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(54) **PROCESS AND DEVICE FOR INCINERATION OF PARTICULATE SOLIDS**

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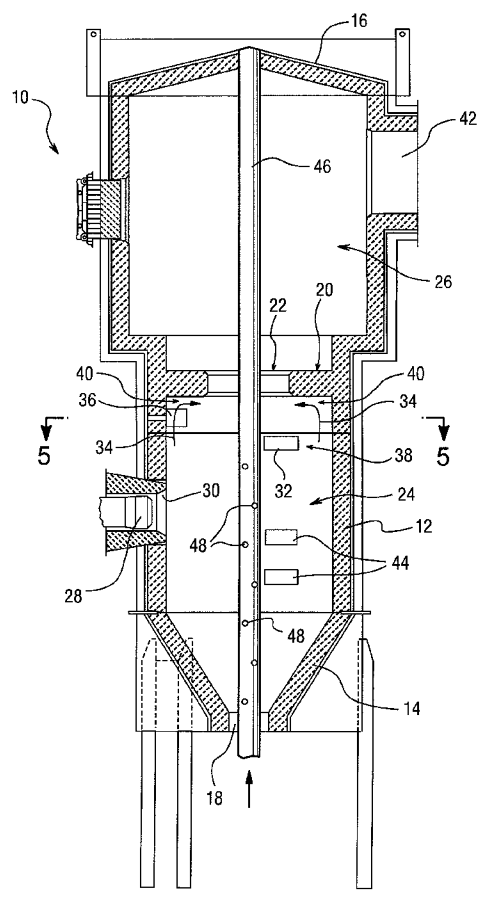
(57) **ABSTRACT**

A process for the incineration of particulate solids, especially biological waste matter with low caloric value, feeds the solids into a combustion chamber of a furnace together with a sub-stoichiometric amount of fresh air to control the rate of combustion and to inhibit the formation of sintered ash. The furnace for implementing the process can be a cyclone furnace having a primary combustion chamber with a first feed inlet for the solids and air and a second air inlet positioned between the first inlet and an exhaust gas outlet. A supply tube extends through the exhaust gas outlet of the primary combustion chamber to supply a source of fresh air at ambient temperature to maintain the primary combustion chamber at a desired temperature. The fresh air maintains the furnace temperature at least at about 850° C. and generally at about 850° C. to less than about 1100° C. A source of fresh air at ambient temperature can also be directed into the primary combustion chamber through an annular air passage surrounding the exhaust gas outlet of the primary combustion chamber. The less than stoichiometric amount of air and the secondary air maintains the furnace at a sufficiently lower temperature to inhibit sintering of the solids.



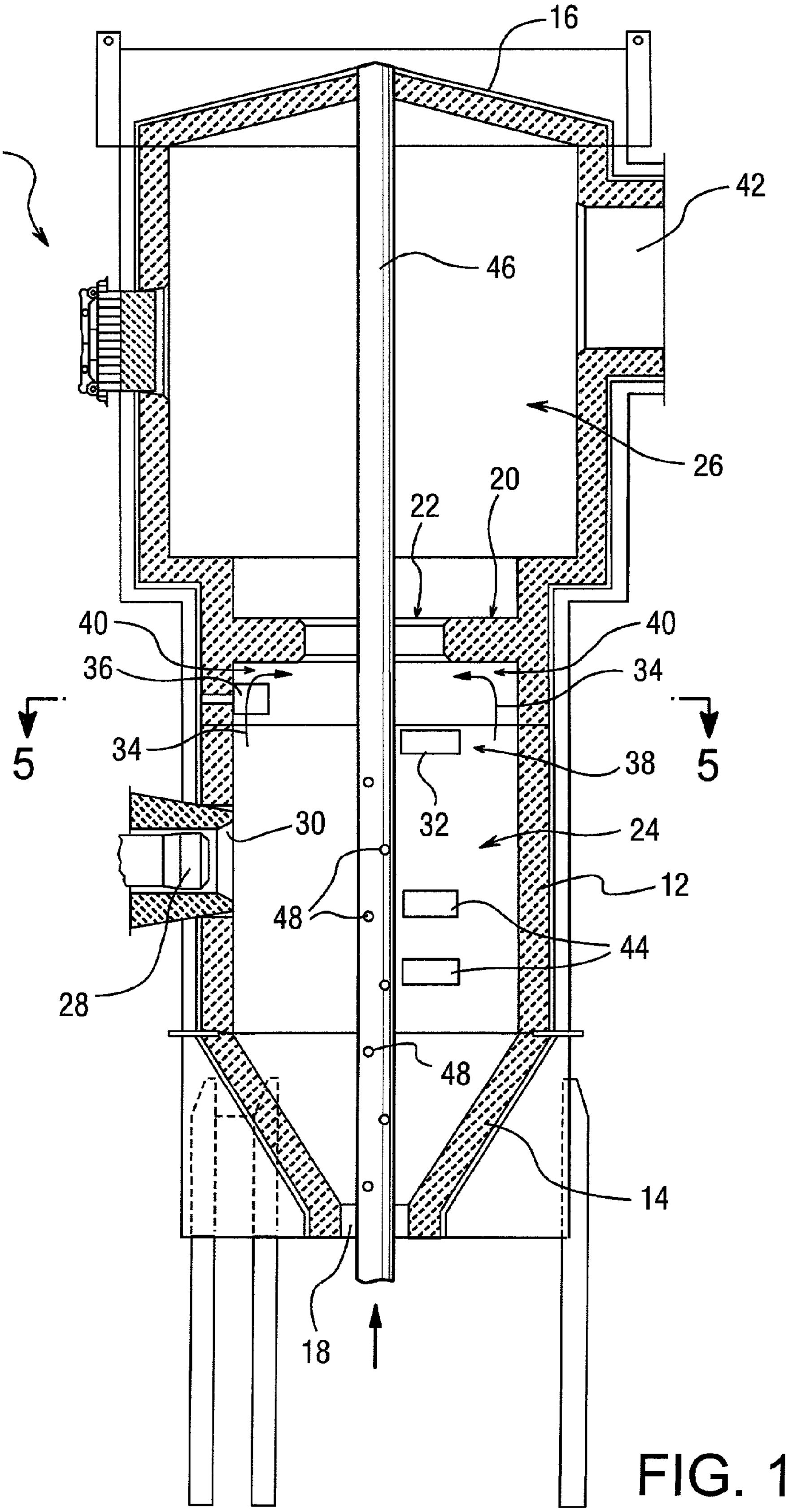
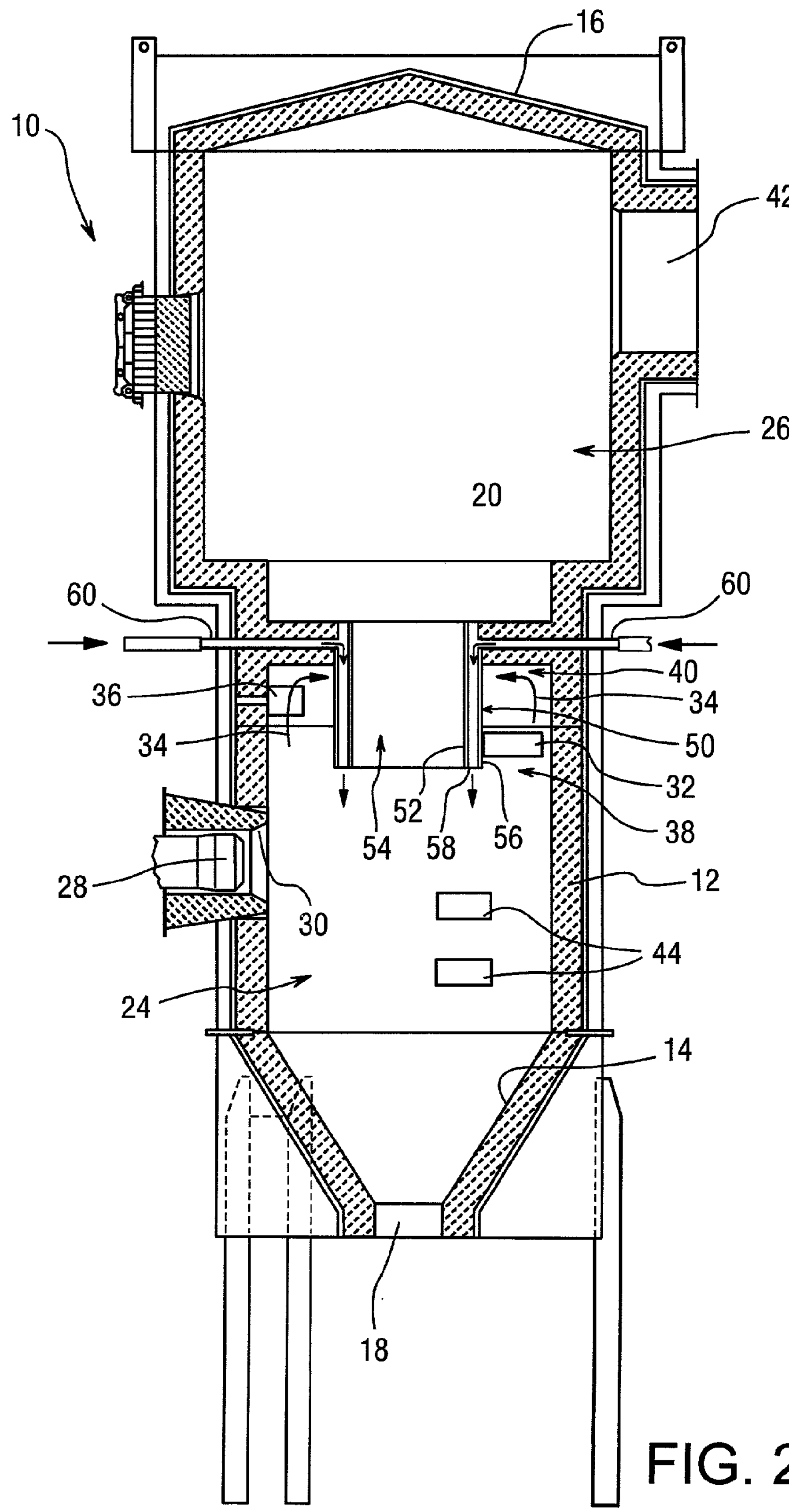


FIG. 1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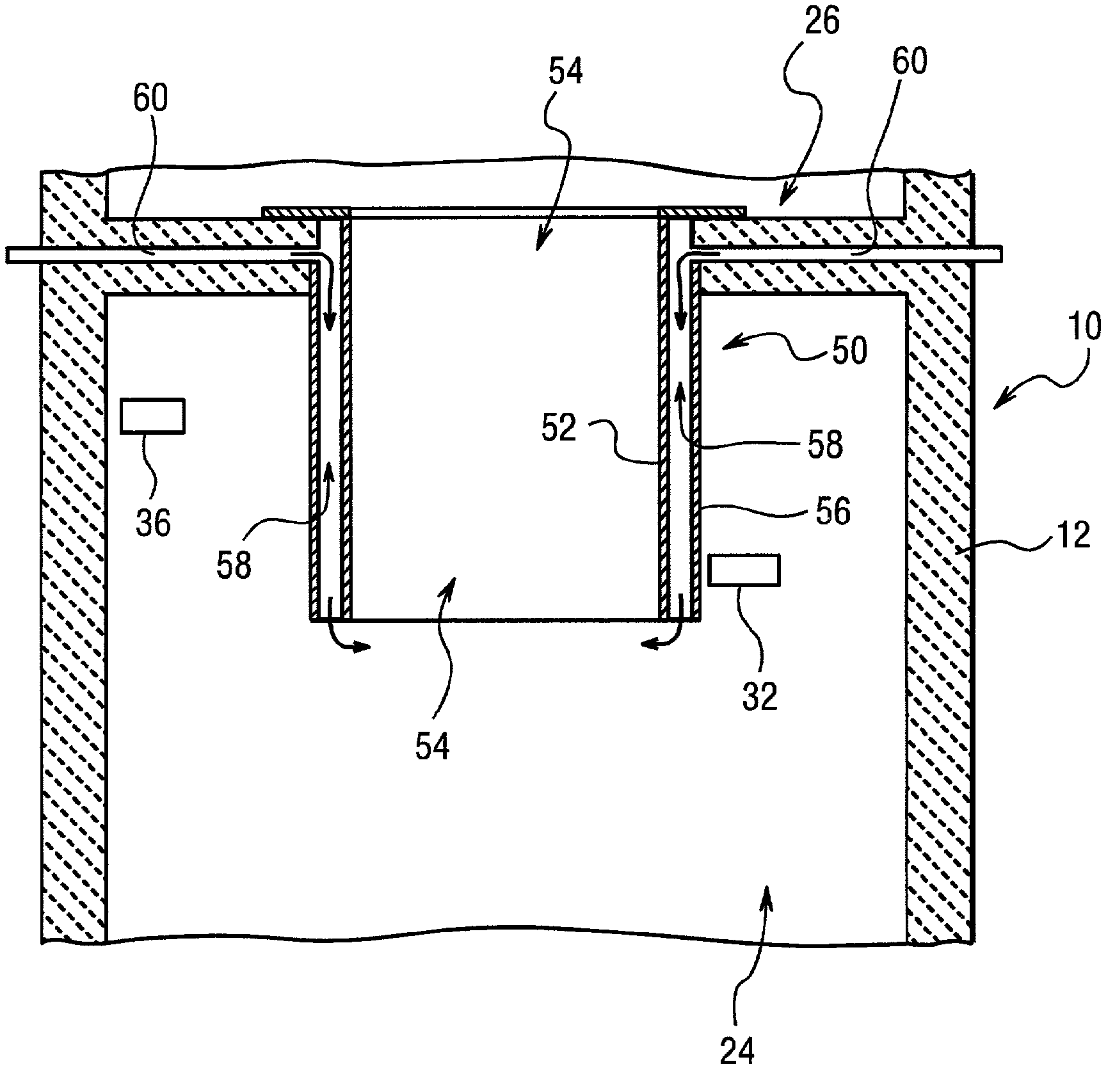

FIG. 3

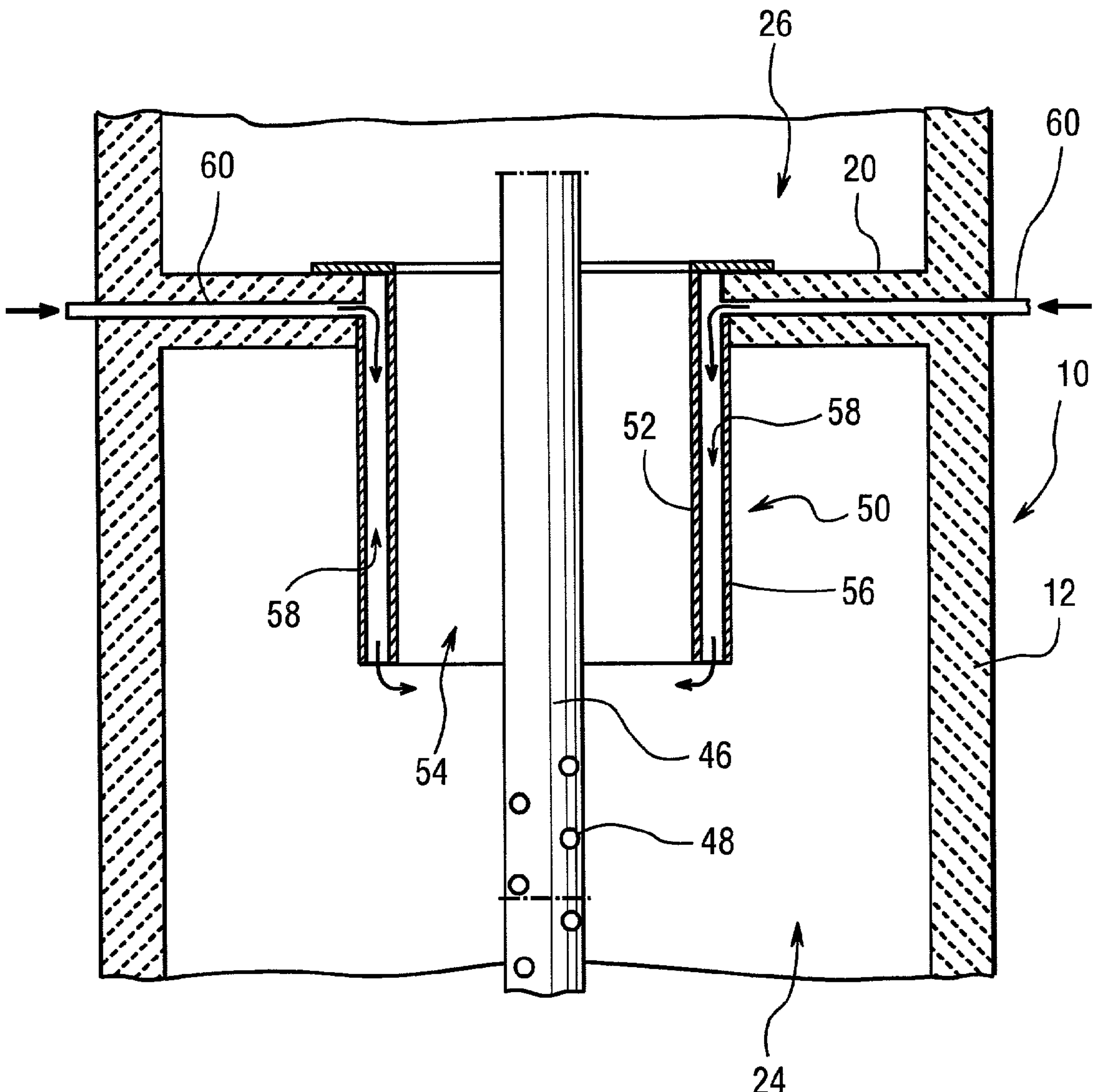

FIG. 4

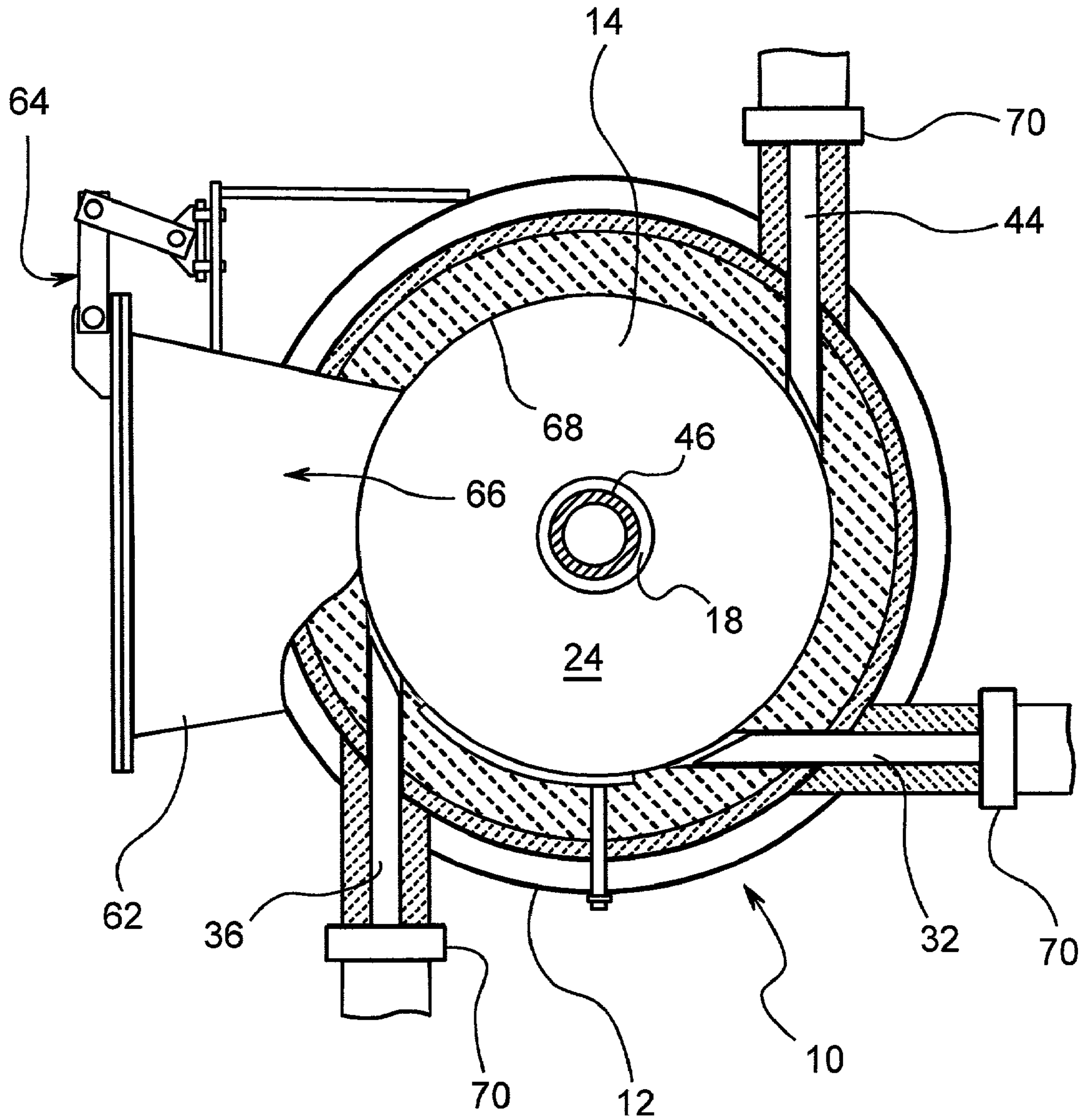

FIG. 5

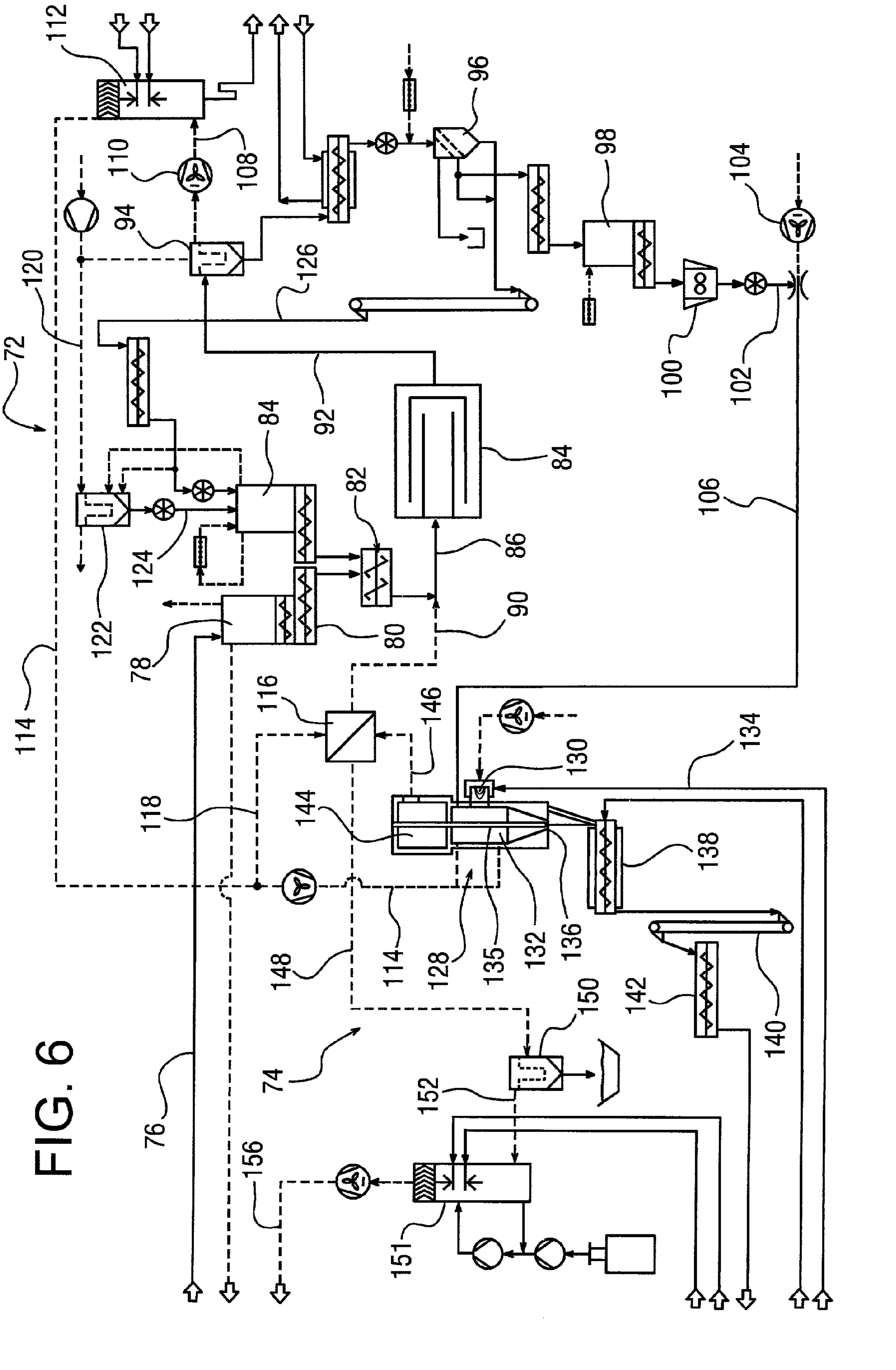
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FIG. 6

PROCESS AND DEVICE FOR INCINERATION OF PARTICULATE SOLIDS

FIELD OF THE INVENTION

[0001] The present invention relates to a process and apparatus for the incineration of particulate solids and particularly, biological waste materials with low caloric values. The invention is further directed to a process and apparatus for incinerating previously dried solid particulates, such as municipal sludge, with reduced formation of sintered ash.

BACKGROUND OF THE INVENTION

[0002] Various processes and devices have been developed for incinerating solid particulate materials for various purposes. In particular, municipal waste and sewer sludge generally must be incinerated before disposal in a landfill. The environmental regulations in many countries limit the amount of organic material which can be present in the sludge prior to disposal. Accordingly, various efforts have been proposed to incinerate municipal waste material and sewer sludge to comply with the regulations.

[0003] One example of a known process for incinerating waste materials is disclosed in WO 92/14969. This publication discloses a process for feeding finely ground, previously dried sludge into a brick lined combustion chamber, together with a supply of primary combustion air. The furnace is a cyclone combustion chamber having a lower section where the incineration of the solid material takes place. A predetermined amount of moist air with a reduced oxygen content is fed into the combustion chamber to inhibit the sintering of the ash. The ash discharge area of the combustion chamber is cooled using the moist air. The amount of air needed as the primary combustion air and the secondary source of moist air is typically preset for a specific furnace size. The heat output of the furnace is regulated by adjusting the amount of the solid material being incinerated in relation to the fixed amount of the primary combustion air. This device has several disadvantages and is not completely efficient in incinerating solid materials. For example, the process disclosed in this publication is generally difficult to regulate and the output of the incinerated material can be adjusted over a very small operating range. Furthermore, fluctuations in the level of solid material being incinerated and the caloric value of the solid material produces inconsistent results in the incineration of the solid material.

[0004] Accordingly, there is a continuing need in the industry for improved processes and apparatus for incinerating solid materials.

SUMMARY OF THE INVENTION

[0005] The present invention is directed to a process and apparatus for the incineration of particulate solid materials. More particularly, the invention is directed to a process and apparatus for incinerating biological waste materials with low caloric value with a reduced output of sintered ash.

[0006] Accordingly, a primary object of the invention is to provide a process and apparatus for incinerating solid materials containing organic matter, such as sewage sludge, in a rapid and efficient manner.

[0007] Another object of the invention is to provide a process and apparatus for incinerating organic materials at low temperatures and to incinerate the materials having a lower ash fusion point without ash sintering.

[0008] A further object of the invention is to provide a process and apparatus for incinerating organic materials in a furnace and to remove the ash more effectively from the exhaust gas stream.

[0009] A still further object of the invention is to provide a process and apparatus for incinerating organic materials in a furnace and for maintaining a temperature of about 1100° C. or less, and preferably about 850° C.

[0010] Another object of the invention is to provide a process and apparatus for incinerating solid particulate materials by blowing a mixture of the solid materials and a sub-stoichiometric proportion of fresh air into a combustion chamber of a furnace.

[0011] Another object of the invention is to provide a process and apparatus for incinerating solid particulate materials where the solid material is incinerated in a first combustion zone containing a deficiency of oxygen followed by feeding additional air to a second combustion zone to provide an excess of oxygen and to further incinerate the solid particulate materials.

[0012] A further object of the invention is to provide a process and apparatus for incinerating solid materials containing organic matter with reduced formation of carbon monoxide.

[0013] Another object of the invention is to provide a process and apparatus for incinerating solid particulate materials containing organic matter where a second source of moist air with a reduced oxygen content compared to the primary combustion air is fed into the furnace to maintain the operating temperature of the furnace at about 850° C.

[0014] Another object of the invention is to provide a process and apparatus for feeding recycled moist air from a drying plant, and feeding the moist air into the furnace for incinerating solid particulate materials.

[0015] Another object of the invention is to provide a cyclone furnace having an annular shaped inlet tube for feeding secondary air into the combustion zone of the furnace in an axial direction.

[0016] A further object of the invention is to provide an apparatus for incinerating solid materials where the furnace includes a centrally located feed tube extending axially through the furnace and the feed tube having a plurality of openings therein for supplying a secondary air source to the combustion zone.

[0017] The objects and advantages of the invention are basically attained by providing a process for incinerating solid particulate materials comprising the steps of: introducing a feed mixture into a first combustion zone of a furnace, the furnace having a lower end and an upper end defining a primary combustion chamber, the feed comprising the solid particulate material and a first source of combustion air in an amount less than a stoichiometric amount needed to completely incinerate the particulate material; and incinerating the solid particulate material in a first incinerating stage in the primary combustion zone in an atmosphere containing less than a stoichiometric amount of air to inhibit the formation of sintered ash.

[0018] The objects and advantages of the invention are further attained by providing an apparatus for incinerating solid particulate materials comprising a furnace wall defining a primary combustion chamber and having a lower end and an upper end; a burner coupled to the furnace wall for introducing hot combustion gases into the primary combustion chamber; a first feed inlet for feeding a feed mixture into a first combustion zone in the primary combustion chamber, the feed mixture including a solid particulate material and a first source of combustion air in less than a stoichiometric amount needed for complete combustion of the solid particulate material; and a second feed inlet for feeding a second source of air into the primary combustion chamber.

[0019] The objects and advantages are also attained by providing a furnace for incinerating a solid particulate material comprising: at least one side wall, a bottom wall, a top wall, and an intermediate wall extending substantially perpendicular to the side wall in an inward direction toward an axial center of the furnace, the intermediate wall having a throat opening concentric with a center axis of the furnace and defining a primary combustion chamber in a lower portion of the furnace and a secondary combustion chamber in an upper portion of the furnace; a feed inlet device in the side wall for feeding a feed mixture tangentially into the primary combustion chamber, the feed mixture including a solid particulate material and combustion air in less than a stoichiometric amount needed for complete combustion of the particulate material; and at least one feed pipe for feeding a supply of fresh air into the center of the primary combustion chamber in an amount to cool the primary combustion chamber at a temperature of about 850° C.

[0020] Other objects, advantages and salient features of the present invention will become apparent from the following detailed description which, taken in conjunction with the annexed drawings, discloses preferred embodiments of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] Referring to the drawings which form a part of this original disclosure:

[0022] **FIG. 1** is a cross-sectional side view of a cyclone furnace in a first embodiment of the invention;

[0023] **FIG. 2** is a cross-sectional side view of a cyclone furnace in a second embodiment of the invention;

[0024] **FIG. 3** is a partial cross-sectional side view of the annular feed device of the furnace of **FIG. 2**;

[0025] **FIG. 4** is a cross-sectional side view of the cyclone furnace in a further embodiment showing the opening between a primary combustion zone and a secondary combustion zone of the furnace;

[0026] **FIG. 5** is a cross-sectional top view of the cyclone furnace in a preferred embodiment of the invention showing the tangential inlets for the combustion gases; and

[0027] **FIG. 6** is a schematic diagram of a sludge drying plant and an incinerating apparatus in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0028] The present invention is directed to a process and apparatus for incinerating solid particulate materials. In particular, the invention is directed to a process and apparatus for incinerating solid materials having an organic component which can be incinerated to remove the organic component from the solid particles. The process and apparatus are particularly suitable for incinerating municipal waste sludges, and particularly sewer sludge, although other solid materials can be incinerated efficiently. In embodiments of the invention, the solid material is previously dried sewage sludge having a moisture content of about 2-10% by weight, corresponding to a dry content of about 90-98% by weight. The solid materials being incinerated generally contain a number of different compounds and components such that the solid particles have a relatively low caloric value.

[0029] In a first embodiment of the invention shown in **FIG. 1**, the apparatus is in the form of a cyclone furnace **10** having a side wall **12**, a bottom wall **14** and a top wall **16**. In the embodiment illustrated, the bottom wall **14** has a substantially frustoconical shape converging toward a central discharge opening **18** in the bottom portion of the furnace **10**.

[0030] The furnace **10** includes an intermediate wall **20** extending substantially perpendicular to the side wall **12** and having a central opening forming a throat **22**. The throat **22** in the intermediate wall **20** is positioned in the center of the furnace **10** such that the center axis of the furnace extends through the center of the throat **22**. As shown in **FIG. 1**, the center opening of the throat **22** in the intermediate wall is aligned with the discharge opening **18** in the bottom wall **14**.

[0031] The intermediate wall **20** divides the furnace **10** into a primary combustion chamber **24** located in the lower portion of the furnace and a secondary combustion chamber **26** located in the upper portion of the furnace **10**. A burner **28** is positioned in an opening **30** in the side wall **12** in the primary combustion chamber **24** which feeds a fuel and air mixture and hot combustion gases into the furnace to ignite the fuel material being incinerated and assist in the combustion of material being fed into the furnace. In the embodiment illustrated, the burner **28** is positioned to direct the hot combustion gases radially into the primary combustion chamber **24** toward the axial center and is positioned at approximately the midpoint between the intermediate wall **20** and the discharge opening **18**.

[0032] An injection nozzle **32** is mounted tangentially in the side wall **12** in the primary combustion chamber **24**. The nozzle **32** is provided to supply a feed mixture of the solid particulate material and primary combustion air. The solid material is generally a biological waste material which functions as a fuel for feeding into the primary combustion chamber **24** for incineration. In preferred embodiments of the invention, the feed mixture supplied through nozzle **32** contains fresh air in an amount less than a stoichiometric amount needed to support complete combustion of the solid material. Generally, the amount of the primary combustion air supplied with the solid material is in an amount to transport the solid particles through the feed nozzle **32** and into the furnace. The nozzle **32** is adjustable to control the feed rate of the feed mixture and to direct the feed mixture in a circular fashion around the side wall **12** of the furnace **10**.

[0033] The solid particulate material of the feed mixture is incinerated in the primary combustion chamber **24** with the assistance of the burner **28**. The feed mixture follows a spiral path in a generally downward direction and then flows upwardly in a generally axial direction toward the throat **22**. Ash is formed in the primary combustion chamber and removed from the cyclone furnace through the discharge opening **18**. The amount of the fresh air stream fed through the nozzle **32** can be selected to provide the desired extent of combustion and can be adjusted according to the combustion capacity of the furnace and the amount of the solid material in the feed mixture as well as the caloric value of the solid material in the feed mixture.

[**0034**] The larger incinerated particles fall downwardly through the primary combustion chamber **26** and are discharged through the outlet **18**. The fine particles are generally carried upwardly along the side wall **12** in a secondary stream indicated by arrows **34**. As shown in **FIG. 1**, the nozzle **32** for supplying the feed mixture is spaced axially from the throat opening **22** in the intermediate wall **20**. The nozzle **32** is positioned at the upper end of the primary combustion chamber **26** and above the burner **28**.

[**0035**] A nozzle **36** is provided in the side wall **12** in the primary combustion chamber **24** and is positioned between the throat opening **22** in the intermediate wall **20** and the injection nozzle **32**. The nozzle **36** feeds a source of secondary air tangentially into the primary combustion chamber **24** to direct a secondary air stream **34** in a circular fashion around the interior of the side wall **12**. Preferably, the nozzle **32** supplies a secondary source of air to provide an excess amount of oxygen for supporting substantially complete combustion of the solid material in the feed mixture. The secondary air is fed at a temperature less than the internal temperature of the furnace to provide a cooling effect and prevent overheating of the furnace and the solid material being incinerated. The secondary air supplied through the nozzle **32** reduces the amount of the fine particle size solid material from being discharged through the opening **22** and being carried to the secondary combustion chamber **26**. The secondary air preferably has an oxygen content less than the normal oxygen content of atmospheric air. Typically, the secondary air has an oxygen content of about 8.0-10.0% compared to about 21% of air. In embodiments, the secondary air is recycled drying air from a drying plant containing moisture and exhaust gases and has an oxygen content of about 8.0 to 10% and a temperature of about 45° C. to about 60° C.

[**0036**] In the embodiment illustrated in **FIG. 1**, the feed mixture of solid material and primary combustion air are fed into the primary combustion chamber **24** through the nozzle **32** such that the solid material is at least partially incinerated in a first combustion zone **38** in the vicinity of the nozzle **32**. The feed mixture contains less than a stoichiometric amount of oxygen for the solid particulate fuel material such that the solid material is only partially incinerated in the first combustion zone **38**. By feeding less than a stoichiometric amount of oxygen with the solid material, the temperature in the first combustion zone can be maintained at a temperature of about 850° C. and prevents or inhibits the formation of sintered ash.

[**0037**] The supply of secondary air through the nozzle **36** which is positioned above the nozzle **32** forms a second combustion zone **40** in the upper portion of the primary combustion chamber **24**. The secondary air is supplied in an amount to effect complete combustion and incineration of the solid material. This provides a two stage combustion process which prevents overheating of the solid material and prevents sintering of the ash. The secondary air typically has a reduced oxygen content which reduces the rate of combustion to maintain the temperature in the first and second combustion zones below the sintering temperature of the ash. The incinerated particles fall downwardly through the furnace and are discharged through the opening **18** and the exhaust gases are discharged through the opening **22** where they are conveyed through the secondary combustion chamber **26** for complete combustion of fuel and unburned materials.

[**0038**] The exhaust gases in the secondary combustion chamber **26** are discharged through an outlet opening **42** in the side wall of the secondary combustion chamber **26**. The exhaust gases are then fed through a heat exchanger for recovering the heat for various process steps, such as the drying of sewer sludge in a drying plant. Alternatively, the exhaust gases can be recycled to a preceding drier loop or treated appropriately for discharging to the atmosphere.

[**0039**] As shown in **FIG. 1, a** plurality of nozzles **44** are provided in the lower section of the primary combustion chamber **24** to feed a source of air tangentially into the bottom portion of the furnace. Preferably, the air fed through the nozzles **44** is moist air with a reduced oxygen content fed from a drier loop in a drying plant. The amount of moist air fed through the nozzles **44** can be adjusted to maintain the temperature in the primary combustion chamber **24** sufficiently low to prevent the sintering of ash in the combustion chamber as it falls downwardly toward the discharge opening **18**. In this manner, the temperature in the lower portion of the primary combustion chamber can be controlled to prevent overheating of the incinerated particles. The moist air typically has an oxygen content of about 8.0% to 10% which is lower than the oxygen content of the feed mixture supplied through nozzle **32**. The moist air is able to maintain the temperature substantially uniform throughout the height of the primary combustion chamber **24**. In addition, the moist air allows the combustion of solid organic materials or fuels with a low ash fusion point without the risk of sintering the ash.

[**0040**] In the embodiment of **FIG. 1, a** distribution pipe **46** is centrally located within the care of the furnace and extends along the center axis of the primary and secondary combustion chambers **24** and **26**, respectively. As shown, the distribution pipe extends through the opening **22** in the intermediate wall **20** and extends downwardly through the primary combustion chamber **24** to the discharge outlet **18**. A plurality of outlet openings **48** are spaced apart along the length and around the periphery of the distribution pipe **46** within the primary combustion chamber **26**. A supply of fresh tertiary air is fed through the distribution pipe and discharged through the openings **48** into the primary combustion chamber **24**. In the embodiment illustrated, the fresh air at ambient temperature is supplied upwardly through the pipe **46**. The air is discharged radially outward from the distribution pipe **46** and supplies the air along the axial length of the primary combustion chamber **24** to cool the primary combustion chamber and maintain a substantially uniform temperature throughout the primary combustion chamber **24**. In addition, the air fed through the distribution pipe provides a cooling effect to prevent overheating in the primary combustion chamber, and thus, inhibits the fusion and sintering of the ash. The amount of fresh air supplied to the furnace through the pipe **46** is sufficient to maintain the temperature of the furnace below 1100° C. and preferably at about 850° C. The additional air fed through the distribution pipe **46** also reduces the nitrogen oxide content in the flue gases discharged through the outlet **42** of the furnace. In the embodiment illustrated, the openings **48** are uniformly spaced along the length of the pipe **46** to uniformly cool the combustion chamber. In further embodiments, the openings **48** are selectively positioned to direct cooling air to hot spots in the combustion chamber.

[**0041**] In the process of the invention, the feed mixture of the solid material being incinerated and the primary combustion air are fed through the nozzle **32** into the furnace where the solid particles are partially incinerated in first combustion zone **38**. The feed mixture contains a less than stoichiometric amount of oxygen to prevent complete combustion of the solid particles in the first combustion zone **38**. The particles are then carried to the second combustion zone **40** where the particles are mixed with the secondary air supplied through the nozzle **36**. The combustion of the solid particles is substantially complete in the second combustion zone **40** at a temperature which prevents the formation of sintered ash. Moist air can be supplied through the nozzles **44** and fresh air is supplied through the distribution pipe **46** having a temperature below the operating temperature of the furnace to provide a cooling effect and prevent overheating of the particles and the formation of sintered ash. The amount of cooling air supplied through the nozzles **36** and/or the distribution pipe can be varied to vary and control the temperature of the furnace. The amount of cooling air is controlled as a function of the burner capacity to optimize incineration at low temperatures.

[**0042**] The amount of moist air supplied through the nozzles **44** can be adjusted to control the temperature within the primary combustion chamber **24**. Preferably, the temperature of the primary combustion zone is maintained at a temperature to substantially inhibit the sintering of the ash particles. The operating temperature of the primary combustion zone is determined by the caloric content of the solid material, the volume of solid material being fed to the combustion chamber and the ratio of the solid material and primary air supplied to the first combustion zone. The supply of secondary air for cooling the interior of the combustion zone can be regulated as a function of the burner capacity and to provide optimum incineration of the particles without the formation of sintered ash.

[**0043**] **FIG. 5** is a cross-sectional end view of the furnace showing the supply inlets into the furnace **10** of **FIG. 1**. As shown, the burner **28** is coupled to a housing **62** and includes a suitable control linkage **64** for controlling the amount of hot air supplied to the furnace. The housing **62** is connected to the opening **66** in the side wall **12** of the furnace **10** to direct the hot gases radially inward toward the axial center of the furnace. The side wall **12** of the furnace includes a refractory lining material **68** forming a substantially cylindrical shaped combustion chamber **24**. The nozzles **32, 36** and **44** extend through the side wall **12** to supply the secondary air tangentially into the combustion chamber **24** in a manner typical in cyclone furnaces. A suitable control valve **70** is coupled to each of the nozzles to control the volume of flow through the nozzles.

[**0044**] Referring to **FIG. 2, a** further embodiment of the cyclone furnace is illustrated which is similar to the embodiment of **FIG. 1**, except for the addition of a submerged feed tube **50**. Thus, identical components of the furnace are identified by the same reference number with the addition of a prime. As shown in **FIG. 2, a** submerged feed tube **50** extends axially downward into the primary combustion chamber **24** from the intermediate wall **20**. The submerged tube **50** defines the center throat opening **22** in the intermediate wall **20** and is coaxial with the center axis of the furnace. Preferably, the submerged tube **50** extends axially downward through the second combustion zone **40** and into the first combustion zone **38** below or in the vicinity of the nozzle **32** for supplying the primary feed mixture of the solid material and primary combustion air.

[**0045**] Referring to **FIG. 3**, the submerged tube **50** includes an inner annular wall **52** which forms an axial passage **54** at the throat between the primary combustion chamber **24** and the secondary combustion chamber **26**. An outer wall **56** is spaced outwardly from the inner wall **52** to form an annular air supply passage **58**. Feed pipes **60** extend through the intermediate wall **20** to the annular passage **58** to supply tertiary combustion air to the primary combustion chamber **24**. The annular passage **58** directs an annular air stream downwardly into the primary combustion chamber **24**.

[**0046**] In the process of the invention, the feed mixture of the solid material and the primary combustion air is fed through the nozzle **32** into the first combustion zone **38** where the solid particles are at least partially incinerated. A secondary air supply is fed through the nozzles **36** in the second combustion zone **40** and through the nozzles **44** as in the previous embodiment. The secondary air preferably has an oxygen content less than the oxygen content of the primary air supplied through nozzle **32**. The secondary air can be recycled drying air having a high moisture content and an oxygen content of about 8% to 10% by volume.

[**0047**] The tertiary air is fed through the supply pipes **60** and through the annular passage **58** to direct an annular flow of fresh air at ambient temperature downwardly through the primary combustion chamber **24**. The fresh air is supplied through the annular passage **58** to provide a cooling effect in the primary combustion chamber and directs the air to the lower portion of the primary combustion chamber to the core of the cyclone furnace. The secondary air mixes with the combustion gases in the primary combustion chamber where they are directed upwardly through the axial passage **54** and into the secondary combustion chamber **26**. As shown in **FIG. 2**, the secondary air fed through the annular passage **58** is supplied to the primary combustion chamber below the nozzle **32** where the feed mixture is introduced to the furnace. The fresh air is supplied through the annular passage **58** at a rate to maintain the temperature of the furnace below 1100° C., and preferably about 850° C.

[**0048**] An alternative embodiment of the invention is illustrated in **FIG. 4**, which is similar to the furnace in the embodiments of **FIGS. 1 and 2**. As shown in **FIG. 4, a** distribution pipe **46** extends axially through the axial passage **54** of the submerged tube **50** into the primary combustion chamber **24**. A supply of fresh air is fed through the distribution pipe **46** and is discharged through the openings **48** into the primary combustion chamber **24**. Simultaneously, fresh air is fed through the annular passage **58** into the primary combustion chamber **24**. In this manner, fresh air can be supplied to the furnace to control the temperature and extent of combustion of the solid material being incinerated. As in the previous embodiments, the fresh air is at ambient temperature and supplied at a rate to maintain the furnace temperature below 1100°, and preferably about 850°. Preferably, a furnace temperature of at least about 850° C. is maintained to prevent odors from being discharged in the exhaust gas. The fresh air mixes with the combustion gases in the furnace. The combustion gases are carried upward through the axial passage **54** into the secondary combustion chamber where they are eventually discharged through the outlet **42**.

[**0049**] **FIG. 6** is a schematic diagram of a sludge drying plant including the incinerating apparatus of the invention. Referring to **FIG. 6**, the sludge drying plant includes a drying section **72** and an incinerating section **74**. Previously dewatered sludge is fed through a supply pipe **76** to a storage silo **78**. The previously dewatered sludge is then conveyed through a screw conveyor **80** to a mixing device **82**. A portion of previously dried sludge material is supplied from a storage silo **84** by a screw conveyor and mixed with the dewatered sludge in the mixer **82** to adjust the solid-liquid ratio of the feed mixture. The resulting mixture is conveyed through a line **86** to a drier **88**. In the embodiment illustrated, the drier **88** is a triple pass, hot air drier as known in the art. Hot air is supplied to the drier **88** through line **90**. Alternatively, the drier can be a fluidized bed, moving fluidized bed drier or other directly or indirectly heated drier.

[**0050**] Moist air and the dried sludge particles are carried through line **92** to a separator **94** to remove the large particles from the exhaust gas stream. The large particles are carried through a cooling screw conveyor and discharged to a screen separator **96**. The larger dried sludge particles are separated and carried to a silo **98** and then fed to a crusher **100**. The crushed and ground dried sludge particles are discharged to a feed pipe **102** which is supplied with air from a blower **104** to carry the sludge particles through a feed pipe **106** to the incinerating portion of the plant.

[**0051**] The exhaust gas from the separator **94** is directed through a pipe **108** by blower **110** to a spray condenser **112**. Water or other purifying liquid is sprayed into the condenser **112** to remove soluble contaminants and fine dust particles. The moist air from the spray condenser is carried through a pipe **114** where a portion of the hot exhaust gas is carried to a heat exchanger **116** through a pipe **118**. The exhaust gas is heated in the heat exchanger **116** by the exhaust gases from the incinerator portion of the plant to reheat the air which is then supplied to the inlet of the drier **88**.

[**0052**] A second portion of the exhaust gas from the separator **94** is carried through a pipe **120** to a second separator **122** where the smaller particulates are recovered from the exhaust gas stream and carried to the silo **84** containing the recycled dried material. A portion of the dried sludge particles separated in the separator **96** are carried through a pipe **126** to the storage silo **84**.

[**0053**] The incinerating section **74** includes a cyclone furnace **128** substantially as shown in the previous embodiments of FIGS. **1-5**. A burner **130** is provided to supply hot combustion gases to the furnace in a primary combustion chamber **132** in the lower portion of the furnace **128**. The ground, previously dried sludge particles are directed into the furnace **128** through the feed pipe **106** which is positioned above the burner **130** in the primary combustion chamber **132**. Fresh combustion air can be supplied through a pipe **134** to the burner **130**. Moist recycled air from the spray condenser **112** is supplied through the feed pipe **114** to the primary combustion chamber **132**. A source of fresh air is supplied to the distribution pipe or the annular feed pipe **135** as in the embodiments of FIGS. **1-5**. The incinerated sludge particles are removed from the furnace through an outlet **136** where they are conveyed through a cooling conveyor **138**. The cooled incinerated sludge particles are conveyed through conveyors **140** and **142** to a suitable discharge site.

[**0054**] The combustion gases in the cyclone furnace **128** are carried from the primary combustion chamber **132** through the secondary combustion chamber **144** and discharged through an outlet pipe **146**. The hot exhaust gases are carried through the pipe **146** to the heat exchanger **116** for heating the feed air to the drum drier of the drying section. The exhaust gases exit the heat exchanger **116** through a pipe **148** to a separator **150** for separating particles in the exhaust gas stream. The exhaust gas stream is then carried through a pipe **152** to a spray condenser **154** for treating the exhaust gas before discharging through a discharge pipe **156**.

[**0055**] In the process of **FIG. 6**, previously dried sludge particles are supplied to a cyclone furnace above the burner to incinerate the sludge particles and remove the organic components of the sludge particles prior to discharge. Moist air from the spray condenser in the drying section is fed to the furnace to control the temperature in the furnace and prevent overheating of the sludge particles thereby preventing the formation of sintered ash.

[**0056**] While several embodiments have been shown to illustrate the invention, it will be understood by those skilled in the art that various changes and modifications can be made therein without departing from the scope of the invention as defined in the appended claims.

What is claimed is:

1. A process for incinerating a solid particulate material comprising the steps of:

introducing a feed mixture into a first combustion zone of a furnace, said furnace having a lower end and an upper end defining a primary combustion chamber, said feed comprising said solid particulate material and a first source of combustion air in an amount less than a stoichiometric amount needed to completely incinerate said particulate material; and

incinerating said solid particulate material in a first incinerating stage in said primary combustion zone in an atmosphere containing less than a stoichiometric amount of air to inhibit the formation of sintered ash.

2. The process of claim 1, wherein said furnace includes a burner and said process comprises directing hot combustion gases into said combustion zone to incinerate said solid particulate material.

3. The process of claim 1, wherein said solid particulate material is dried biological waste or sludge particles.

4. The process of claim 1, further comprising feeding a second source of air into a second combustion zone of said primary combustion chamber to cool said secondary combustion zone, said second source of air being fed into said secondary combustion zone at a location above said feed of said first source of combustion air.

5. The process of claim 4, wherein said second source of air is moist air having a lower oxygen content than said first source of air to maintain said second combustion zone at about 850° C.

6. The process of claim 5, wherein said second source of air is recycled air from a sludge drying assembly.

7. The process of claim 4, wherein said furnace is a cyclone furnace and said process comprises feeding a third source of air into a center portion of said first combustion chamber of said furnace to cool said first combustion zone, wherein said third source of air is fresh air at ambient temperature.

8. The process of claim 7, wherein said furnace includes a feed pipe extending through said primary combustion chamber in an axial direction with respect to said furnace and having a plurality of outlet openings, said process comprising feeding said third source of air through said feed pipe into said primary combustion chamber.

9. The process of claim 8, wherein said outlet openings of said feed pipe are spaced along a length of said feed pipe for directing said third source of air radially outward.

10. The process of claim 7, wherein the amount of said second source of air fed to said furnace is different from said third source of air.

11. The process of claim 4, wherein said furnace has an exhaust gas outlet positioned in an upper end of said primary combustion chamber, a first annular wall surrounding said exhaust gas outlet and extending axially into said first combustion zone, and a second annular wall concentric to said first annular wall and forming an annular air passage between said first and second annular walls, said process further comprising feeding a third source of fresh air through said annular air passage downwardly into said first combustion chamber.

12. The process of claim 1, comprising feeding said first source of air into said furnace in an amount to incinerate said solid particulate material at a predetermined rate.

13. The process of claim 4, comprising feeding said second source of air into said furnace in an amount based on a capacity of said furnace.

14. The process of claim 1, wherein said furnace is a cyclone furnace, said process comprising feeding said feed mixture tangentially into said furnace.

15. The process of claim 1, comprising feeding a further source of air into said furnace at a location below said feed mixture.

16. The process of claim 1, comprising maintaining said combustion zone at a temperature of about 850° C.

17. The process of claim 4, wherein said primary combustion chamber of said furnace includes an exhaust gas outlet, said first combustion zone being spaced from said exhaust gas outlet, said process comprising feeding said second source of air into said second combustion zone, wherein said second combustion zone is positioned between said first combustion zone and said exhaust gas outlet, and said second source of combustion air is provided to supply a stoichiometric excess of oxygen to said second combustion zone to provide complete combustion of said solid particulates.

18. An apparatus for incinerating a solid particulate material comprising:

a furnace wall defining a primary combustion chamber and having a lower end and an upper end;

a burner coupled to said furnace wall for introducing hot combustion gases into said primary combustion chamber;

a first feed inlet for feeding a feed mixture into a first combustion zone in said primary combustion chamber, said feed mixture including a solid particulate material and a first source of combustion air in less than a stoichiometric amount needed for complete combustion of said solid particulate material; and

a second feed inlet for feeding a second source of air into said primary combustion chamber.

19. The apparatus of claim 18, further comprising a feed pipe extending axially through said primary combustion chamber for supplying a tertiary source of air into said primary combustion chamber in an amount to maintain said primary combustion chamber at a temperature of about 850° C.

20. The apparatus of claim 19, wherein said feed pipe extends through a center of said primary combustion chamber, said feed pipe including a plurality of air outlet openings spaced along a length of said combustion chamber for feeding said tertiary source of air radially outward into said primary combustion chamber.

21. The apparatus of claim 18, wherein said second feed inlet is spaced upward from said first feed inlet with respect to said upper end of said furnace.

22. The apparatus of claim 18, further comprising an annular air inlet positioned in said primary combustion chamber for directing an annular column of fresh air downwardly into said primary combustion chamber.

23. The apparatus of claim 22, said primary combustion chamber having a central opening in said upper end communicating with a secondary combustion chamber, and said annular air inlet surrounding said central opening.

24. The apparatus of claim 23, wherein said annular inlet comprises an inner annular wall and an outer annular wall, said inner and outer annular walls having a length to extend toward said lower end beyond said first feed inlet.

25. The apparatus of claim 18, wherein said furnace is a cyclone furnace and said first inlet feeds said feed mixture tangentially into said furnace.

26. A furnace for incinerating a solid particulate material comprising:

at least one side wall, a bottom wall, a top wall, and an intermediate wall extending substantially perpendicular to said side wall in an inward direction toward an axial center of said furnace, said intermediate wall having a throat opening concentric with a center axis of said furnace and defining a primary combustion chamber in a lower portion of said furnace and a secondary combustion chamber in an upper portion of said furnace;

a feed inlet device in said side wall for feeding a feed mixture tangentially into said primary combustion chamber, said feed mixture including a solid particulate material and combustion air in less than a stoichiometric amount needed for complete combustion of said particulate material; and

at least one feed pipe for feeding a supply of fresh air into said center of said primary combustion chamber in an amount to cool said primary combustion chamber at a temperature of about 850° C.

27. The furnace of claim 26, wherein said feed pipe comprises an annular pipe having an annular outlet surrounding said opening in said intermediate wall for feeding fresh combustion air into said primary combustion chamber a substantially downward direction toward said bottom wall.

28. The furnace of claim 27, wherein said annular pipe has a length extending axially into said primary combustion chamber beyond said feed inlet device and for directing said combustion air in a downward direction.

29. The furnace of claim 27, wherein said annular pipe comprises an inner wall forming an axial passage between said primary combustion chamber and said secondary combustion chamber.

30. The furnace of claim 29, wherein said annular pipe further comprises an outer wall forming said annular outlet between said inner and outer walls for directing a substantially annular stream of air into said primary combustion chamber.

31. The furnace of claim 27, further comprising a cylindrical pipe concentric with said annular pipe and extending through said first feed pipe for feeding air into said primary combustion chamber.

32. The furnace of claim 31, wherein said cylindrical pipe includes a cylindrical side wall having a plurality of outlet openings for feeding said air in an outward direction with respect to said cylindrical side wall into said primary combustion chamber.

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