSITION SENSOR
R
227

Fig. 5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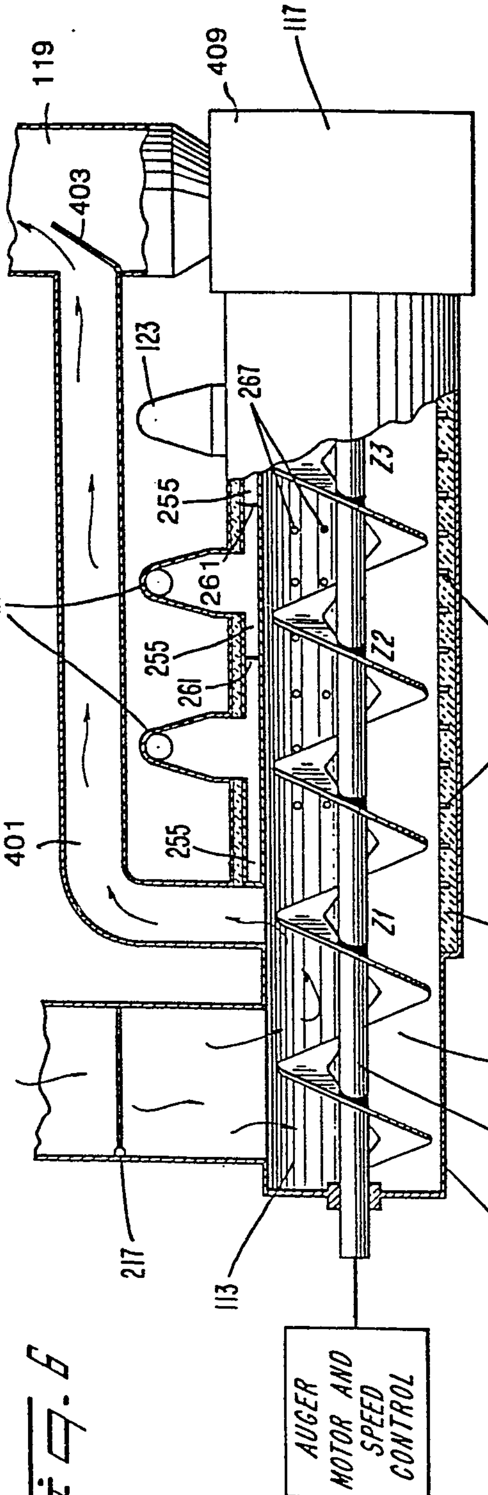

FIG. 6

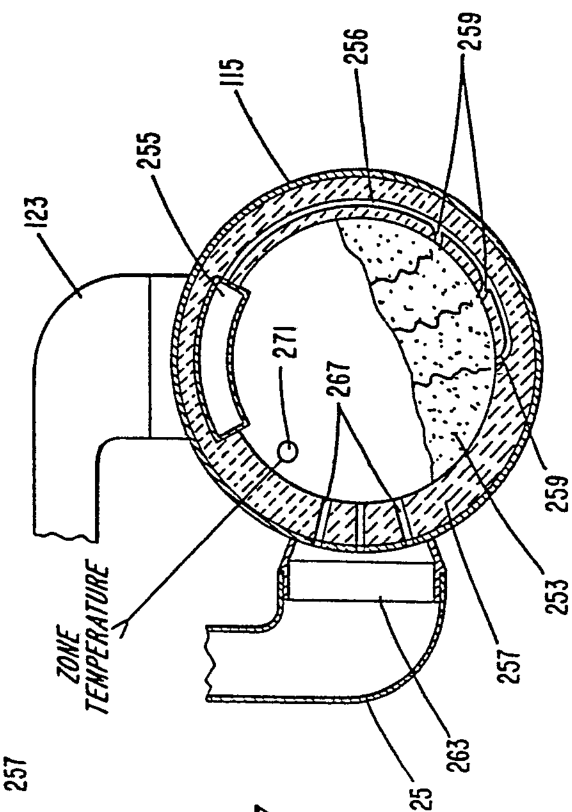

FIG. 7

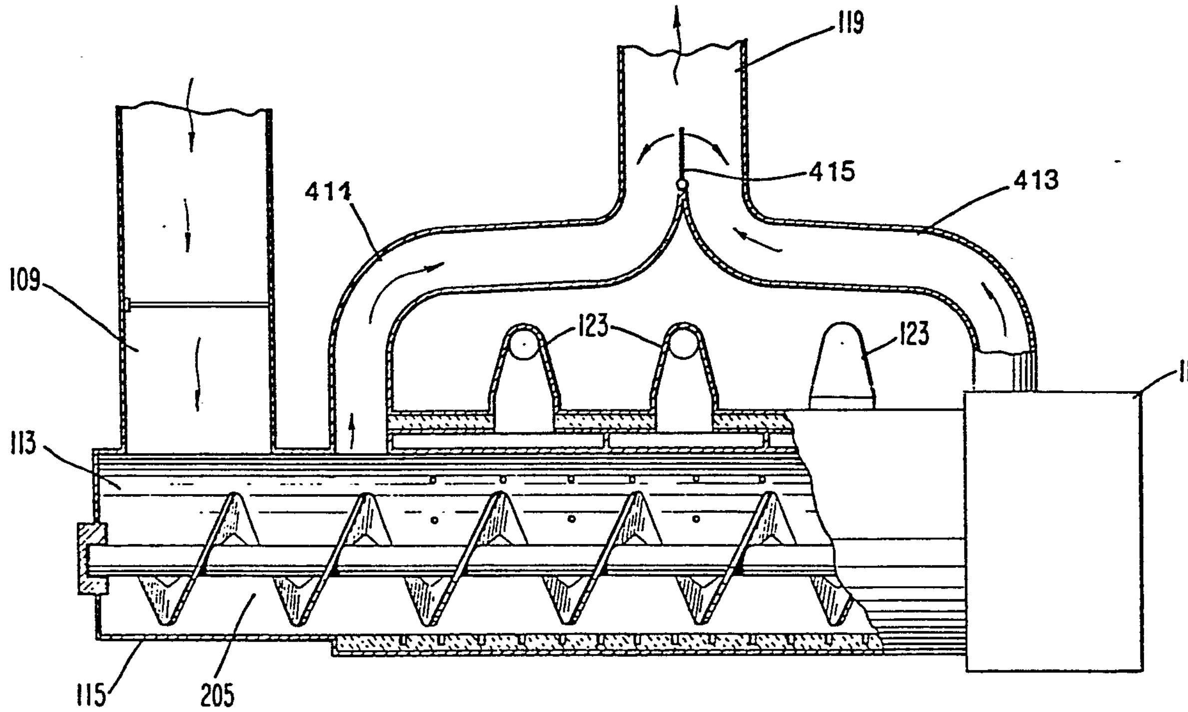

Fig. 6A

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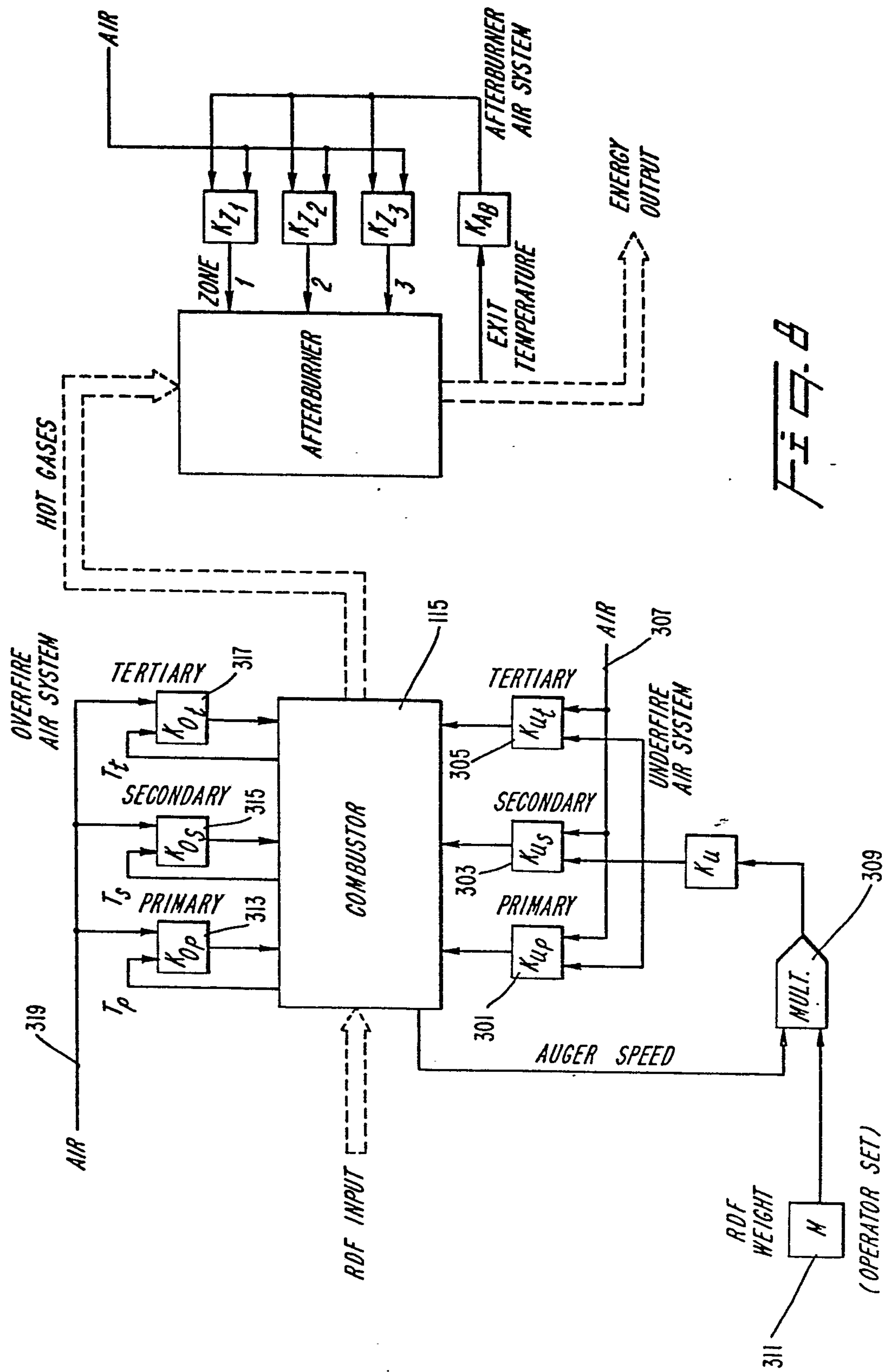


FIG. 8

Fig. 9

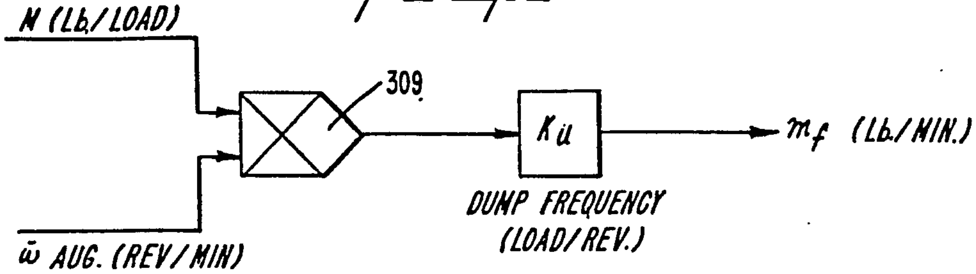
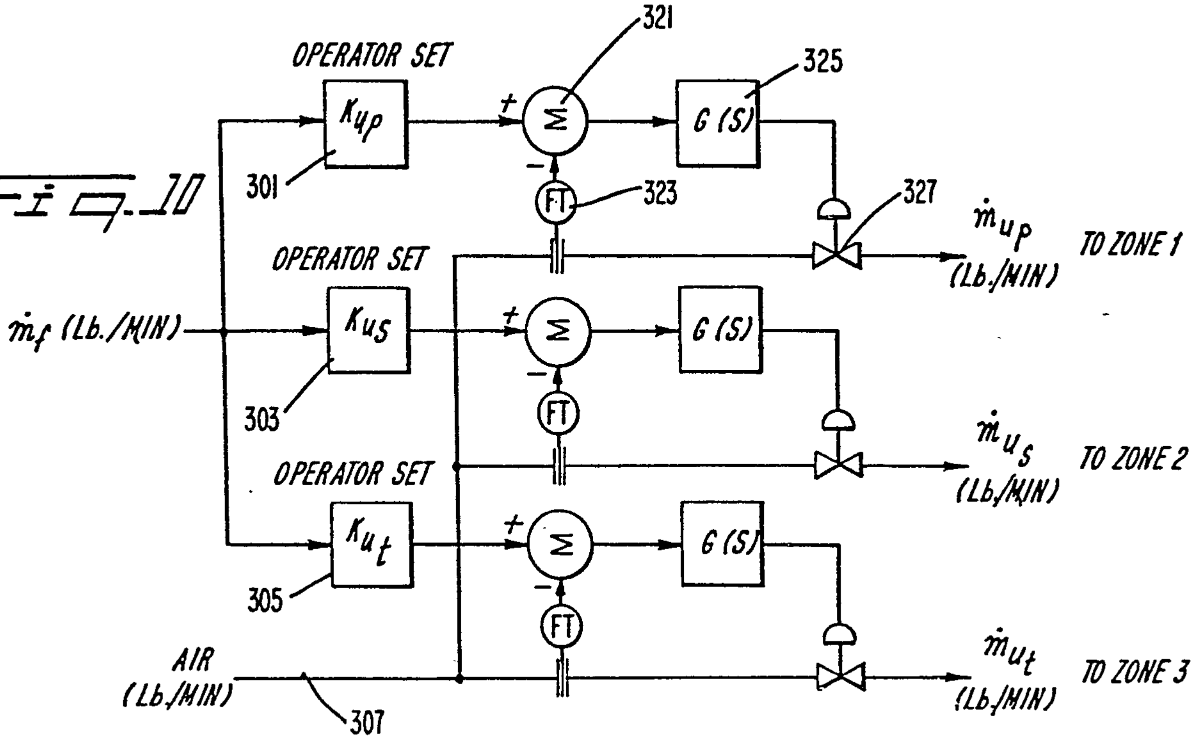


Fig. 10



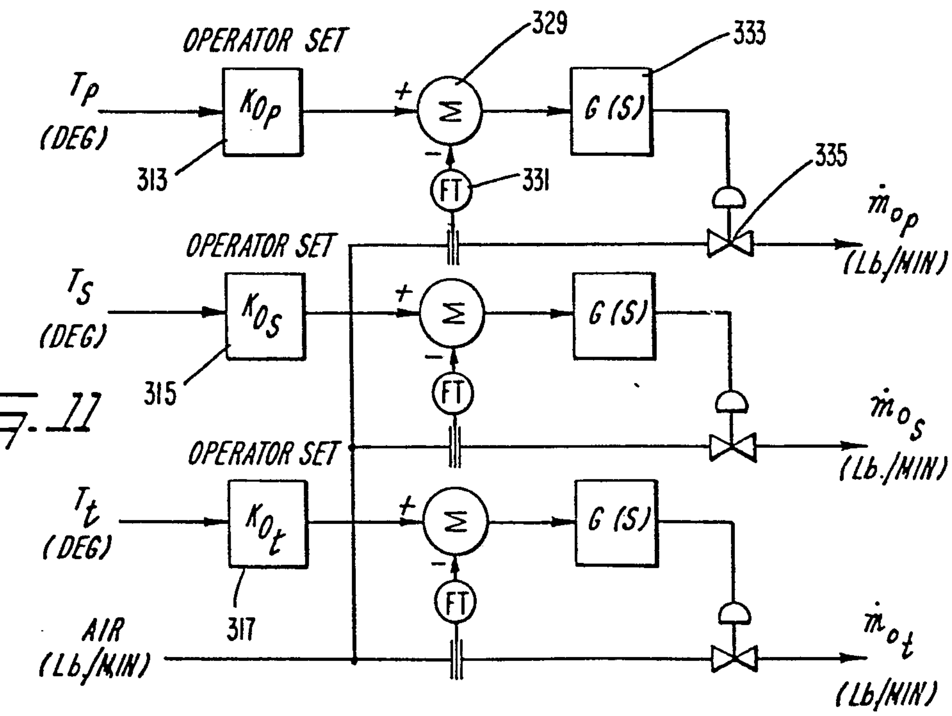


Fig. 11

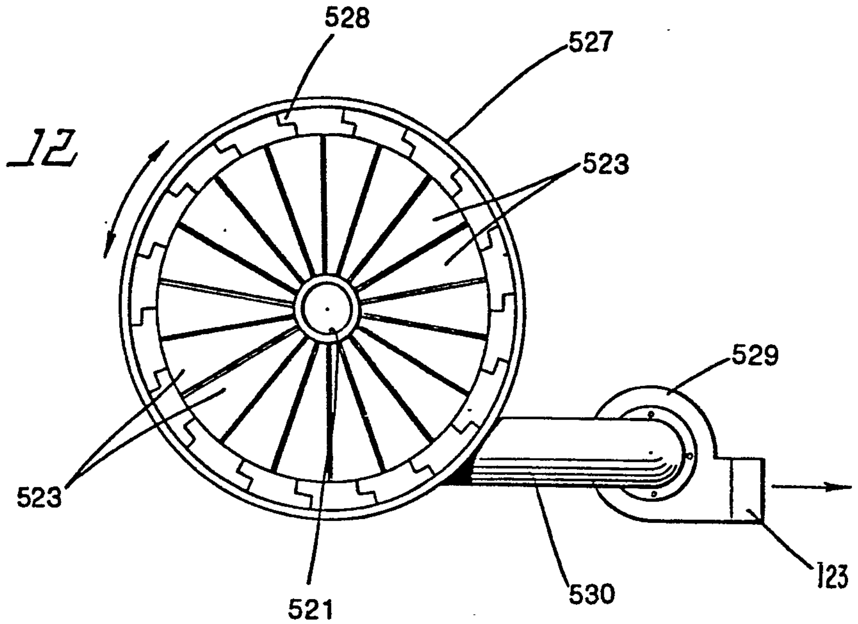

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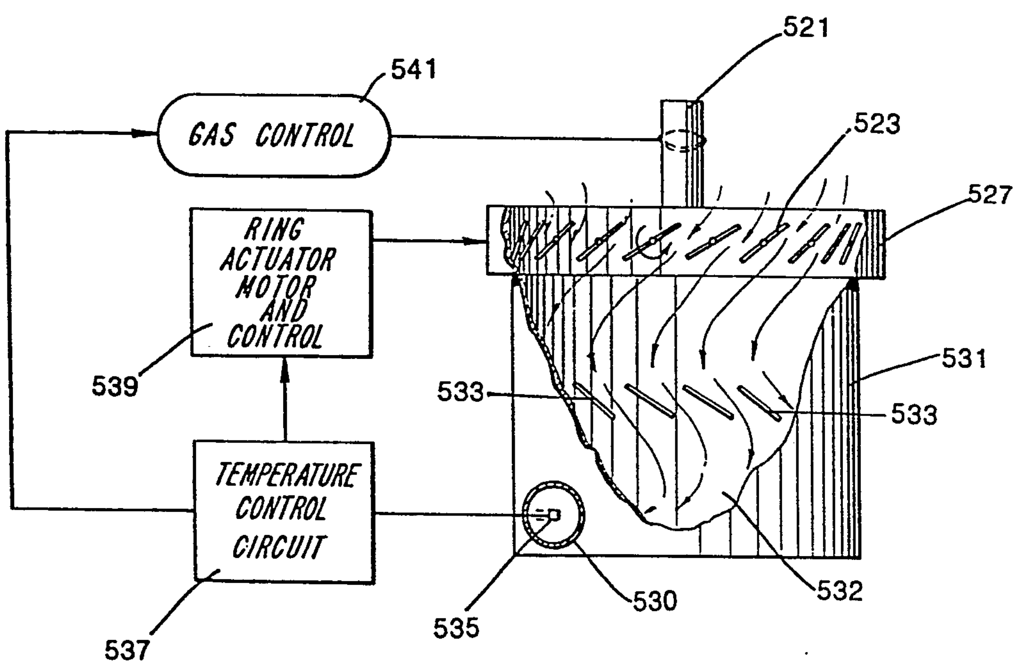
Fig. 12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RING ACTUATOR MOTOR AND CONTROL
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TEMPERATURE CONTROL CIRCUIT
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532
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Fig. 13