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(72) Inventor: KAREL R. DAHMEN

(19)

(54) METHOD AND APPARATUS FOR THE COMBUSTION OF WASTE GASES

(71) We, CONTINENTAL CARBON COMPANY, a company organised and existing under the laws of the State of Texas, United States of America, of 4120 Southwest Freeway, P.O. Box 22085, Houston, Texas 77027, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

This invention relates to the combustion of industrial waste gases having relatively low calorific values, and includes but is not limited to the combustion of waste gases produced in carbon black plants.

Disposal of industrial waste gases has presented many problems, the solutions to which have ranged from combustors where no supporting fuel is needed to sustain combustion, to those where supporting fuel, normally natural gas, is used to obtain ignition and complete combustion of the waste gases. These systems rely upon baffle walls and refractory checker work in the combustion zone to provide stabilization by heat radiating surfaces. They also rely upon long residence time in combustion chambers of large volume, preheating of combustion air and intensive mixing.

The rapid escalation of fuel prices and shortage of natural gas are strong incentives for the development of combustion systems capable of efficiently burning low calorific value gases of varying composition. Using carbon black plant waste gases as an example, waste gases having calorific values varying from 35 to 60 BTU/ft^3. are produced, depending upon the grade of carbon black being produced.

It is particularly desirable to eliminate the need for supplemental or supporting fuel when burning these gases and to achieve high heat release rates so as to minimize combustor size.

It is also important to minimize the total pressure drop across the system due to large fans and hence large amounts of power required to pressurize the system.

Cyclone combustors of cylindrical form utilizing a plurality of tangential inlet ports of air and fuel distributed over a substantial part of the length of the cylinder have desirable characteristics for waste gas combustion in that they combine a long residence time with the presence of an aerodynamic reverse-flow/ recirculating zone near the outer refractory walls by which heat recirculates to one side of the flame front and heat radiates from the walls to the other side of the flame front. For example, see Agrest, J., "The Combustion of Vegetable Materials & Cotton Husk Combustion Problems," *J. Inst. Fuel*, vol. 38, pp. 344-348, 1965; Schmidt, K.R., "The Rotary Flow Furnace of Siemens-Agrest," V.D.I.-Berichte, Vol. 146, pp. 90-101, 1970.

Preliminary experimental work utilizing a cyclone combustor for carbon black plant waste gases is described in a paper presented at the April 21-22, 1975 Joint Meeting of Central and Western States Sections of the Combustion Institute: "The Combustion of Low Calorific Value Waste Gas," by K.R. Dahmen and N. Syred. In this cyclone combustor, the gas/air mixture enters a cylindrical combustion chamber or furnace through a plurality of tangential inlet ports and the outlet of the furnace is of smaller diameter than the diameter of the combustion chamber.

This invention is directed to an improvement on the cyclone combustor described in the Dahmen-Syred paper, whereby the aerodynamics of operation of the combustor can be adjusted so as to minimize the pressure losses across the system for waste gases of relatively low but varying calorific values.

The capability of a cyclone combustor to burn gases with very low calorific values is improved by increasing the degree of swirl of the tangentially-flowing gases and also by

decreasing the ratio of exit diameter to the combustion chamber diameter.

The beneficial effects of the above arrangements are diminished by considerable pressure drop over the system, and the improvements in combustion characteristics are sometimes hard to realize without incurring unacceptably high pressure losses.

Analysis of the pressure losses show that one part of these losses is directly related to the velocity in the tangential inlet ports, independent of conditions within the combustion chamber. This tangential inlet velocity is also an important factor in the magnitude of the swirl ratio hereinafter quantified by swirl number "S" defined hereinbelow. The second part of the pressure losses is determined by the flow velocity in the furnace and expecially in the restricted outlet.

If the furnace could be designed for a narrow range of waste gas quality, a combination of dimensions for inlets and outlets could be chosen to provide the optimum combustion characteristics commensurate with an acceptable pressure loss. In the majority of applications in a carbon black plant, however, waste gases having a wide range of qualities will have to be burned. The combustor will have to be designed for waste gas of the lower quality level with respect to tangential inlet velocity of swirl number and outlet velocity in the restricted exit throat. Such a design then will involve the highest acceptable system pressure drop.

However, when grades of carbon black are produced which yield a waste gas of higher heating value, the temperatures in the furnace and in the outlet are much higher resulting in increased combustion chamber drag and outlet velocity, increasing the pressure drop significantly. As a result, the provisions to overcome the pressure losses have to be greater than would be required for the burning of the low calorific waste gas.

As suggested above, the leaner waste gases of very low calorific value require the use of a higher swirl number than the richer waste gases having higher calorific values. In as much as the swirl ratio is directly proportional to the tangential inlet velocity, the tangential inlet velocity can be reduced when richer gases are burned, thus reducing the inlet pressure losses so as to balance or substantially balance the increases in combustion chamber drag and outlet pressure loss. Such a balanced design not only increases efficiency but reduces capital investment by reducing the required maximum design capacity or capacity of the cyclone combustor and of the fans needed for pressurizing the system.

Accordingly one aspect of the present invention provides a method of combusting industrial waste gases of varying calorific values, comprising the steps of introducing a mixture of said gases and air into a cylone combustor through a plurality of tangential inlets, causing said mixture to burn, passing the gaseous combustion products through an outlet of smaller diameter than the diameter of said combustor, and varying the tangential inlet velocity for a given mass flow rate so as to reduce said velocity when burning waste gases of relatively high calorific value and to increase said velocity when burning waste gases of lower calorific value, thereby substantially to balance the overall pressure losses across said inlets, combustor and outlet.

According to another aspect of the present invention there is provided a cyclone combustor for industrial waste gases comprising:

an elongate, cylindrical combustion chamber;

a plurality of tangential inlets connected to said combustion chamber, at least one of said inlets including flow control means for the closing and opening thereof;

an outlet for said combustion chamber having a diameter equal to 0.4 to 0.75 of the diameter of said chamber.

When using a tangential inlet cyclone combustor in accordance with the invention for burning industrial waste gases of varying calorific values, the tangential inlet velocity can be varied so as to reduce such velocity when burning richer waste gases and to increase such velocity when burning leaner gases. A preferable method of reducing the tangential inlet velocity for a given mass flow of waste gas and air is to install one or more additional tangential inlet ports with valves which can be opened when richer waste gas is available. Optionally, these valves can be automatically operated using the exit temperature or somewhat less desirably, using static pressure, as the controlling element.

The use of the additional port(s) reduces the inlet velocity which in turn reduces the inlet pressure drop losses to balance the increased chamber drag and outlet pressure drop resulting from the higher combustion temperature of the richer gas. This reduction in inlet velocity, when utilizing richer waste gases, is consistent with the fact that richer gases do not require swirl ratios as high as leaner gases. Therefore, the tangential inlet velocity can be reduced to the extent that the reduction in inlet pressure loss is equal or approximately equal to the increase in chamber drag and outlet pressure loss. Thus, a substantially balanced design is achieved with optimum aerodynamical combustion characteristics at minimum pressure loss. Furthermore, useful heat may be recovered by the combustion with concommitant energy conservation and certain atmospheric pollutants may be eliminated.

In order to enable the invention to be more readily understood, reference will now be made to the accompanying drawings, which illustrate diagrammatically and by way of example an embodiment thereof, and in which:-

Figure 1 is a longitudinal elevation, partly in section, of a cyclone combustor, and *Figure 2* is a sectional view taken along the line 2-2 of Figure 1, and illustrating one pair of tangential ports for the entry of waste gas and air and in addition a suitable arrangement of ignition/support burners utilizing natural gas or fuel oil.

Referring to the drawings, there is shown a cyclone combustor. In the combustor, a mixture of waste gas and air enters a header 1 and passes tangentially into a circular section combustion chamber or incinerator 9 through a plurality of pipes 2. Alternatively, the combustion air could be mixed with the waste gases at other locations, for example in pipes (not shown) connected to the inlet pipes 2.

Preferably, there are two headers 1 and thus two rows of pipes 2 and inlets 3 separated by at least 90° on the circumference of the circular section of the combustor, but preferably diametrically opposed.

Optionally, at least the pair of pipes 2*a* and inlets 3*a* nearest to the combustor outlet are inclined as shown, in order to give an upstream direction to the flow of the incoming mixture. The inlets 3 may be rectangular (as shown) or circular.

One or more pipes 2*c* are equipped with flow control means such as butterfly valves 4 for reasons which are explained below.

Purely as a matter of engineering design, the portion of each header 1 supplying the pipes 2*c* can be of reduced diameter.

Although the cyclone combustor 9 is shown in Figure 1 as being vertically-positioned, it could alternatively be horizontally-oriented.

Auxiliary burners 6 are provided for the combustion of auxiliary fuel (liquid or gas supplied through pipes 7) as and when needed to initiate and/or sustain combustion of the waste gases, and air for the combustion of the auxiliary fuel is introduced through pipe (s) 8.

The mixture of gas and air, upon entering through the tangential inlets 3 is induced by the shape of the chamber in rotational motion. As the radial distance from the wall towards the centre increases, the rotational velocity of the mixture increases to a maximum which can be as high or higher than two times the velocity close to the cylinder wall. This maximum is located at about two-thirds the radial distance from wall to centre. From this location towards the centre, the rotational velocity rapidly declines to approximately zero. Along the cylindrical wall, over approximately two-thirds of the length of the combustor, a thin annulus of axially reversed flow, that is away from the discharge end, recirculates hot combustion products into the incoming flow of gas and air, whereby ignition is first established in this annulus and combustion is supported by radiation from the glowing refractory of the adjacent wall face. Ignition then proceeds from this outer annulus to the inner region of the combustor resulting in stable burning of the entire inner volume of the combustor.

The combustion products then exit from the combustor through a restricted outlet 10, and pass to a stack (not shown) or to heat recovery means (not shown) such as a boiler.

The combustor is equipped with refractory castable and insulating firebrick, and external insulation is normally provided but is not shown in the drawings.

As indicated above, for burning waste gases of low calorific value, a high tangential inlet velocity through the inlets 3 is needed, in combination with a reduced-diameter exit (outlet 10). The high inlet velocity provides the required high degree of swirl, as expressed by the Swirl Number "S". The amount of reduction of the exit diameter is expressed as the ratio of De (exit diameter, i.e. diameter at 10) to the diameter Do of the combustion chamber 9. This ratio De/Do should be designed to be 0.4 to 0.75 depending upon the ranges of composition of the waste gases.

The Swirl Number "S", used herein as a nondimensional criterion to characterize and to control the aerodynamic behaviour in a cyclone combustor of this type, is the ratio of the moment about the central axis of the tangential inlet momentum to the product of the axial thrust in the discharge opening and the exit radius.

For example the calculation of the Swirl Number "S" for the operational conditions listed in Example 1 is as follows:

A. Tangential Inlet Flow

The tangential inlet momentum is the product of the Mass Flow "M_t" (gas and air) and Velocity "V_t"

M_t = 20.22 Lbs./Sec.

$$V_t = \frac{\text{Flowing Volume}}{\text{Tangential Inlet Area}} = \frac{446.6}{3.265} = 136.8 \text{ Ft./Sec.}$$

$M_t \times V_t$ = 2,766 (Lbs.) (Ft.)/Sec.^{2}

The radius of the combustor = 3.75 Ft.

Therefore, the moment of the tangential inlet momentum about the central axis = 2,766 × 3.75 = 10,373 (Lbs.) (Ft.)^2/Sec.^{2}.

B. Outlet Flow

The axial thrust is the product of the Mass Flow of the exit products "M_e" and the Exit Velocity "V_e"

M_e = 20.22 Lbs./Sec.

$$V_e = \frac{\text{Flowing Volume}}{\text{Outlet Area}} = \frac{1,219}{11.04} = 110.37 \text{ Ft./Sec.}$$

$M_e \times V_e$ = 2,232 (Lbs.) (Ft.)/Sec.^{2}

The radius of the exit opening is 1.875 ft.

The product of outlet thrust and radius = 4,185 (Lbs.) (Ft.)^2/Sec.^{2}.

Therefore, the Swirl Number "S" $= \frac{10,373}{4,185} = 2.48$.

It has been found that for burning lean waste gases of very low calorific value (35 to 45 BTU/ft.^{3}) in a cyclone combustor, it is desirable for "S" to be in the range of 1.6 to 2.5, preferably 2.5. For such an operation the butterfly valves 4 are closed and in this disposition provide for the tangential inlet velocity required to obtain the above swirl through inlets 3.

When burning richer waste gases of higher calorific value (46 to 60 BTU/ft.^{3}), the increased volume of resulting combustion products increases the total pressure losses by increasing the combustion chamber drag and the pressure drop across the restricted-diameter outlet 10. When burning richer gases, therefore, the butterfly valves 4 are opened to reduce the inlet velocities at the openings from pipe 2 into chamber 3 and therefore reducing the inlet pressure losses to balance the increased chamber drag and outlet pressure drop. This is consistent with the fact that the Swirl Number may be reduced to 1.0 to 1.5 when richer gases are burned.

If the differences in calorific values varies by greater amounts, additional velocity-reducing inlet pipes 2c can be used.

The invention will now be further illustrated by the following Examples.

Typical waste gases from the production of two grades of carbon black have the following approximate compositions:

	Mole Percent	
	Example 1	*Examples 2 to 4*
H_2	5.67	7.80
A	0.43	0.43
CO_2	2.96	2.61
N_2	37.51	35.27
C_2H_2	0.43	0.43
CH_4	0.24	0.27
CO	5.76	6.19
H_2O	47.00	47.00
Calorific value, BTU/ft.^{3}, Net	42.55	50.05

The apparatus of Figure 1 and 2 having the following dimensions is operated under the following conditions to obtain the following results, using the waste gases described above:

	Examples			
	1	2	3	4
Length of combustor, ft.	18.75	18.75	18.75	18.75
D_o, ft.	7.5	7.5	7.5	7.5
D_c, ft.	3.75	3.75	3.75	3.75
Entry Products:				
Waste Gas-calorific value, Net BTU/SCF*	42.55	50.05	50.05	50.05
- quantity, SCF/sec.	233.7	233.7	233.7	233.7
Air				
- quantity, SCF/sec.	87.8	102.9	102.9	102.9
Density of mix lbs./SCF	0.0629	0.0635	0.0635	0.0635
Mass flow lbs/sec	20.22	21.37	21.37	21.37
Flowing pressure (design), inches W.C.	8	8	8	8
Flowing temperature °F.	280	280	280	280
Flow volume, $ft.^3/sec$	446.6	469.7	469.7	469.7
Exit Products:,				
Quantity, SCF/sec	310.3	319.8	319.8	319.8
Density, lb./SCF	0.0652	0.0668	0.0668	0.0668
Manflow lbs/sec	20.22	21.37	21.37	21.37
Flowing pressure, inches W.C.**	3.5	6	6	6
Flowing temperature, °F.	1600	2050	2050	2050
Flow volume, $ft.^3/sec$	1219	1536	1536	1536
Outlet velocity, ft./sec	110.37	139.10	139.10	139.10
Swirl Number, S	2.48	2.48	2.07	1.5
Requires:				
Tangential inlet velocity, ft./sec	136.8	173.88	143.86	104.32
Hence:				
Tangential inlet area, $ft.^2$	3.265	2.701	3.265	4.5
Pressure Drop:				
Inlet, inches W.C.	3.50	5.78	3.95	2.08
Chamber & outlet, Inches W.C.	4.40	5.82	5.82	5.82
TOTAL:	7.90	11.60	9.77	7.90

*SCF = Standard Cubic Feet ** W.C. = Water Column

Explanatory notes:

Example 1

The system is designed in accordance with Example 1 to burn waste gas of 42.55 BTU/SCF. Net at a Swirl Number of S = 2.5. For the given dimensions of the combustor this would require a total area of tangential inlet ports 3 or 3.265 ft^2. This could be provided satisfactorily by two rows of ten openings 3, each 4.5 inches × 5.25 inches, connected to six-inch pipes 2. The pressure drop for this system is 7.9 inches W.C.

Example 2

Due to the higher temperature resulting from burning gas of 50.05 BTU Net and a slightly higher air to gas ratio required to burn the richer gas, the exit velocity is increased substantially. If one would insist on maintaining the same swirl S = 2.48 the inlet velocity would also have to be increased. This would result in increased pressure drop in the tangential inlets as well as over the combustion chamber and outlet adding up to 11.6 inches W.C. These conditions would be essentially satisfied by closing two pipes 3 in each row. However, there would be no incentive to do so inasmuch as this gas will burn at lower swirl number.

Example 3

When the inlet area is maintained equal to Example 1, the swirl number is reduced to S = 2.07, when burning the 50.05 BTU gas. The pressure drop for this arrangement is 9.77 inches W.C., which is higher than the design for Example 1.

Example 4

By reducing the swirl number to S = 1.5, the pressure drop can be reduced to the same value as for Example 1. This would require adding 1.235 ft.^{2} tangential inlet area which can be done by opening valves in 8-inch diameter supply pipes 2*c* to four openings 3*c* each 7¼" × 6⅛".

WHAT WE CLAIM IS:-

1. A method of combusting industrial waste gases of varying calorific values, comprising the steps of introducing a mixture of said gases and air into a cyclone combustor through a plurality of tangential inlets, causing said mixture to burn, passing the gaseous combustion products through an outlet of smaller diameter than the diameter of said combustor, and varying the tangential inlet velocity for a given mass flow rate so as to reduce said velocity when burning waste gases of relatively high calorific value and to increase said velocity when burning waste gases of lower calorific value, thereby sustantially to balance the overall pressure losses across said inlets, combustor and outlet.

2. A method as claimed in claim 1, in which the tangential inlet velocity is varied by changing the number of tangential inlets by opening or closing flow control means in at least one of said inlets.

3. A method as claimed in claim 1 or 2, in which said waste gases are waste gases from a carbon black plant.

4. A method as claimed in any preceding claim, in which the waste gases have a calorific value of 35 to 45 BTU/ft.^{3}; the Swirl Number (as defined herein) is 1.6 to 2.5; and the ratio of combustor outlet diameter to combustor diameter is 0.4 to 0.75.

5. A method as claimed in any one of claims 1 to 3, in which the waste gases have a calorific value of 46 to 60 BTU/ft.^{3}; the Swirl Number (as defined herein) is 1.0 to 1.5; and the ratio of combustor outlet diameter to combustor diameter is 0.4 to 0.75.

6. A method of combusting industrial waste gases of varying calorific values substantially as hereinbefore described with reference to the accompanying drawings and/or in the foregoing Examples.

7. A cyclone combustor for industrial waste gases comprising:

an elongate, cyclindrical combustion chamber;

a plurality of tangential inlets connected to said combustion chamber, at least one of said inlets including flow control means for the closing and opening thereof;

an outlet for said combustion chamber having a diameter equal to 0.4 to 0.75 of the diameter of said chamber.

8. A combustor as claimed in claim 7, in which a supplemental burner or burners is or are provided for initiating and sustaining combustion of said waste gases.

9. A cyclone combustor substantially as hereinbefore described with reference to the accompanying drawings and/or in the foregoing Examples.

TREGEAR, THIEMANN & BLEACH,
Chartered Patent Agents,
Enterprise House,
Isambard Brunel Road,
Portsmouth PO1 2AN
and
49/51, Bedford Row,
London, WC1V 6RI

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1 SHEET This drawing is a reproduction of the Original on a reduced scale

Fig.2.

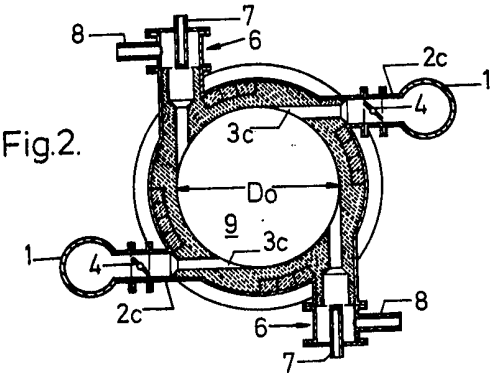


Fig.1.

