May 10, 1966 J. J. ZELINSKI 3,250,236

COMBUSTION APPARATUS AND METHOD OF OPERATION

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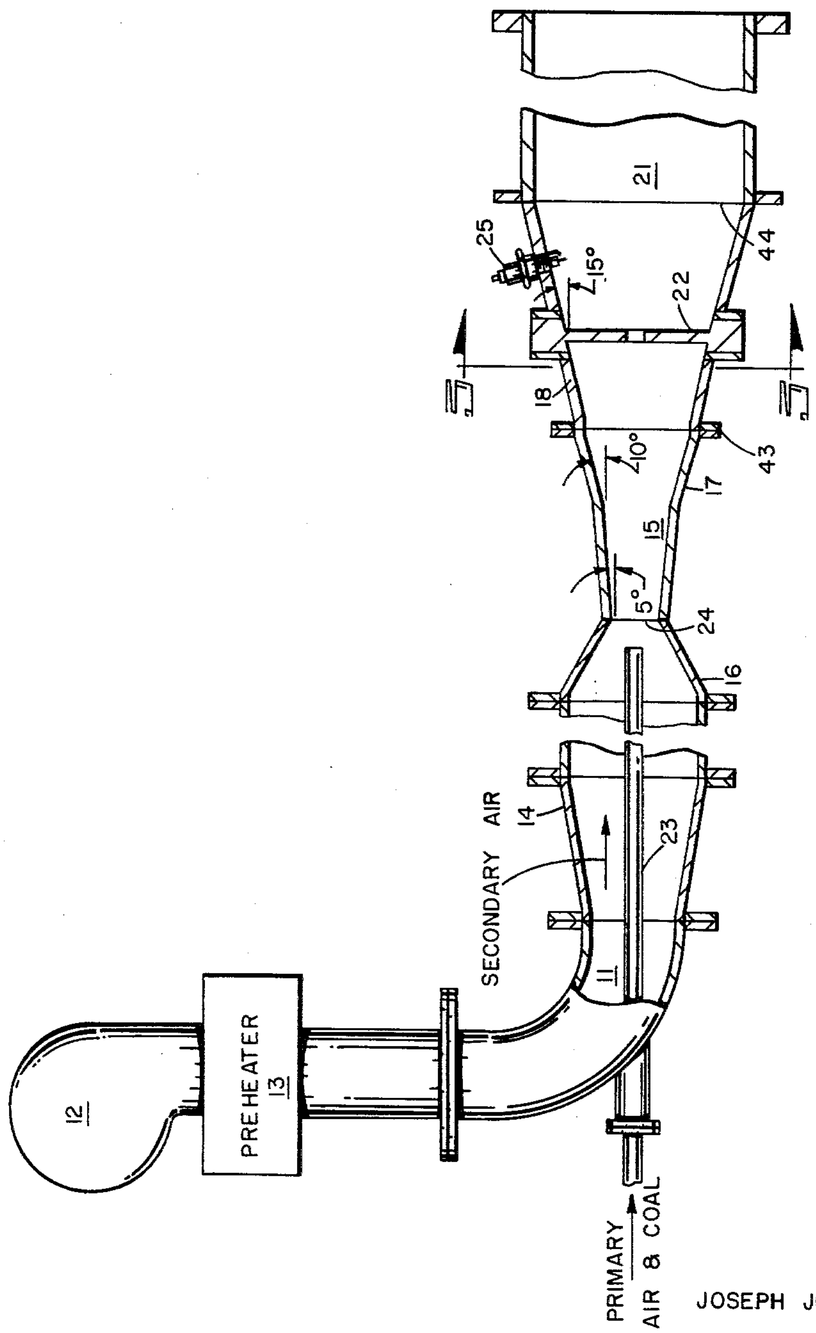

FIG. 1

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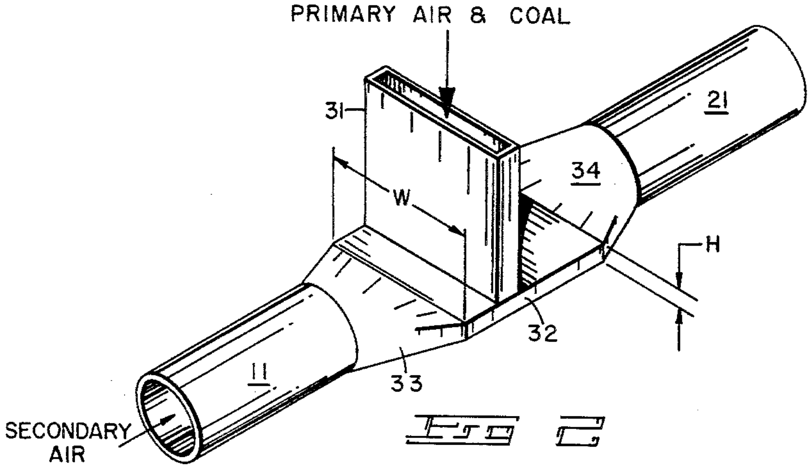

FIG. 2

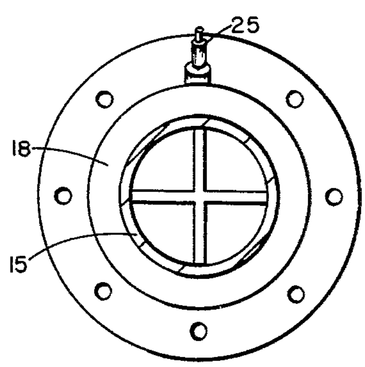

FIG. 3

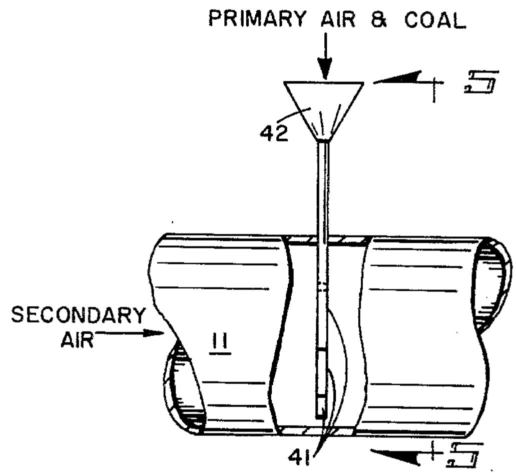

FIG. 4

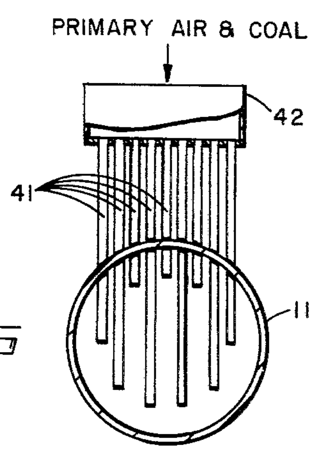

FIG. 5

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COMBUSTION APPARATUS AND METHOD OF OPERATION

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16 Claims. (Cl. 110—28)

This invention relates generally to the combustion of pulverized fuel and is directed toward and contemplates the production of large quantities of highly heated and high velocity products of combustion which are suitable for operating magnetohydrodynamic generators and the like.

Conventional equipment for burning pulverized coal generally burns the coal with a portion of the total air used (primary air) and then adds the remainder of the air necessary (secondary air). Such apparatus relies on the mixing in a combustion chamber of a burning core of hot gases with the relatively cold air of the secondary stream.

Even in apparatus where it has been suggested that pulverized coal be mixed with air prior to introduction into the combustion chamber such arrangements do not provide the necessary volumetric heat release rates at high pressures as required by magnetohydrodynamic generators wherein it is necessary that the effluent from the combustion chamber be uniformly at temperatures at about 5000° F.

According to the present invention, a primary gas which typically is air and pulverized coal are mixed with preheated, oxygen-enriched secondary air to produce a homogeneous mixture before combustion. The mixing is accomplished in mixing means wherein the preheated, oxygen-enriched air is preferably accelerated to high velocities in the throat of a nozzle, at which point the primary gas pipe is placed to give a large velocity difference between the stream of primary gas plus pulverized coal and the stream of secondary air. The mixture of pulverized coal with the preheated, oxygen-enriched air causes the release of volatile matter from the coal which is evenly distributed in the divergent portion of the mixing nozzle prior to ignition. This combustible mixture is ignited and the combustion thereof stabilized by a flameholder at the inlet of the combustion chamber.

Accordingly, it is an object of the present invention to provide combustion apparatus for burning pulverized coal under conditions of high volumetric heat release rates at high pressures and velocities with preheated oxygen-enriched air.

It is another object of the present invention to provide combustion apparatus and a method of operating such apparatus which permits closer control over the combustion process than is possible with conventional equipment.

It is another object of the present invention to provide combustion apparatus wherein it is not necessary to provide mixing of hot gases with cold secondary air in the combustion chamber.

It is a still further object of the present invention to provide combustion apparatus and a method of operation for burning pulverized coal wherein combustible gases are released from the coal and a homogeneous mixture of pulverized coal, oxygen-enriched secondary air, primary air, and combustible gases released from the coal is provided upstream of the combustion chamber.

The novel features that are considered characteristic of the invention are set forth in the appended claims; the invention itself, however, both as to its organization and method of operation, together with additional objects and advantages thereof, will best be understood from the following description of a specific embodiment when read in conjunction with the accompanying drawings, in which:

FIGURE 1 is a longitudinal sectional view through combustion apparatus constructed and arranged according to the invention;

FIGURE 2 is a perspective view of a modification of the mixing means;

FIGURE 3 is an end view taken on line 3—3 of FIGURE 1;

FIGURE 4 is a side view with the parts broken away of another modification of the mixing means; and

FIGURE 5 is an end view taken on line 5—5 of FIGURE 4.

In the embodiment of the invention illustrated in FIGURE 1, there is shown a duct **11** defining a path of a combustion-supporting secondary gas supplied from a compressor generally designated **12**. After leaving the compressor **12**, the secondary gas is heated in a preheater **13** of conventional design to a temperature sufficient to effect the release of combustible volatile matter in coal. Coupled to the outlet end of **14** of the duct **11** is mixing means **15** shown in the form of a nozzle having a convergent portion **16** for receiving the secondary gas from duct **11** and further increasing its velocity and a divergent portion **17** for exhausting and effecting high pressure recovery of the secondary gas. Coupled to the outlet end **18** of the mixing means **15** is a combustion chamber generally designated by the numeral **21**. A flameholder **22** is disposed at the inlet end of the combustion chamber **21**. Returning now to the mixing means **15**, a pipe **23** is disposed in the duct **11** for supplying from a suitable source (not shown) pulverized fuel in preferably a combustion-supporting primary gas to the convergent portion **16** of the mixing means **15**. The pipe **23** terminates in the convergent portion **16** at or slightly upstream of the throat **24** of the mixing means. The pulverized coal may be introduced with a small amount of primary gas as compared to the amount of secondary gas and at a velocity of about fifty feet per second or more. The primary gas may be equal to about ¼–⅓ of the coal by weight.

Two functions are accomplished in the mixing means **15**. Firstly, mixing of the secondary air and primary air plus coal takes place in the throat **24** and secondly, the preheated oxygen-enriched secondary air causes release of combustible volatile matter from the coal. Because of the homogeneity of the mixture of coal with the preheated, oxygen-enriched air, the mixture of combustible matter released from the coal will be evenly distributed in the secondary air. This combustible mixture is ignited and the combustion thereof stabilized by a conventional flameholder. The flameholder may be of the solid body type placed in the high velocity gas stream at the outlet **18** of the mixing means **15** which provides in its wake a recirculation zone where combustible gases can reside long enough to burn to a high degree of combustion efficiency and act as the ignition source from which flame spreads into the high velocity gas stream. This method of ignition and flame stabilization assures smoother combustion than conventional systems which rely on thermal radiation for the ignition of solid particles. The flameholder produces a fixed ignition source whereas conventional methods produce an oscillating, explosion-type flame front. Combustion is completed in the combustion chamber 21 at high pressure and high velocity. The inner surface temperature of the combustion chamber may be controlled in conventional manner by the provision of cooling, selection of suitable refractory materials and the manner of construction. The shape of the combustion chamber is not critical and further, the combustion gases may, if desired, be accelerated to higher velocities by a convergent or convergent-divergent nozzle as they leave the combustion chamber. Initial combustion may be effected in a conventional manner, as by spark plug **25**.

The geometry of the flameholder **22** may be varied as desired. While FIGURE 1 and FIGURE 3 show a cruciform shape for the flameholder, other geometries may be used such as, for example, a single bar, a grid, an annulus, or a series of concentric annuli, either in one plane or staggered in the direction of gas flow. The cross-sectional shape of the flameholder bar may be circular, rectangular, triangular, hemispherical, or ony other suitable geometrical shape. Further, the shape of the duct for conveying the secondary air can be of any geometric shape although it has been shown as circular in FIGURE 1.

FIGURE 2 shows a modified form for introducing the pulverized coal. As illustrated in this figure, the coal is preferably fed under pressure through a second duct **31**. The coal may be gravity fed if desired. The duct **11**, shown as cylindrical, communicates with a rectangular section **32** whose width dimension W is substantially greater than its height dimension H. The height dimension H is in the direction of flow of coal and is small as compared to the width dimension W to provide efficient mixing of the coal and secondary air. The rectangular section **32** is connected to the duct **11** and combustion chamber **21** by respectively transitions **33** and **34**. This arrangement shown in FIGURE 2 is satisfactory where mixing is required only for a short distance.

A further modification for introducing the pulverized coal is shown in FIGURES 4 and 5. As shown in these figures, a plurality of pipes **41** project into the duct **11** in a plane normal to the direction of flow through the duct **11**. The pipes **41** terminate at spaced points adjacent the inner periphery of duct **11** such that the coal is introduced into the heated secondary air at spaced points lying on a circumference having a diameter about three fourths of that of the duct **11**. The coal is preferably supplied under pressure to the pipes **41** from a hopper **42**. Further, the coal may be fed on the periphery of concentric circles if desired.

In the embodiment illustrated in FIGURE 1, pulverized coal was supplied through pipe **23** by a primary air stream at a temperature of 100° F. and a velocity of fifty feet per second. The ratio of primary air to coal was set at 4 to 1 with the primary air amounting to 3% of the total flow. Distribution of the coal in the secondary air which was heated to a temperature of 1500° F. was accomplished in the mixing means **15** by the high relative velocity between the primary and secondary air. The secondary air comprised a nitrogen-oxygen mole ratio of 2. The mixing and volatilization of gases from the coal by the hot secondary air produced a homogeneous combustible mixture which was not ignited until it reached the flameholder **22**. Ignition and stabilization of the homogeneous combustible mixture was provided by flameholder **22**. At the flameholder **22**, the flame spreads into the mixture and combustion is completed in the remainder of the combustion chamber **21**. The high temperature products of combustion were exhausted from the combustion chamber at sonic velocity through a convergent nozzle (not shown).

The physical dimensions of a combustion chamber are dictated by the exit nozzle size, the operating conditions, and the residence time of the products of combustion in the combustion chamber. In this case, an exit nozzle area of the combustion chamber was chosen as 3 square inches to be compatible with existing hardware. A combustion chamber pressure of 4 atmospheres required a mass flow rate of 1.3 pounds per second with a residence time of the products of combustion in the combustion chamber of the order of 60 milliseconds. The combustion chamber had a diameter of 10 inches and a length of 36 inches.

Rapid mixing in the mixing means **15** is achieved by a high relative velocity between the primary and secondary air. The throat **24** was sized at 1.70 inches to give a flow Mach number of 0.5, thereby setting the velocity of hot gas in the throat at 1080 feet per second. High pressure recovery in the mixing means was obtained by providing an initial expansion half angle of 5° as shown in FIGURE 1. At a diameter of 3 inches, the expansion half angle was increased to 10°. From a diameter of 4 inches to a full diameter of 10 inches, the expansion half angle was set at 15°. The distance from the end of the primary air pipe **23** to the throat **24** was 1.7 inches. The distance from the throat **24** to the 4 inch station, designated by the numeral **43**, was 13 inches. The distance from the 4 inch station to the 10 inch station, designated by the numeral **44**, was 11 inches. The residence time of the gas in the mixing means from the throat **24** to the maximum diameter varied substantially linearly from 0 to 3.6 milliseconds, with a residence time of about 2.0 milliseconds from the throat **24** to the flameholder **22**. Pulverized coal will ignite spontaneously in a combustion supporting medium at about 200° F. While this temperature is sufficient to effect release of volatile matter from the coal, preheat temperatures of about 1500° F. and oxygen enrichment are necessary to produce products of combustion having temperatures of the order of 5000° F. Generally speaking, the distance from the point of injection of the coal to the flameholder should be consistent with a gas residence time between the point of injection of the coal and the flameholder sufficient to provide mixing of the gases and coal and release of volatile matter from the coal before spontaneous combustion can occur.

The present invention permits the burning of pulverized coal and closer control over the combustion process than is possible with conventional equipment. Except for initial ignition of the mixture, as for example by the spark plug **25**, or, alternately, by means which is integrated with the flameholder, no pilot burner or warm-up time is needed. The ignition point and a stable flame front is fixed by the flameholder whose design may be determined by the type of coal being used. Because homogeneity in the combustion supporting medium is established before ignition, no effort need be spent or additional apparatus utilized to mix hot gases and secondary air in the combustion chamber. Further, volumetric heat release rates are higher than in conventional systems due to the aforementioned homogeneity and volatilization of the coal prior to ignition.

The various features and advantages of the invention are thought to be clear from the foregoing description. Various other features and advantages not specifically enumerated will undoubtedly occur to those versed in the art, as likewise will many variations and modifications of the preferred embodiment illustrated, all of which may be achieved without departing from the spirit and scope of the invention as defined by the following claims:

What is claimed is:

1. In combustion apparatus for burning pulverized coal the combination comprising:

(a) a duct defining a path for a combustion-supporting gas;

(b) means for heating said gas to a temperature sufficient to effect the release of combustible volatile matter in coal;

(c) means for supplying said heated gas to said duct;

(d) mixing means having an inlet end for receiving said heated gas from said duct and pulverized coal and an outlet end for exhausting said gas and coal at subsonic velocities;

(e) means communicating with the inlet end of said mixing means for introducing pulverized coal into said heated gas at a velocity less than that of said heated gas, said mixing means having a length in the direction of flow of said gas sufficient to provide mixing of said gas and said coal and release of volatile matter from said coal before spontaneous combustion can occur;

(f) a combustion chamber for receiving the mixture of said gas, coal and volatile matter from said mixing means at said subsonic velocities and providing maximum flame temperatures.

(g) flameholding means disposed at the inlet of said combustion chamber for igniting and stabilizing combustion of the mixture of said gas, coal and volatile matter received from said mixing means whereby said maximum flame temperatures are provided in said combustion chamber.

2. In combustion apparatus for burning pulverized coal the combination comprising:

(a) a duct defining a path for a combustion-supporting gas;

(b) means for heating said gas to a temperature sufficient to effect the release of combustible volatile matter in coal and in excess of the spontaneous combustion temperature of coal;

(c) means for supplying said heated gas to said duct;

(d) mixing means having an inlet end for receiving said heated gas from said duct and pulverized coal and an outlet end for exhausting said gas and coal at subsonic velocities;

(e) means communicating with the inlet end of said mixing means for introducing pulverized coal into said heated gas at a velocity less than that of said heated gas, said mixing means having a length in the direction of flow of said gas sufficient to provide mixing of said gas and said coal and release of volatile matter from said coal before spontaneous combustion can occur;

(f) a combustion chamber for receiving the mixture of said gas, coal and volatile matter from said mixing means at said subsonic velocities and providing maximum flame temperatures; and

(g) flameholding means disposed at the inlet of said combustion chamber for igniting and stabilizing combustion of the mixture of said gas, coal and volatile matter received from said mixing means whereby said maximum flame temperatures are provided in said combustion chamber.

3. In combustion apparatus for burning pulverized coal the combination comprising:

(a) a duct defining a path for a combustion-supporting gas;

(b) means for heating said gas to a temperature sufficient to effect the release of combustible volatile matter in coal and in excess of the spontaneous combustion temperature of coal;

(c) means for supplying said heated gas to said duct at a high velocity;

(d) mixing means having an inlet end for receiving said heated gas from said duct and pulverized coal and an outlet end for exhausting said gas and coal at subsonic velocities;

(e) means communicating with the inlet end of said mixing means for introducing pulverized coal into said heated gas at a velocity substantially less than that of said heated gas, said mixing means having a length in the direction of flow of said gas for a

predetermined temperature and velocity of said heated gas sufficient to provide mixing of said gas and said coal and release of volatile matter from said coal before spontaneous combustion can occur;

(f) a combustion chamber for receiving the mixture of said gas, coal and volatile matter from said mixing means at said subsonic velocities and providing maximum flame temperatures; and

(g) flameholding means disposed at the inlet of said combustion chamber for igniting and stabilizing combustion of the mixture of said gas, coal and volatile matter received from said mixing means whereby said maximum flame temperatures are provided in said combustion chamber.

4. In combustion apparatus for burning pulverized coal the combination comprising:

(a) a duct defining a path for an oxygen-enriched combustion-supporting secondary gas;

(b) means for heating said gas to a temperature of about 1500° F;

(c) means for supplying said heated secondary gas to said duct at a high velocity;

(d) mixing means having an inlet end for receiving said heated secondary gas from said duct and pulverized coal in a primary gas and an outlet end for exhausting said secondary gas, coal and primary gas at subsonic velocities;

(e) means communicating with the inlet end of said mixing means for introducing pulverized coal in a primary gas into said heated gas at a velocity substantially less than that of said heated secondary gas, said mixing means having a length in the direction of flow of said gas sufficient to provide mixing of said heated primary gas and said coal and release of volatile matter from said coal before spontaneous combustion can occur;

(f) a combustion chamber for receiving the mixture of said gas, coal and volatile matter from said mixing means at said subsonic velocities and providing maximum flame temperatures; and

(g) flameholding means disposed at the inlet of said combustion chamber for igniting and stabilizing combustion of the mixture of said gas, coal and volatile matter received from said mixing means whereby said maximum flame temperatures are provided in said combustion chamber.

5. The combination as defined in claim 4 wherein the velocity of said heated secondary gas at the inlet end of said mixing means is about one thousand feet per second and residence time of said gases and coal in said mixing means is from about two milliseconds to not more than about one second.

6. In combustion apparatus for burning pulverized coal the combination comprising:

(a) a duct defining a path for a combustion-supporting gas;

(b) means for heating said gas to a temperature sufficient to effect the release of combustible volatile matter in coal and in excess of the spontaneous combustion temperature of coal;

(c) means for supplying said heated gas to said duct at a high velocity;

(d) mixing means having a first inlet for receiving said heated gas from said duct, a second inlet adjacent said first inlet for receiving pulverized coal and an outlet end for exhausting said gas and coal at subsonic velocities;

(e) means communicating with said second inlet of said mixing means for introducing said pulverized coal into said heated gas at a velocity substantially less than that of said heated gas, said mixing means having a length from said second inlet in the direction of flow of said gas sufficient to provide mixing of said gas and said coal and release of volatile matter from said coal before spontaneous combustion can occur;

(f) a combustion chamber for receiving the mixture of said gas, coal and volatile matter from said mixing means at said subsonic velocities and providing maximum flame temperatures; and

(g) flameholding means disposed at the inlet of said combustion chamber for igniting and stabilizing combustion of the mixture of said gas, coal and volatile matter received from said mixing means whereby said maximum flame temperatures are provided in said combustion chamber.

7. The combination as defined in claim 6 wherein said second inlet comprises a plurality of pipes terminating at spaced points adjacent the inner periphery of said mixing means.

8. The combination as defined in claim 7 wherein said mixing means is generally cylindrical in cross section.

9. The combination as defined in claim 7 wherein said mixing means comprises a convergent first inlet portion and a coaxial divergent portion and said pipes are located in said convergent portion.

10. The combination as defined in claim 6 wherein said mixing means comprises a convergent first inlet portion, a coaxial divergent outlet portion, and said second inlet comprises a pipe terminating coaxially in said convergent portion upstream of the junction of said convergent and divergent portions.

11. The combination as defined in claim 6 wherein said mixing means is generally rectangular in cross section, the width dimension being substantially greater than the height dimension thereof and said second inlet extends substantially across said mixing means in the width direction.

12. In combustion apparatus for burning pulverized coal the combination comprising:

(a) a duct defining a path for oxygen-enriched secondary air;

(b) means for heating said secondary air to a temperature at least sufficient to effect release of combustible volatile matter in coal and in excess of the spontaneous combustion temperature of coal;

(c) means for supplying said heated secondary air to said duct at a high velocity and pressure;

(d) a mixing nozzle having a convergent portion for receiving said secondary air from said duct and increasing its velocity and a divergent portion for exhausting said secondary air from said nozzle with high pressure recovery at subsonic velocities;

(e) means including a primary air pipe disposed in said duct for supplying at said convergent portion pulverized coal dispersed in primary air at a velocity substantially less than that of said secondary air, the outlet end of said pipe being positioned in said convergent portion to give a large velocity difference between said primary air and said secondary air, said divergent portion having a length in the direction of flow of said air sufficient to provide substantially complete mixing of said air and coal and release of volatile matter from said coal before spontaneous combustion can occur;

(f) a combustion chamber for receiving said air, coal and volatile matter from the divergent portion of said nozzle at said subsonic velocities and providing maximum flame temperatures; and

(g) flameholding means disposed at the inlet of said combustion chamber for igniting and stabilizing combustion of the mixture of said air, coal, and volatile matter received from said mixing nozzle whereby said maximum flame temperatures are provided in said combustion chamber.

13. The method of operating a pulverized fuel furnace comprising:

(a) heating a combustion supporting gas to a temperature sufficient to effect the release of combustible

volatile matter from coal and in excess of the spontaneous combustion temperature of coal;

(b) introducing said heated gas into a mixing zone at subsonic velocities;

(c) introducing pulverized coal into said mixing zone at a velocity substantially less than that of said heated gas and mixing said gas and coal;

(d) maintaining said heated gas and coal in said mixing zone for a period sufficient to effect release of volatile matter from said coal but insufficient to effect combustion in said mixing zone;

(e) confining and directing the mixture of said gas, coal and volatile matter to a combustion zone at subsonic velocities; and

(f) igniting and stabilizing combustion of the mixture in said combustion zone to provide maximum flame temperatures in said combustion zone.

14. The method of operating a pulverized fuel furnace comprising:

(a) heating a combustion supporting gas to a temperature in excess of the spontaneous combustion temperature of pulverized coal;

(b) introducing said heated gas into a mixing zone at less than supersonic velocity;

(c) introducing pulverized coal into said heated gas in said mixing zone at a velocity substantially less than that of said heated gas and mixing said gas and coal;

(d) maintaining said heated gas and coal in said mixing zone for a period sufficient to effect release of volatile matter from said coal but insufficient to effect combustion in said mixing zone;

(e) confining and directing the mixture of said gas, coal and volatile matter from said mixing zone at subsonic velocities to a combustion zone; and

(f) igniting and stabilizing combustion of the mixture in said combustion zone to provide maximum flame temperatures in said combustion zone.

15. The method of operating a pulverized fuel furnace comprising:

(a) heating oxygen-enriched air to a temperature in excess of the spontaneous combustion temperature of pulverized coal;

(b) introducing said heated air into a mixing zone at less than supersonic velocity;

(c) introducing pulverized coal into said heated air in said mixing zone at a velocity substantially less than that of said heated air and mixing said heated air and coal;

(d) maintaining said heated air and coal in said mixing zone for a period sufficient to effect release of volatile matter from said coal but insufficient to effect combustion in said mixing zone;

(e) confining and directing the mixture of said gas, coal and volatile matter at subsonic velocities to a combustion zone; and

(f) providing a recirculating motion of the said mixture at the inlet of said combustion zone for igniting and stabilizing combustion of the mixture in said combustion zone to provide maximum flame temperatures in said combustion zone.

16. The method of operating a pulverized fuel furnace comprising:

(a) heating oxygen-enriched air to a temperature of about 1500° F.;

(b) introducing said heated air into a mixing zone at about one thousand feet per second and about four atmospheres pressure;

(c) introducing pulverized coal into said mixing zone at a velocity substantially less than that of said heated air and mixing said heated air and coal;

(d) maintaining said heated air and coal in said mixing zone for about two milliseconds to effect release of volatile matter from said coal before spontaneous combustion can occur;

(e) confining and directing the mixture of said air, coal and volatile matter at subsonic velocities to a combustion zone immediately downstream of said mixing zone; and

(f) providing a recirculating motion of part of said mixture at the inlet of said combustion zone for igniting and stabilizing combustion of the mixture in said combustion zone to provide maximum flame temperatures in said combustion zone.

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