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(54) **Methods and apparatus for the combustion of organic matter.**

(57) Methods and apparatus for combustion of organic matter involve introducing a gas and air into a combustion chamber (23:51) which is defined by a surface of revolution (38:84) about a longitudinal axis (37:85) via one or more inlets (18:67) at an inlet end of the combustion chamber, combusted gas is withdrawn via an outlet (27:73) and a pressure gradient operates and reduces from the inlet end to the outlet end of the chamber.

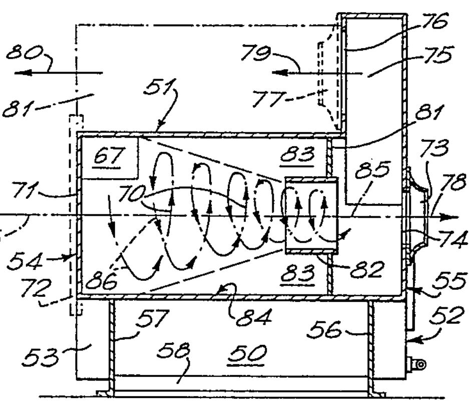

FIG.4.

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Description

METHODS AND APPARATUS FOR THE COMBUSTION OF ORGANIC MATTER

This invention relates to the combustion of organic matter, for the purpose of generating heat energy, and is concerned with improved methods and apparatus of combustion. The present invention is based upon the discovery and development of improved methods of (1) gasification of organic materials of all kinds and (2) combustion of the resultant gas products, which themselves comprise organic matter. Furthermore, the present invention is also concerned with improvements in the principles of construction and operation of various forms of apparatus, including combustion units per se and also thermal converters, for use in carrying out the combustion of organic matter.

The efficient and cheap generation of energy in the form of heat is of major industrial, commercial and domestic importance, especially in view of the costs involved in the use of conventional methods and in the construction and operation of known forms of equipment. Other important factors include the progressive exhaustion of and the rising cost of coal, oil and other fuels and, in addition, the virtually universal need for supplies of thermal energy, e.g. for the heating of buildings and for carrying out many manufacturing processes. However, another widespread need is the disposal of waste materials, a need which continues to raise numerous and substantial difficulties. For example, a high proportion of domestic and industrial refuse consists of organic matter, which is therefore generally of an easily combustible nature. Moreover, a major part of the waste generated in commercial operations is paper-based, so that commercial refuse is also organic and so easily combustible. In addition, many industries produce vast quantities of waste or by-products which are largely or wholly of an organic nature, such as straw and chaff from cereal production, mixed organic waste from vegetable growing and animal farming and cellulosic waste from wood-based industries such as paper conversion, forestry and timber production. It is a fact that almost all manufacturing industries both require heat energy and also generate waste, much of which is combustible, although in general the heat energy is derived by the combustion of conventional fuels, on the one hand, and, on the other, the waste is usually dumped or simply burnt so that the resultant heat is dissipated to the atmosphere. It would be a major improvement if the usual practices changed and, instead, the heat from disposal of the waste is used in the manufacturing processes themselves or even is employed to maintain reasonable temperature conditions in the premises where the manufacturing processes are being carried out. As one example, cereal production almost invariably requires the cereal grain, when harvested, to be dried for storage, whilst it is a very widespread practice to dispose of the straw simply by setting fire to it in the fields where the cereal has been grown. The present invention provides methods and apparatus which, in relation to the example just mentioned, enable the unwanted straw to undergo combustion and so generate heat energy efficiently and economically, sufficient to provide all the heat required for drying the grain produced in the same overall operation.

According to one aspect of the invention, a method of combustion comprises introducing a combustible gas and air into a gas combustion chamber effecting combustion of the gas and the air within the chamber and withdrawing from the chamber a hot combusted gas stream, characterised in that:

(a) the combustion chamber is defined by a surface of revolution defined about a longitudinal axis of the combustion chamber, the axis extending from an inlet end of the chamber to an outlet end of the chamber;

(b) the combustible gas and the air are introduced into the chamber via at least one inlet at the inlet end and the combusted gas stream is withdrawn from the chamber end via an outlet at the outlet end, and

(c) combustion is effected under a pressure gradient which reduces from the inlet end to the outlet end of the chamber.

Preferably, the inlet or inlets is/are disposed tangentially of a circle described about the chamber axis and the flame produced by the combustion follows a cyclonic path about the chamber axis.

One consequence of the method of combustion of the invention is that any non-combustible solids entering the chamber and/or resulting from the combustion are separated from the combusted gas stream; this can be accomplished by reason of the fact that any such solids tend to migrate toward the chamber surface. A preferred feature of the method of the invention is the provision of means at the outlet end for collecting any such solids and so preventing them from becoming entrained in the hot combusted gas stream discharged from the chamber outlet.

According to a feature of one preferred embodiment of the method of the invention, the combustible gas and the air are introduced into the combustion chamber as separate streams, and the air stream is located, at the inlet end, between the gas stream and the chamber wall. This enhances the various effects whereby the flame formed by the combustion, as it follows the cyclonic, i.e. elongated helical, path from the inlet end toward the outlet end, tends to be spaced inwardly from the chamber wall.

According to a feature of another preferred embodiment of the invention, the outlet end of the chamber includes an axial outlet aperture, i.e. the outlet for the combusted gas stream is disposed about the axis of the combustion chamber. Preferably, this axial outlet or aperture is radially smaller than the chamber or (at least) the tangent circle at the inlet end of the combustion chamber, whereby the combustion flame assumes a conical shape tapering from the chamber inlet end to the outlet aperture or outlet end, which aperture itself is preferably circular.

Preferably, the combustible gas, whether in the form of a gas stream separate from a combustion air stream or in the form of a gas mixture comprising combustible gas and air and in either case introduced into the chamber via an inlet, is the product obtained by the air-induced thermal gasification of organic matter effected within a primary chamber and is introduced, if necessary, in conjunction with one or more separate combustion air streams, into a secondary chamber comprising the above-mentioned gas combustion chamber. In one embodiment, the combustible gas is withdrawn from the outlet in the primary combustion chamber and such outlet is connected to an inlet end of the first-mentioned chamber, i.e. the gas combustion chamber. While the primary chamber, like the secondary chamber, can be defined by any surface of revolution about a longitudinal axis, the primary chamber can conveniently be cylindrical or conical; it can also be of other shapes, as described below. Preferably, the longitudinal axes of the two chambers are parallel.

According to a preferred feature of the invention, the pressure gradient provided between the inlet end and the outlet end of the gas combustion chamber is derived by connecting the outlet to a source of suction or the inlet to a source of pressure, such as an electrically-driven fan, connected appropriately to the chamber, either directly to its outlet or indirectly.

If the apparatus comprises a primary or gasificaton chamber, serving as the source for production of the combustible gas introduced into the secondary or combustion chamber, the pressure gradient can if desired by established between the inlet to the primary chamber, e.g. by supplying combustion air under pressure to the inlet to the gasification chamber.

It will be appreciated that, whether a reduced pressure is generated at the outlet end or an increased pressure is generated at the inlet end, the combustion air and the combustible gas are drawn through the combustion chamber in a helical path, due to the tangential arrangement of the inlet end, where one and preferably both of the gas and the air enter tangentially. The one or more inlets are preferably located at or adjacent one end of the chamber, while the outlet aperture is located at or adjacent the other end. This arrangement gives the maximum length for the cyclonic or helical path of the combustion flame. The maximum length of the flame is, in practice, merely limited by the physical dimensions of the combustion chamber, the size and shape of the inlet or inlets and therefore the effective width of the air stream, i.e. in a direction parallel to the long axis of the chamber, and the magnitude of the pressure gradient through the chamber. If this is of cylindrical shape, for example, having an inlet width of, say, 15 cm (6"), a diameter of 75 cm (30") and a length of 105 cm (42"), a flame having a maximum length of about $\frac{105}{15} \times 75\,\pi \simeq$ 16.5 m (approximately 54') can be generated, i.e. a length of about 15 times the longitudinal dimension of the chamber. An important result of effecting combustion under the exceptional conditions involved in the method of the invention is that the flame temperature can be raised to very high values. For example, the hot product gas stream can leave the outlet at a temperature up to 1500°C, while the combustion air can enter at room temperature, e.g. 15° to 25°C. The temperature of the combustible gas stream largely depends upon the way in which it is produced. The flame temperature can be exceptionally high, for instance, within the range from 2000°C to 2800°C. Where highly refractory constructional materials would normally be required to handle gas streams at such high temperatures, a major feature of the invention, namely, the cyclonic flame path and the means by which it is spaced inwardly from the chamber wall, whether or not this is assisted by the interposition of a combustion air stream between the combustible gas and the chamber, means that normal and therefore much less expensive materials can be used to make the apparatus in which the combustion takes place. This is because the very high temperatures in the flame per se are not present at the wall of the chamber, because the high speed of the combustion air stream, the centripetal effect of the cyclonic form of the flame and the tendency of the cooler air to migrate outwardly all combine to separate the wall from the flame throughout the interior of the chamber. If a separate combustion airstream, e.g. at room temperature, is fed in so as to be radially outside the stream of gas, this also contributes to spacing the flame from the chamber wall. By way of example, in a small air-induced thermal converter, constructed according to the present invention, having a cylindrical chamber of the dimensions given above, the flame can be kept out of direct contact with the wall so effectively that there can be, for instance, a central flame temperature of 2000° to 2500°C, a temperature midway to the wall of 1200°C and a wall temperature of 400°C. This means that the materials of construction of the apparatus need not include or be lined with ceramic refractories, for instance, as mild steel is a wholly satisfactory material for making the whole of the apparatus, even though it softens at about 1500°C and melts at 1800°C i.e. up to 1000°C or even more below the maximum flame temperatures likely to be attained. Thus, according to a preferred and important feature of the invention, the maximum flame temperature obtained in carrying out the method of the invention is higher than the softening temperature of the material of construction of the gas combustion chamber.

According to another preferred feature of the invention, the inlet into the combustion chamber has an area in cross-section, at the point from which the combustion flame is generated, which is from one half to three-quarters and, most preferably, two thirds of the area in cross-section of the outlet. The inlet is preferably so constructed that, in operation, the gas and air streams enter the chamber in amounts in the proportion of 1.1:1 by volume, under the same conditions of temperature and pressure. It has been found that each of these features has a significant effect upon the series of reactions involved in the combustion of the gas with the air and that this maximises the flame temperature and therefore the efficiency of the conversion of the combustible gas into heat energy in the form of the hot product gas stream. Where the combustible gas is derived from waste organic solids, these features therefore conduce to the highest degree of efficiency, by which the organic matter is converted into thermal energy.

According to another aspect of the invention, combustion apparatus comprises a combustion chamber, defined by a surface of revolution about an axis extending longitudinally from an inlet end to an outlet end of the chamber, and means for producing within the chamber a pressure gradient which reduces from the inlet end to the outlet end, wherein the inlet end includes, for introducing the gas and/or the air into the chamber, at least one inlet disposed tangentially of a circle about the chamber axis, whereby in operation the combustion flame follows a cyclonic path about the chamber axis. Preferably, in an apparatus according to the invention, the combustion chamber is arranged so that its longitudinal axis is horizontal.

According to a feature of a preferred embodiment of the apparatus of the invention, the outlet end of the combustion chamber includes an axial outlet aperture. This aperture, as indicated above, is preferably radially smaller than the chamber or at least the tangent circle at the inlet end; it is also preferable for the outlet aperture to be associated with means at the outlet end for retaining any non-combustible material introduced into or formed in the combustion chamber. One form of such means, which can be very effective in ensuring that the hot gas stream is substantially free from solid contaminants, comprises a tube coaxial with the chamber and itself defining the outlet aperture, which extends into the chamber from a wall defining the outlet end, whereby an annular region is formed by the end wall and the adjacent parts of the chamber surface and the tube.

A combustion apparatus according to one preferred embodiment of the invention comprises a cylindrical chamber having a tangential inlet adjacent one end of the chamber and an outlet adjacent the other end, the inlet end being separately connectible to a source of combustible gas and to a source of combustion air, the latter desirably entering the inlet between the combustion gas and the the wall of the chamber, and means for producing a pressure gradient which reduces from the point of entry of the combustion air into the inlet to the outlet, whereby the flame formed by the combustion follows an elongated helical path from the inlet toward the outlet and is spaced inwardly from the chamber wall.

Preferably, the apparatus comprises:

(1) a primary or gasification chamber for receiving combustible solid organic material and subjecting it to gasification by heating in the presence of air;

(2) a secondary or gas combustion chamber for receiving a combustible gas stream comprising air and the products evolved by the organic material in the primary or gasification chamber;

(3) a duct interconnecting the primary and secondary chambers and comprising the tangential inlet into the latter;

(4) an outlet for discharging a hot combusted gas stream from the secondary or gas combustion chamber; and

(5) a fan unit connected either to the primary chamber (1), the secondary chamber (2) or to the duct (3), as a blower or pressure source, or to the outlet (4), as an extractor or suction source, for the purpose of establishing a reducing pressure gradient from the inlet end to the outlet end of the combustion chamber (2), during operation of the apparatus.

According to a preferred embodiment of the apparatus of the invention, the primary and secondary chambers comprise generally similarly shaped, e.g. cylindrical, compartments disposed horizontally and mutually parallel, so that the inlet end of the primary chamber and the outlet end of the secondary chamber are located at one end of the apparatus and the respective outlet and inlet ends and the duct interconnecting them are located at the other end the apparatus.

According to a further preferred feature of the apparatus, where the primary or gasification chamber is a horizontally-disposed compartment, the solid organic material is introduced into it, either batchwise or continuously, via an inlet doorway or port incorporated into the inlet end of the compartment and the primary or gasification air is also introduced at such inlet end. It is preferable, with this arrangement of the apparatus, to provide as the main source of combustion air for gasification, an air duct which is connected to an air inlet pipe disposed longitudinally of the primary chamber along its lowest part and therefore generally parallel to the chamber axis. In this way, the air inlet pipe, desirably provided with a large number of air apertures disposed along its length, not only supplies combustion air for gasification of the biomass or other organic material fed into the primary chamber, but also does so in a way which effectively fluidizes the organic material. This prevents undesirable agglomeration of the organic material and ensures that it undergoes gasification in as rapid and uniform a manner as possible. The air inlet tube can advantageously be a duct, e.g. of square cross-section, mounted so as to lie in contact with the lowest part of the inner wall surface of the primary chamber, and having a series of air discharge holes in each of its side walls and, if required, also in its upper wall. Although the gasification thus takes place, in this embodiment of the apparatus of the invention, in the form of a fluidized bed lying in a horizontal cylindrical chamber, the resultant combustible gas stream, mixed with combustion air, can readily be made to undergo the desired spiralling or vortex-like movement, when it passes into the secondary or combustion chamber. The duct interconnecting the two chambers can advantageously discharge from the primary chamber tangentially, so that the gas stream readily continues this path of movement as it leaves the interconnecting duct and passes tangentially into the secondary chamber.

Another advantageous feature of a preferred form of the apparatus of the invention comprising the primary and secondary chambers resides in a particular volume relationship between the two combustion chambers, which has been found empirically to give highly satisfactory results. If the primary combustion chamber, instead of being a horizontally-disposed cylinder, is essentially square in plan and rectangular in elevation and the secondary or combustion chamber is cylindrical and thus circular in end elevation, the longitudinal axis of the cylinder lying horizontal, it has been found that the upright primary or gasification chamber, which operates on the downdraught principle, should desirably have a height which is the same as the length of the secondary or combustion chamber, whilst the side of the square horizontal cross-section of the primary or gasification chamber is the same as the diameter of the secondary or combustion chamber. The internal volume of the primary chamber is thus greater than the internal volume of the secondary chamber; it is found that this volume relationship ensures that the combustion takes place in a highly satisfactory way, even though the reasons for this are not easily ascertainable. It will of course be appreciated that an induced thermal converter or other apparatus can be constructed, in accordance with this embodiment of the apparatus of the present invention, which has a different volume relationship between the units comprising the primary and secondary combustion chambers.

In this form of apparatus, a primary air intake is preferably provided at one side of the lower part of the gasification chamber and combustion actually takes place there in a lateral or downdraught mode, in the lower part of the chamber proper. The mixing throat leading to the secondary or gas combustion chamber is preferably disposed under a second grate, located on the opposite side of the primary chamber from the primary air intake. The mixing throat leads to the tangential inlet into the secondary chamber and the pressure gradient reducing from the inlet to the outlet of the secondary chamber is then established, preferably by air induction,for instance by the operation of a driven, e.g. electrically-operated, suction fan connected to the outlet from the secondary chamber. This causes a secondary air stream to enter the mixing throat and it meets the combustible gas stream travelling by way of the same mixing throat from the primary chamber to the secondary chamber, so that the two streams meet in the mixing throat. The combustion air stream is thus located externally of the combustible gas stream, in relation to the longitudinal axis of the cylindrical secondary or combustion chamber. In view of the temperature of the combustible gas stream leaving the primary chamber and passing via the mixing throat, spontaneous ignition takes place as it meets the secondary air stream in the mixing throat and, as the latter is disposed between the combustible gas stream and the wall of the secondary chamber, the resultant flame also is spaced from the wall. The flame is induced by the suction of the fan to follow a long helical path travelling around the axis of the secondary chamber near to but not at its wall and discharging via the outlet duct. Alternatively, the secondary air intake supplying. the combustion air stream to the secondary chamber can be connected to the outlet from a fan, which therefore establishes the aforementioned pressure gradient by increasing the pressure of the combustion air stream at the inlet to the secondary chamber. Whichever method of air induction is used, a reduced pressure is established at the mixing throat so that the combustion air stream is brought into contact side-by-side with and generally parallel to the combustible gas stream.

In carrying out the method of the invention and using the various forms of apparatus of the invention, organic solid material of any particulate size and nature can be used, including essentially cellulosic products such as paper, rags, wood, sawdust and scrap card and similar products. The material is preferably divided into pieces which are sufficiently small to enable the mass of solid material to be easily feedable into the primary or gasification chamber, where it is ignited, e.g. on a grate area, at the base of the primary chamber.

The helical or cyclonic motion of the gas stream, as it passes around the wall of the secondary or combustion chamber, generates a zone of reduced pressure adjacent the longitudinal axis of the cylindrical chamber. Together with the location of the combustion air stream outside the combustible gas stream or the tendency of the less expanded air to be flung outwardly, this ensures that the flame which results from the combustion is itself drawn inwardly toward the axis of the secondary or combustion chamber and therefore away from direct contact with its cylindrical wall. The primary effects of the combustion arrangements according to the invention are that the flame travels at a much higher speed than would otherwise be the case, it therefore reaches a much higher temperature and extends over a much greater length, ensuring the substantially complete combustion of all particulate matter in the combustible gas stream, including any solid particulate materials which may be entrained in the gas stream as it enters the combustion chamber. The hot gaseous stream which is discharged from the outlet from the secondary combustion chamber is therefore much hotter and cleaner than would otherwise be the case.

On start-up of the apparatus, a quantity of organic combustible material is put into the primary chamber, the fan is operated so as to induce an air current, e.g. through the secondary air intake, and to establish the helical path for the air stream from the inlet to the outlet of the secondary combustion chamber, the solid material is then ignited and continues to burn under the influence of the primary air stream. The products therefore gasify so that the resultant combustible gas stream is drawn into the inlet to the secondary combustion chamber, which it enters tangentially, because of the constructional arrangements described.

In order that the invention may be more readily understood, the constructional and operational details of typical forms of apparatus according to the invention and thus the details of typical methods of combustion of the invention are briefly described below, in conjunction with the accompanying drawings, in which:

Fig. 1 shows a first embodiment, based upon an air-induced thermal converter shown in vertical section, taken along the line I-I of Fig. 2;

Fig. 2 shows the apparatus of Fig. 1 in plan view;

Fig. 3. shows a second embodiment of an apparatus according to the invention, for the combustion of a gas for combustion, heat exchange, steam-raising or other purposes, in diagrammatic perspective view;

Fig. 4 shows a vertical sectional view of the apparatus of Fig. 3, taken on the line IV-IV.

Referring to the embodiment of apparatus of the invention shown in Figs. 1 and 2, firstly, the converter is constructed of mild steel plate or tube, as required, except as indicated below. A primary or gasification chamber 10 consists of four generally rectangular steel side plates 11 welded at their upright edges and connected at their lower ends to a square base plate 12. The side plates 11 are rectangular, one side plate, 11a, including a circular aperture 13 to which is attached a primary air intake duct 14. This duct 14 can include an air control valve, indicated diagrammatically at 15. A primary air stream, for the combustion in the primary chamber 10 of organic material, for the purpose of its gasification enters the duct 14 under control of the valve 15, as indicated by the arrow 16. The opposite side plate 11b of the gasification chamber 10 includes a lower aperture 17, which may be of full or partial width, and leads to a mixing throat 18, the construction of which is described in more detail below. From above the duct 14 to the base plate 12, a front grate 19 is preferably located so as to be inclined towards the base of the chamber 10, while a rear grate 20 is similarly located at the opposite side of the base of the chamber 10, extending from above the mixing throat 18 to the base plate 12. Also, as indicated in Fig. 2 by broken lines 21, the lower part of the chamber 10 can in practice be constructed so that the solid material fed into it from the top falls downwardly and towards the centre as it undergoes combustion, so that gasification takes place generally in the lower part of the volume of the primary chamber 10, approximately beneath the chain-dotted line 22 indicated in Fig. 1. It is unnecessary for the primary chamber 10 to include any lid, though one can be provided if so desired. In practice, almost the entire combustion air enters in the direction of the arrow 16 via the duct 14 and the gaseous products fo combustion leave the chamber 10 through the rear grate an the mixing throat 18.

The secondary or gas combustion chamber 23 is a cylinder having an inlet end and an outlet end and is defined by a cylindrical wall 24, the inside of which is a surface of revolution 38 described about a horizontal longitudinal axis 37 and closed at its inlet and outlet ends by respective circular end plates 25. The mixing throat 18 constitutes an inlet both for the combustible gas produced by the gasification in the chamber 10 and for the combustion air introduced via the open top of the chamber 10, the duct 14 and another duct 30, as described below. The throat or inlet 18 is connected tangentially to the secondary chamber 23 adjacent its inlet end 25a, namely an inlet end plate 25, via an inlet aperture 26. It will be appreciated that the end plate 25 joins the wall 24 at a circle about the axis 37 and that the (or each) inlet 18 is disposed tangentially of that circle. At the opposite or outlet end of 25b of the chamber 23, formed by a second or outlet end plate 25, an outlet conduit 27 is attached and leads, as best shown in Fig. 2, to a suction fan unit 28. The fan unit 28 can be of any suitable construction and typically is a turbine fan driven by an electric motor (not shown), indicated diagrammatically in Fig. 2 by a shaft 29.

The mixing throat 18 comprises a duct, the upper part of the entry end of which, adjacent the aperture 17, is connected to the outlet from the primary chamber 10. The lower part of the entry to the throat 18 is an aperture 34, which is the exit end of a secondary air inlet duct 30 disposed beneath the chamber 10 and including a control valve 32, to which secondary combustion air is fed as indicated by an arrow 33. As can be seen in Fig. 1, a gas stream from the primary chamber 10 entering the mixing throat 18 via the aperture 17 is located above the aperture 34 forming the exit from the inlet duct 30 where the secondary air stream enters. The cross-sectional area of the inlet aperture 26 leading from the mixing throat 18 to the chamber 23, in the vertical plane, is preferably approximately two thirds the area fo the exit aperture from the secondary combustion chamber 23 represented by the cross-section of the outlet conduit 27.

In operation, combustible organic solid waste material supplied to the primary chamber 10 is combusted, i.e. gasified, under the influence of the primary combustion air stream represented by the arrow 16, the gaseous product stream passes from the primary chamber 10 to the secondary combustion chamber 23, which it enters tangentially via the aperture 26, in conjunction with the secondary combustion air stream entering via the duct 30 and represented by the arrow 33. It will be understood that the tangential entry of the gas and/or air is brought about because the inlet aperture 26 and the throat 18 are disposed tangentially of a circle (not shown) about the horizontal longitudinal axis of the cylindrical chamber 23. At the inlet aperture 26, a long flame is generated as the combustible gas stream and the combustion air stream meet and this flame follows a cyclonic, i.e. a generally helical, path around and therefore along the secondary or combustion chamber 23, as indicated by the circular series of arrows 35 in Fig. 1.

In operation, the fan 28 discharges a hot gas product stream, as indicated by the arrow 36. The pressure gradient can be generated in practice by locating the fan 28 so that it provides suction, as indicated at S, at the outlet 27 from the secondary chamber 23 or it can be connected instead to the inlet duct 30 and generate the desired pressure gradient by inducing pressure at that inlet, as indicated in Fig. 1 by P. The preferred spatial relationship between the primary chamber 10 and the secondary chamber 23 is given if the height a of the primary combustion chamber 10, as indicated in Fig. 1, is at least approximately equal to the length c of the secondary chamber 23, i.e. its dimension in the direction of its longitudinal axis, whilst the side b of the square section primary chamber 10 of Fig. 1 is approximately equal to the diameter d of the circular cross-section of the secondary chamber 23.

Referring now to the second embodiment of the method and apparatus of the invention shown in Figs. 3 and 4, a combuster of considerable versatility and yet simple and robust construction is shown. Two mild steel cylindrical chambers are arranged side by side and with their longitudinal axes horizontal and therefore mutually parallel. Each of the chambers, shown at 50 and 51, has an inlet end and an outlet end, the inlet end 52 of the primary chamber 50 and the outlet end 55 of the secondary chamber 51 being at one end of the apparatus, while the outlet end 53 of the chamber 50 and the inlet end 54 of the chamber 51 are at the opposite end of the apparatus. They can be secured together,e.g. by being welded to a spaced pair of upright steel plates 56,57 which have outward flanges at their lower edges and are joined together at ground level by welded angle irons 58. This enables the apparatus to stand upon any suitable level surface.

The inlet end 52 of the primary or gasification chamber 50 is equipped with a large rectangular opening 59 surrounded by projecting walls 60 and formed in the circular end plate 61 welded to the chamber 50 at the inlet end 52. Solid organic material to be gasified is fed via the opening 59 to the interior of the chamber 50 by any suitable means. For instance, the organic matter can be introduced in batches or continuously; in the latter case, a conveyor (not shown) can be arranged to deliver organic material for gasification through the opening 59. Means supporting the conveyor can be conveniently mounted on the flange walls 60, for instance. If necessary, an enclosure can be provided to shut the opening 59 in the end wall formed by the plate 61. Below this opening 59, the plate 61 receives an inlet pipe 62 for combustion air, which is fed to the pipe 62 under pressure, as indicated by an arrow 63. Within the chamber 50, the pipe 62 is connected to a combustion air supply duct 64, in the form of a square-section tube extending substantially the whole length of the chamber 50 from its inlet end 52 to its outlet end 53. The air supply duct 64 is mounted within the chamber 50 adjacent its lowest point, so that it is located underneath the mass of organic matter fed into the chamber 50 to be gasified. A series of air holes 65 are provided along the two sides of the duct 64 and, if desired, also in its top, as indicated at 66. Air under pressure (63) supplied via the air holes 65 (and 66 if provided) fluidizes the layer of organic material charged into the chamber 50 and this leads to its efficient and thorough gasification. Combustion for this purpose can be initiated by igniting the organic material and regulating the process so that gasification continues. The product consists of a combustible gas stream, which can also contain oxygen in the form of non-combusted air, and this passes to the outlet end 53 of the chamber 50 under the influence of the reducing pressure gradient established from the inlet end 52 to the outlet end 55 of the chamber 51.

The combustible gas stream is discharged from the chamber 50 and passed to the chamber 51 via a duct 67 interconnecting their respective ends 53 and 54. The duct 67 can consist of a rectangular conduit formed of welded steel plates, which passes tangentially from the outlet end 53 and also tangentially into the inlet end 54. The plate forming the inlet end 54 is circular, as shown, and thus defines a circle at its perimeter where it is welded to the chamber wall 51, such circle having the inlet 67 tangential to it about the axis 85. If desired, the duct 67 can include an inlet aperture 68, by which secondary or further combustion air can be fed into the duct 67, as indicated by the arrow 69. The aperture 68 can be closed, if it is not required for this purpose, e.g. by means of an attached plate. As explained in detail below, because the combustible gas the combustible air enter the chamber 51, which being a cylinder, is defined by a surface of revolution about its longitudinal axis extending from its inlet end 54 to its outlet end 55, under a reducing pressure gradient and tangentially, the resultant combustion flame follows a cyclonic path. This is shown diagramatically by a series of arrows 70 in Fig. 4.

The secondary or gas combustion chamber 51 can be closed off at its inlet end 54 by an end plate 71 or, instead, can be provided with a removable closure plate, as indicated in dotted lines at 72. Removal of the plate 72 can facilitate discharge from the chamber 51 of solid material, as explained in detail below. At its outlet end 55, the chamber 51 may be provided with a pipe connection 73, attached over an axial aperture 74 in the end plate 74 of the chamber 51 and capable of connection to an outlet or exhaust pipe (not shown) or any other suitable connection, by which the hot combusted gas stream can be conveyed to its place of use, for heating, heat exchange, steam raising or other purpose. The outlet end 55 of the chamber 51 can also be provided with an upwardly-extending end chamber 75, formed by steel plates welded to the cylinder. This end chamber 75 can include a rectangular or other aperture 76 facing longitudinally over the chamber 51 and can receive any one of a number of forms of apparatus for use of the heat of the hot combusted gas product. For instance, as shown in dotted lines, a pipe connection 77 can be provided instead of the connection 73 attached directly to the outlet end 55. The hot gas product can thus leave the apparatus via the outlet end 55 and an axial connection 73, as indicated by the arrow 78, or it can leave via the end chamber 75 and the connection 77, as indicated by the arrow 79. As a further possible adaptation, the outlet from the end chamber 75 represented by the aperture 76 can be coupled for instance to a bundle of tubes (not shown in detail) attached above the chamber 51 and having one end of the bundle connected to the aperture 76 and the other end discharging cooled or heat exchanged gas product as indicated by the arrow 80. The tube bundle used for such heat exchange purposes can thus be located within the region indicated at 81 and bounded by chain-dotted lines.

It is very desirable to provide the gas combustion chamber 51 with means for ensuring that solid matter, either entrained with the combustible gas or the combustion air in the chamber 50 or formed as a result of the combustion, is trapped and collected within the chamber 51. Because of the cyclonic flame path, indicated by the arrows 70, set up in the chamber 51, this can be achieved very efficiently and yet very simply. An annular baffle plate 81 is welded inside the chamber 51 adjacent the outlet end 55. Where the end chamber 75 is provided, the plate 81 is conveniently located just upstream of it. The plate 81 has its periphery sealed to the interior of the chamber 51 and includes an axial aperture, in which a baffle tube 82 is mounted, e.g. by welding. This tube 82 is located so as to extend from the plate 81 towards the inlet end of the chamber 51. As a result of this construction, the flame assumes a tapering conical shape, so that its velocity increases and the centrifugal force causing any solids to migrate from the axis towards the surface of the chamber 51 also increases, as it approaches the outlet end 55. Any non-combustible solids are thus flung towards the exterior of the cylindrical chamber 51 and become trapped in the annular region, indicated at 83, located between the chamber 51 and the tube 82, adjacent the plate 81. The result is that solids are not discharged with the hot gas product, which is notably clean, and can be discharged from the apparatus, for instance by reversing the direction of air, when combustion is not taking place, by removing the accumulated solids after detaching the removable plate 72 or in some other way.

Claims

1. A method of combustion, which comprises introducing a combustible gas and air into a gas combustion chamber (23;51), effecting combustion of the gas and the air within the chamber and withdrawing from the chamber a hot combusted gas stream, characterised in that:

(a) the combustion chamber is defined by a surface of revolution (38;84) defined about a longitudinal axis (37;85) of the combustion chamber, the axis extending from an inlet end (25a;54) of the chamber to an outlet end (25b;55) of the chamber,

(b) the combustible gas and the air are introduced into the chamber via at least one inlet 18;67) at the inlet end (25a;54) and the combusted gas stream is withdrawn from the chamber via an outlet (27;73) at the outlet end (25b;55), and

(c) combustion is effected under a pressure gradient which reduces from the inlet end to the outlet end of the chamber.

2. A method according to claim 1, wherein the inlet or inlets is/are disposed tangentially of a circle described about the chamber axis and the flame produced by the combustion follows a cyclonic path (35;86) about the chamber axis.

3. A method according to claim 1 or 2, wherein the combustible gas and the air are introduced as separate streams (17,34) and the air stream (34) is located, at the inlet end of the chamber, between the gas stream (17) and the chamber wall (24).

4. A method according to claim 1, 2 or 3, wherein non-combustible solids entering the chamber with the gas and/or with the air or resulting from the combustion are separated from the combusted gas stream.

5. A method according to claim 4, wherein the outlet (82) for the combusted gas stream is disposed about the axis (85) of the combustion chamber.

6. A method according to claim 6, wherein the axial outlet is radially smaller than the tangent circle at the inlet end of the combustion chamber, whereby the combustion flame (86) assumes a conical shape tapering from the inlet to the outlet.

7. A method according to any preceding claim, wherein the combustible gas and the air comprise a gas mixture introduced via an inlet into the chamber.

8. A method according to any of claims 1 to 6, wherein the combustible gas and the air are introduced separately into the chamber.

9. A method according to any preceding claim, wherein the combustible gas is the product obtained by the air-induced thermal gasification of organic matter carried out in a primary combustion chamber (10;50), the combustible gas is withdrawn from an outlet (17;67) in the primary combustion chamber and such outlet is connected to the inlet end (25a;54) of the first-mentioned gas combustion chamber.

10. A method according to claim 9, wherein the primary combustion chamber is defined by a surface of revolution (53) about an axis (86).

11. A method according to claim 10, wherein the axis of the primary combustion chamber is parallel to the longitudinal axis of the gas combustion chamber.

12. A method according to any preceding claim, wherein the pressure gradient is derived by connecting the outlet to a source of suction (36) or the inlet to a source of pressure (16).

13. A method according to any preceding claim, wherein combustion is effected so that the maximum flame temperature is higher than the temperature at the surface of the chamber.

14. A method according to claim 13, wherein the maximum flame temperature is higher than the softening temperature of the material of construction of the gas combustion chamber.

15. A method according to any preceding claim, wherein the inlet to the gas combustion chamber has an area in cross-section which is from one half to three quarters of the cross-section at the outlet.

16. A method according to any preceding claim, wherein the gas and air streams are

supplied in amounts in the proportion of 1.1 : 1 by volume.

17. A combustion apparatus for carrying out the combustion of a gas and air, which comprises a gas combustion chamber (23;51) having at least one inlet (18;67) at an inlet end (25a;54) and an outlet (27;73) at an outlet end (25b;55), characterised in that:

(a) the combustion chamber is defined by a surface of revolution (38;84) itself defined about a longitudinal axis (37;85) which extends from the inlet end to the outlet end,

(b) the or each inlet is connectible to a source or separate sources of the gas and the air, and

(c) means are provided for imposing a pressure gradient upon the combustion chamber, which gradient reduces from the inlet end to the outlet end.

18. An apparatus according to claim 17, wherein the inlet or inlets is/are disposed tangentially of a circle described about the chamber axis and the flame produced by the combustion follows a cyclonic path (35;86) about the chamber axis.

19. An apparatus according to claim 17 or 18, wherein baffle means (83) are associated with the outlet end for separating from the combusted gas stream any non-combustible solids introduced into or forward in the chamber during the combustion.

20. An apparatus according to claim 17, 18 or 19, wherein the outlet (82) for the combusted gas stream is disposed about the axis (85) of the combustion chamber.

21. An apparatus according to claim 20, wherein the axial outlet is radially smaller than the tangent circle at the inlet end of the combustion chamber, whereby the combustion flame (86) assumes a conical shape tapering from the inlet end to the outlet.

22. An apparatus according to any of claims 17 to 21, wherein a primary combustion chamber (10;50) is provided, for the production of the combustible gas by the air-induced thermal gasification of organic matter and such primary combustion chamber has an outlet (17;67) for the resultant gas connected to the inlet end (25a;54) fo the first-mentioned gas combustion chamber.

23. An apparatus according to claim 22, wherein the primary combustion chamber is defined by a surface of revolution (53) about an axis (86).

24. An apparatus according to claim 27 or 28, wherein the axis of the primary combustion chamber is parallel to the longitudinal axis of the gas combustion chamber.

25. An apparatus according to any of claims 17 to 24, wherein a source of suction (36;78) is connected to the outlet and/or a source of pressure (16;63) is connected to the inlet, to establish the pressure gradient.

26. An apparatus according to any of claims 17 to 25, which comprises:

(1) a primary or gasification chamber (10;50) for receiving combustible solid organic material and subjecting it to gasification by heating in the presence of air;

(2) a secondary or gas combustion chamber (23;51) for receiving a combustible gas stream comprising air and the products evolved by the organic material in the primary or gasification chamber;

(3) a duct (18;67) interconnecting the primary and secondary chambers and comprising the tangential inlet into the latter;

(4) an outlet (28;74) for discharging a hot combusted gas stream from the secondary or gas combustion chamber; and

(5) a fan unit connected to the primary chamber, the secondary chamber or to the duct, as a blower or pressure source, or to the outlet, as an extractor or suction source, for the purpose of establishing a reducing pressure gradient from the inlet end (25a;54) to the outlet end (25b;55) of the combustion chamber, during operation of the apparatus.

27. An apparatus according to claim 26, wherein the primary and secondary chambers comprise cylindrical compartments (50;51) disposed horizontally and mutually parallel, so that the inlet end (52) of the primary chamber and the outlet end (55) of the secondary chamber are located at one end of the apparatus and the respective outlet (53) and inlet (54) ends and the duct (67) interconnecting them are located at the other end of the apparatus.

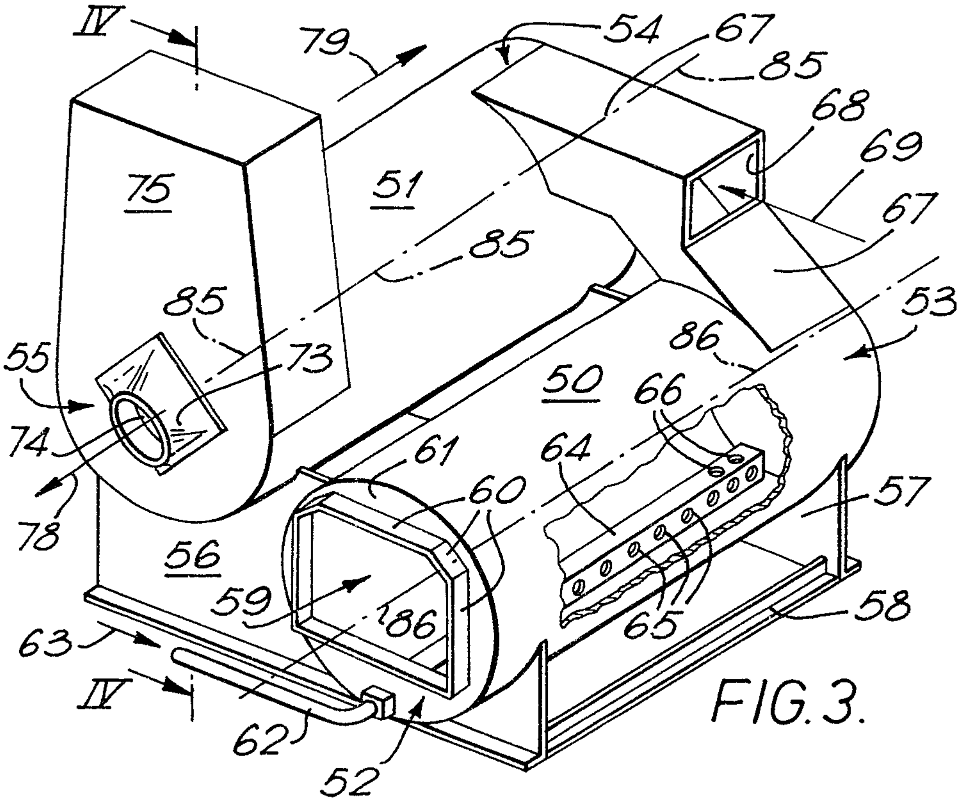
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FIG.3.

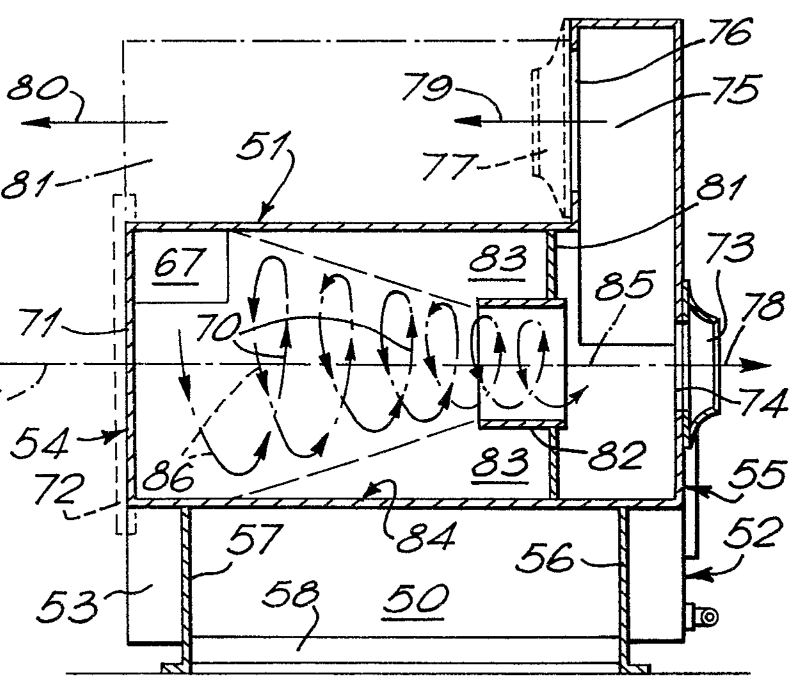
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FIG.4.

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FIG.1.

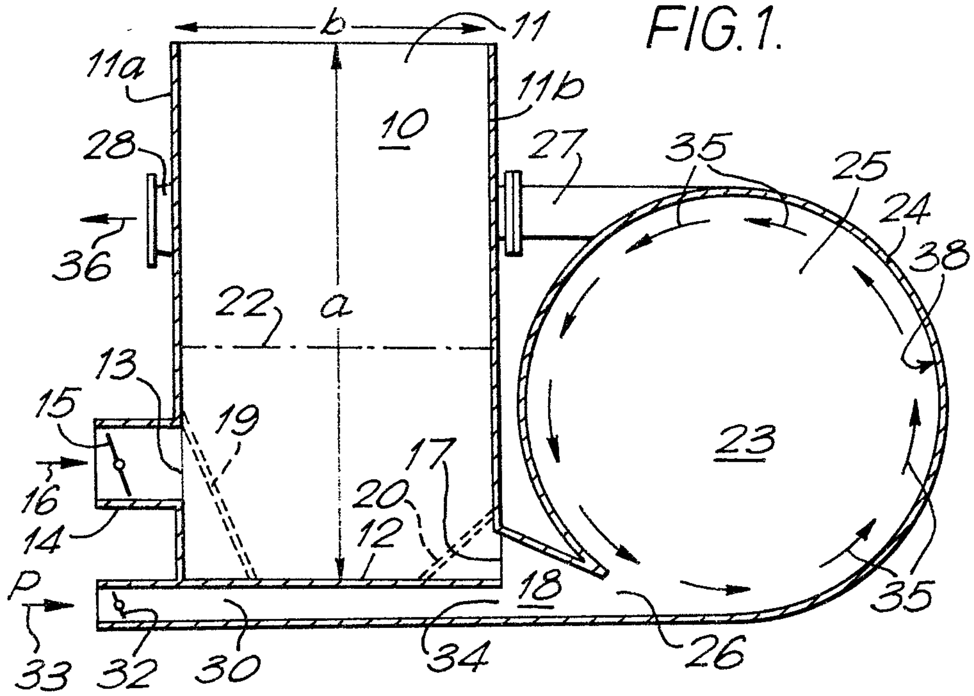

FIG.2.