

June 2, 1964

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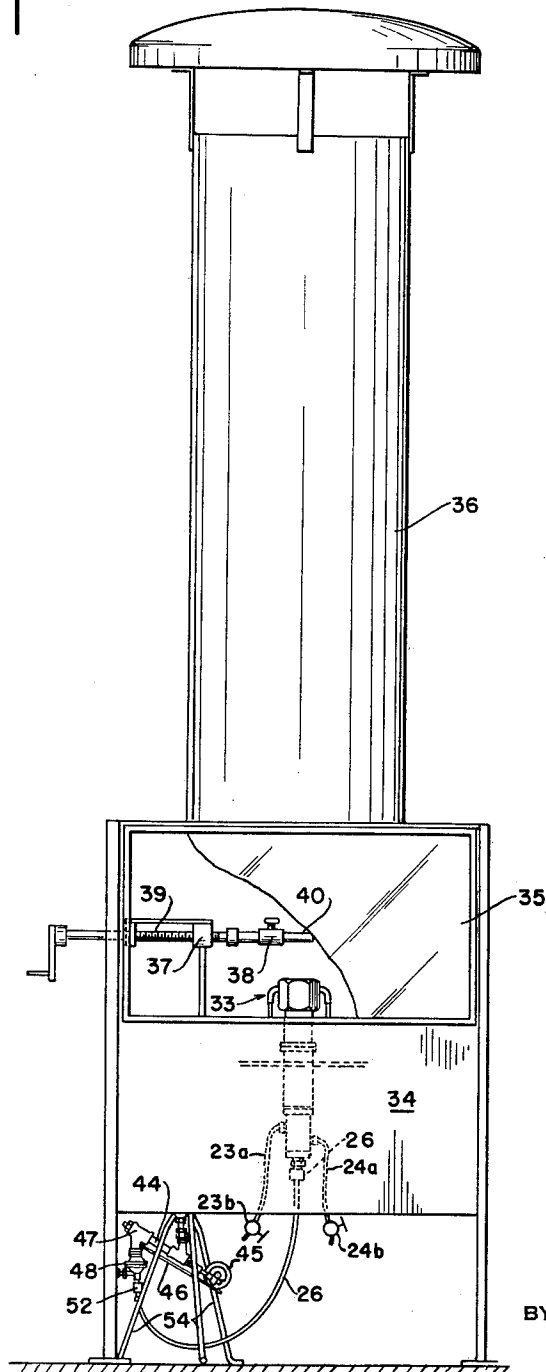
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INTERNAL COMBUSTION METHODS AND APPARATUS

Filed Jan. 30, 1961

2 Sheets-Sheet 1

FIG. 1



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2 Sheets-Sheet 2

FIG. 2

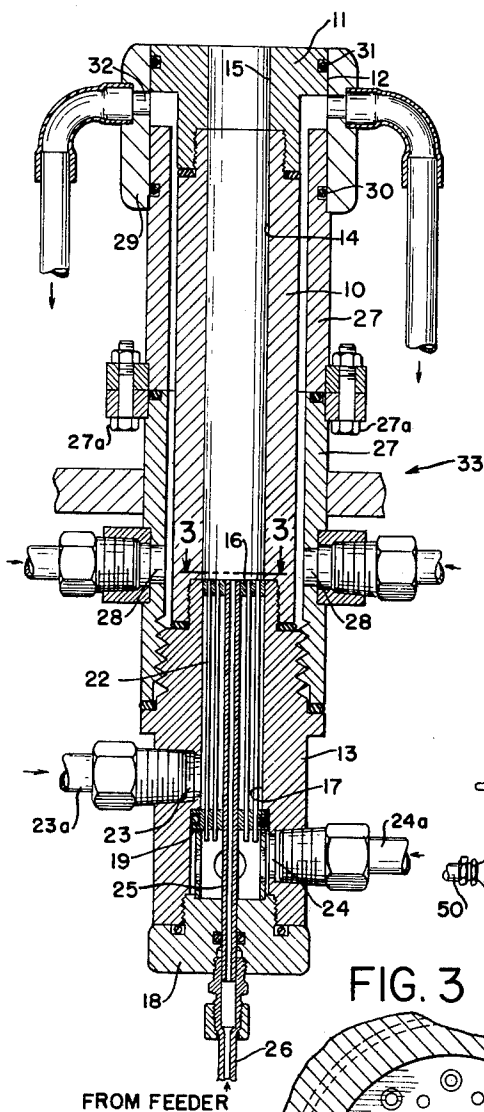


FIG. 4

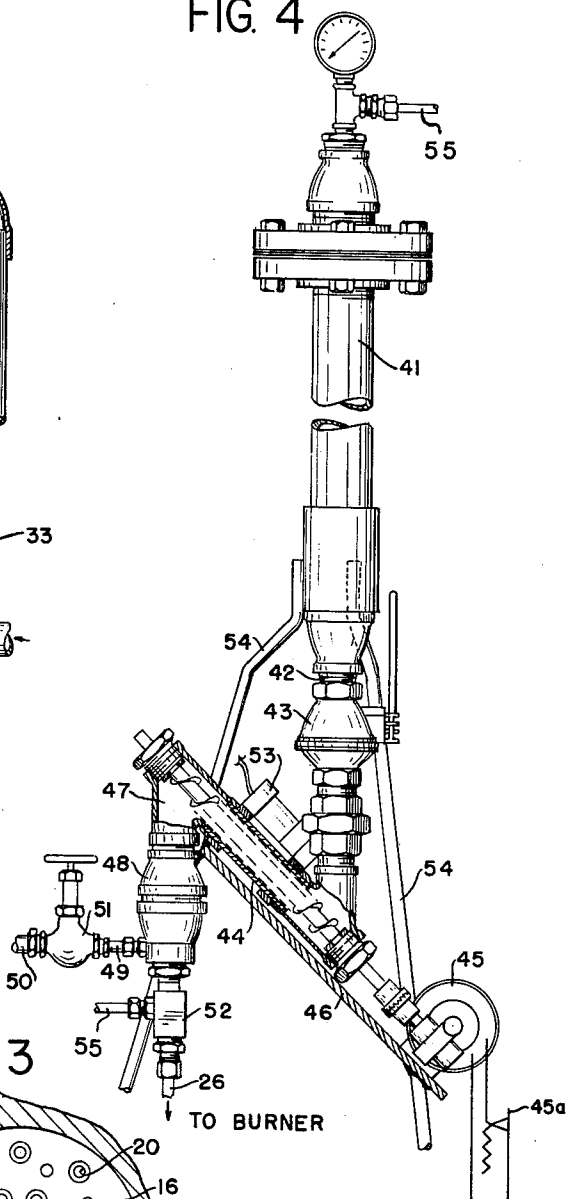
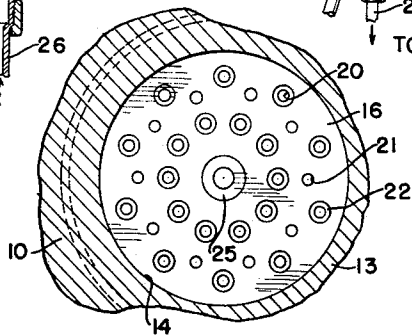


FIG. 3



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INTERNAL COMBUSTION METHODS AND APPARATUS

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13 Claims. (Cl. 117-105.2)

This invention relates to burners such as are used for space heating and for flame coating or flame spraying. More particularly the invention relates to a burner using oxygen and fuel gas, capable of operating over a much wider range than burners of the prior art. In other aspects the invention also relates to improved methods and apparatus for impinging a coating material at high velocity and high temperature upon the surface of a base material, whereby to provide the base material with a durable coating and also is concerned with an improved mixture of materials for use in connection with such coating methods to produce surface coatings having valuable and superior qualities.

The so-called flame or spray coating of one material onto another is, in general, well known. Most of the known processes for flame coating or flame spraying involve the introduction of a coating material in powdered or wire form into a combustion zone, and causing the combustion gases or a flame front initiated therein to melt or soften the coating material. The heated material is propelled toward the surface to be coated by the products of combustion or by an auxiliary gas stream. The methods presently known are not entirely satisfactory in certain respects, and particularly with respect to the control of the temperature of the coating material and the nature of the atmosphere surrounding the heated particles. For example, in certain of the known methods, it is not possible to control the period of time in which the coating material is in transit through the combustion zone, without materially affecting the flame temperature and the temperature of the coating material. As a result, a separate postheating operation is often required, during which the coating material is remelted or "wetted in" to obtain good bonding and to reduce the porosity of the coating. This disadvantage may sometimes be avoided by introducing the coating material into the combustion zone in the form of a wire or rod, with the rate of feeding of the wire being accurately controlled so that the melting and depositing of the coating material proceeds at the desired rate. However, the use of a coating material in wire or rod form may result in such additional expense as to offset any advantage otherwise resulting.

It is an object of this invention to provide an improved burner for heating a space or the surface of a workpiece, and to provide a flexibility of operation that can be used for more efficient flame coating or spraying, and especially for controlling the length of time that particles of coating material are exposed to the action of the heating flame system.

In accordance with the present invention, a continuously operating, high velocity, high temperature flame is produced in a rocket-like gun. A coating material in powdered form may be introduced into the inner end of the gun. The coating particles are propelled from the burner or gun in a stream of combustion products and are impinged upon the surface to be coated. The new rocket burner has flexibility in the amount of gas discharged, the amount of heat generated, the velocity of the gas and other variables; and the method of heating and the delivery of the coating material can be controlled to insure that the particles of the particular coating material and the surface of the workpiece are at optimum con-

ditions at the time of impingement on the surface to be coated. Moreover, the nature of the rocket flame may be easily controlled to provide oxidizing or reducing environmental conditions during the coating process.

As a more specific object, the invention seeks to provide a novel and improved apparatus and method for producing surface coatings which incorporates a novel rocket-type fuel burner adapted for operation with commercially available fuels such as natural gas and oxygen. The new method and apparatus is thus suitable for commercial use without requiring excessive investment in special equipment.

The improved burner incorporates novel arrangements for supplying fuel gas and oxygen, as well as means for introducing a separate fluid stream such as powdered coating material, into the combustion chamber of the burner. The fuel gas and oxygen are injected into the combustion chamber in a manner such as to promote mixing of the gases, while eliminating the possibility of backfire. The coating material, in powdered form, may be fluidized by fuel gas, and directed into the rocket burner, wherein it is heated and projected from the burner at high velocity by the products of combustion.

The improved burner of this invention includes a dual flame system. Spaced and generally parallel streams of oxygen and of fuel gas are close enough together to produce mixing of the gases in eddy currents and the production of a stable low-velocity anchoring flame system near the face of the plate through which the separate streams of gas are projected into the combustion chamber of the rocket burner in directions generally parallel to the longitudinal axis of the combustion space. This anchoring flame system is in a stabilizing combustion zone with streams of flame reaching to the main combustion zone in the burner for insuring ignition of the mixed gas in the main combustion zone.

The construction thus provides a flame holder for insuring combustion of the high velocity gas which mixes with the oxygen at various distances from the plate, depending upon the rate of feed of the gases and the resulting velocity and "stiffness" of the jets, in a second and main combustion flame system that ordinarily extends beyond the discharge end of the combustion chamber.

The improved burner device also incorporates novel features of construction which facilitates cooling of the burner components during operation. Due to the high temperature of the rocket burner flame, it is necessary to provide for forced cooling by means of water or other coolant fluid. Because of the high relative expansion of certain parts of the burner apparatus with respect to others, the provision of water cooling means presents certain problems with respect to fluid leakage, etc. In accordance with the invention, however, the new burner device incorporates a novel and highly simplified structure which permits of substantial relative movement of certain burner components due to differential expansion and contraction, without leakage of the cooling fluid.

The invention also provides an improved coating composition suitable for use in the new method and productive of surface coatings having more desirable characteristics than heretofore obtainable. For the coating of mild steel, drill rod, cast iron, molybdenum, and similar materials, a coating material comprising a mixture of chromium, nickel, aluminum, magnesium and graphite applied by the present process produces a highly desirable high temperature oxidation resistant surface coating.

For a better understanding of the invention, reference should be made to the following detailed specification and accompanying drawings, in which:

FIGURE 1 is a front elevation, with parts broken away, of a rocket burner installation incorporating the teachings of the present invention;

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FIGURE 2 is an enlarged longitudinal cross-section of the novel and improved rocket burner device incorporated in the installation of FIGURE 1;

FIGURE 3 is an enlarged fragmentary cross-section taken generally on the line 3—3 of FIGURE 2; and

FIGURE 4 is a front elevation, partly in section, of an improved feeder device incorporated in the installation of FIGURE 1 for feeding coating material to the rocket burner.

Referring to the drawing, the numeral 10 (FIGURE 2) designates an elongated tubular member having threaded portions at each end. At the upper end of the tubular member 10 is threadedly secured a collar 11 having an outwardly extending flange 12 at its upper end. A sleeve 13 is threadedly secured to the lower end of the tube 10, in coaxial relation therewith and forms an extension at the lower end of the tubular member 10. The tubular member 10 has an axial bore 14 therein which is advantageously of uniform diameter throughout. Likewise, the flanged collar 11 has a bore 15 forming a continuation of the bore 14.

In accordance with the invention, the tubular element 10 defines an elongated burner or combustion chamber, open at its upper end and effectively closed at its lower end. To this end, the sleeve 13 has an apertured plate 16 at its upper end. The plate 16 is secured in the sleeve in any suitable manner, and, except for the apertures provided therein (see FIGURE 3), forms a wall closing off the lower end of the tubular member 10 and defining the closed end of the burner combustion chamber.

As shown in FIGURE 2, the sleeve 13 has a central bore therethrough which is closed at its upper end by the apertured plate 16 and at its lower end by a threaded cap 18. Immediately above the cap 18, the bore 17 is enlarged, defining a shoulder for the reception of a second apertured plate 19. In accordance with the invention, the second apertured plate 19 has a plurality of apertures corresponding to apertures in the first plate 16. However, the plate 16 has additional apertures, of which there is no counterpart in the second plate 19. More specifically, the plate 16, as shown in FIGURE 3, has a plurality of large diameter openings 20 and a plurality of smaller diameter openings 21. The second plate 19 has a plurality of openings therein corresponding in number and location to the large diameter openings 20 of the plate 16, but has no openings corresponding to the smaller diameter openings 21.

When the apertured plates 16, 19 are assembled in the sleeve 13, the corresponding openings of these plates are arranged in alignment with one another, and a plurality of elongated and parallel tubes 22 are received in each of the aligned pairs of large diameter openings 20. As shown in FIGURE 2, the upper ends of the tubes 22 open into the chamber defined by the bore 14 while the lower ends of the tubes open into the chamber below the lower apertured plate 19. Thus, a pair of isolated flow paths are provided leading into the burner chamber 14; a first path leads from the chamber below the plate 19 and through the plurality of tubes 22, while a second path leads from the space between the apertured plates 16, 19 and into the burner chamber 14 through the plurality of small diameter openings 21 in the upper plate 16.

In the illustrated apparatus, the sleeve 13 is provided, intermediate the apertured plates 16 and 19, with a radial passage 23 which serves as an inlet for a fuel gas. Likewise, a radial passage 24 opens into the enlarged lower portion of the bore 17 of the sleeve and serves as an inlet for oxygen.

Gases are supplied to the passages 23 and 24 through tubes 23a and 24a. The pressure and rate of flow through each of the tubes 23a and 24a can be regulated independently of that in the other tube by adjustable valves 23b and 24b, respectively, shown in FIGURE 1.

As will be more fully described, during operation of the new burner device, oxygen and fuel gas are continuously fed into the chamber 14 through the passages 23, 24

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(FIGURE 2) and through the openings in the plate 16 to maintain combustion within the chamber 14. Fed in the proper volumes and proportions, the oxygen and fuel gas mixture produces a high temperature flame within chamber 14 resulting in the high velocity exhausting of the products of combustion from the open end of the chamber, in a manner of operation similar to a conventional rocket.

Oxygen streams discharge from the tubes 22 parallel to the longitudinal axis of the combustion chamber 14. Streams of fuel gas discharge from the openings 21 in directions parallel to the longitudinal axis of the chamber 14. These oxygen and fuel gas streams are discrete streams when they pass through the plate 16 and into the combustion chamber 14, but they expand in the chamber and come together, first along their boundary layers and then into a turbulent mixing region as they expand through one another's boundary layers.

The location at which the oxygen and fuel gas streams mix to a combustible ratio depends upon the relative amount of oxygen supplied with respect to the fuel gas; and also upon the amount and velocity of both oxygen and fuel gas. Larger gas flows increase the velocities of the gas streams and make the streams "stiffer" because of their greater momentum. Consequently, higher velocity moves the turbulent mixing region further from the plate 16, partly because the gases are moving faster and partly because the stiffer streams resist breaking into a turbulent mixing condition.

An eddy current zone is created adjacent the face of the plate between the oxygen and fuel gas streams into which combustible gases are drawn therefrom to produce a flame holding effect. The eddy currents compare to the condition produced by conventional impingement type flame holders disposed in a downstream obstructing relation to a gas stream. In the present case, of course, no impingement or obstruction of the gas streams is necessary and the significant advantages of the present invention are obtained without the disadvantages attending the conventional flame holders heretofore used. The gas streams exert an aspirator action that reduces pressure in the space between the streams. Some oxygen and fuel gas from the boundary layers of the streams eddy into these spaces of reduced pressure, and these eddy flows produce a combustible mixture of oxygen and fuel gas. This mixture burns in low velocity flames which are independent of the amount of gas in the oxygen and fuel gas streams and independent of the velocity of these streams.

Because they are independent of the rate of flow and velocity of the gas streams, these eddy flow flames provide anchoring or stabilizing flames for maintaining the combustion of the mixed gases of the high velocity streams. This initial or eddy flame system is "independent" of the other gas streams, in the sense that its existence does not depend upon any particular ratio of gas flows or upon flow rates or velocities. In describing this eddy flame system as independent of the other flame system which exists of the region of turbulent mixing of the streams, it should not be thought that changes in the oxygen and fuel gas streams, which affect the main combustion flame system, do not affect the eddy flame system. They do; but only to the extent that the eddy flame system compensates for changes in the main combustion system.

For example, the eddy flame system has stringers of flame that extend to the region of turbulent mixing of the main gas streams. As the velocity of the main gas streams is increased with larger rates of flow, the higher velocities at the tube exits produce stronger aspirator action and the region of this reduced pressure extends further from the plate 16 because of the greater stiffness of the generally parallel streams of oxygen and fuel gas. This produces two compensating effects in the eddy flame system. One is that the reduced pressure off-sets the higher stream inertia of the gas streams to produce the eddy flow of oxygen

and fuel gas into the space where the eddy flame system burns; and the other is that the reduced pressure area between the discrete streams is lengthened with resulting increase in the length of the stringers of flame of the eddy flame system to reach the main combustion region which has moved further from the plate 16 as a result of the higher velocity gas flow. The eddy flame system is thus self compensating.

At their lowest rates of flow, the eddy flame system and the main combustion flame system may merge, but for flow rates where a burner of this type may be used advantageously the eddy flame system and the main combustion flame systems are two distinct systems with the eddy flame system acting as a stabilizing combustion zone to prevent the blowing away or lifting of the main combustion flame system. The normal rate of flame propagation of the combustible mixture does not impose an upper limit to the velocity at which the burning gases may be discharged from the combustion chamber. Thus, the flame holder effect of the eddy current flame system will insure ignition of the turbulently mixed main gas streams independently of the velocity thereof and the resulting burner mixture may, therefore, be discharged at sonic and higher velocities without blow-away or instability. This is made possible inasmuch as the ignition is furnished by the eddy flame system and does not depend upon self-ignition of the mixed gas itself.

In operation, the main combustion flame system is laterally confined by the walls of the combustion chamber 14 and seals the open end of the chamber from air dilution. This effect is obtained by the ignition of the main combustion flame system at its various regions of contact with flame stringers of the eddy flame system and the burning thereof transversely to the boundary layer of the turbulent gas mixture by the time the mixture reaches the open, discharge end of the chamber 14. Thus, a certain minimum length of the chamber is advantageous for any given diameter. The ratio of the length to the diameter of the chamber 14 is the "slenderness ratio" and it should advantageously not be less than about one to one, and preferably at least about $1\frac{1}{2}:1$. This is for a construction where the gas streams through the closed end of the chamber 14 are substantially parallel and there are a plurality of both oxygen and fuel gas streams, both groups being generally symmetrical about the longitudinal axis of the combustion chamber 14.

To obtain an effective flame holder effect, the oxygen and fuel gas openings may be advantageously arranged in a circular pattern in the manner shown in the drawings, including inner and outer rings of oxygen ports and an intermediate ring of fuel ports. In the preferred construction, the adjacent passages from which oxygen and fuel gas issue are not closer than $d/4$ where " d " is the diameter of the opening. The spacing is measured from the circumference of the openings and is not a center-to-center distance. The openings that supply the oxygen and fuel gas streams are preferably no further apart than $3d$ with distance again measured between the circumferences of the openings. The above spacings are applicable where the diameters of the respective passages for fuel and oxygen are the same. Where the oxygen and fuel gas passages, respectively, are of different diameters, the minimum spacing advantageously corresponds to the distance $d/4$, where " d " is the diameter of the smaller opening and the maximum spacing corresponds to the distance $3d'$, where " d' " is the diameter of the larger opening. It will be evident that various arrangements and spacings of the oxygen and fuel ports are possible as long as the ports are arranged in at least a portion of the area of the manifold plate at the inner end of the elongated combustion chamber, such that aspiration and eddy current formation occur and form a corresponding stable, low-velocity, anchoring flame system effective to ensure ignition of the mixed gas in the main combustion zone.

Although the combustion in the main combustion flame system spreads across the width of the chamber 14 by

the time the turbulent gas mixture reaches the discharge end of the chamber, it is not necessary to confine the flame combustion within the length of the chamber. Ordinarily much of the main combustion occurs beyond the end of the chamber 14. It is objectionable to make the chamber so long that the main flame system does not extend beyond it.

At a given flame temperature, the heat transfer rate to a workpiece depends primarily upon the velocity of the gases in the flame. Best results are obtained in heating a workpiece when the chamber 14 is long enough to permit the turbulent burning, gas stream to accelerate to sonic velocity by the time it reaches the end of the chamber, but any extension of the burner chamber beyond this length results in unnecessary loss of heat to the cooling jacket.

Such considerations of design must be for expected working conditions, and with other flows the optimum conditions are only approximated, and at very low rates of flow may not be approximated, but there is not the same requirement for performance when operating in extremes of the very wide operating range of the burner. For space heating, the velocity of the flame is not of the same importance as when heating a workpiece surface when applying coating material.

One of the important advantages of this invention, and that gives the invention such a wide operating range, is that critical gas velocities in excess of the rate of flame propagation are not necessary at the openings through the plate 16. No matter how low the velocity at low output, the flame cannot pop back into the burner because the oxygen and fuel gas are not premixed. As gas flow is increased, velocities through the openings in the plate 16 can be pushed up to sonic values but this does not impose a limit on the gas flow because the pressure can be increased and greater flow obtained as the result of increased density.

The range of operation in the ratio of oxygen to fuel gas may be considered as running between the limits that produce combustible mixtures for the main combustion flame system. Too much fuel gas will not produce a combustible mixture in the turbulent mixed gases, and the same is true with too little fuel gas; but the eddy flames will burn as long as there is oxygen and fuel gas which can eddy into the space between the oxygen and fuel gas streams, and the amount of gas which eddies into these spaces does not depend upon the relative proportions of gas supplied to the different streams. There is a self-compensating feature here because the weaker stream, when using disproportionate oxygen and fuel gas ratios, tends to eddy more than the stronger stream, and this increases the proportion of gas from the weaker stream.

If the supply of oxygen is pushed so high that the turbulent mixed gas stream is no longer combustible, then the stabilizing flames will continue to burn and cause the burner to supply warm oxygen (with some dilution by fuel gas and products of combustion), but the apparatus is no longer being used as a rocket burner.

While combustion takes place in the chamber 14, a coating material may be introduced into the chamber, to be heated and carried out with the hot products of combustion. To this end, the plates 16, 19 and the cap 18 are provided with enlarged central bores for receiving an elongated tube 25. The tube 25 opens into the chamber 14 at one end and projects outwardly from the cap 18 at its other end for connection with a feed line 26 supplying the coating material in powdered, fluidized form.

One advantage in changing the oxygen, fuel gas ratio is to change the rate of flame propagation and this increases or decreases the length of the zone in which combustion takes place and hence the length of time that a particle of coating material is within the flame. This time is known as the "residence time" or "dwell time," the amount required depends upon the particular material being used for the coating. Another feature of the per-

missible variation of the oxygen to fuel ratio is control of flame temperature.

When combustion takes place in the chamber 14, considerable heat is generated therein and transferred to the walls of the tubular burner. To cool the burner, a water jacket 27 surrounds the tubular member 10, and is spaced from the member 10 to leave an annular passage for cooling water. In the illustrated apparatus, the jacket 27 is made in two sections connected together by bolts 27a. This two section cooling jacket 27 is threadedly secured at the lower end to the sleeve 13 and extends upwardly, terminating a short distance from the flange 12 of the collar 11. Adjacent to the base of the tubular burner, the cooling jacket 27 is provided with openings 28 serving as inlets for water or other cooling fluid.

Since the tubular burner is exposed directly to the heat of combustion in the chamber 14, while the cooling jacket 27 remains relatively cool, the expansion and contraction of the burner tube 10, when combustion is initiated and terminated, will be substantially greater than that of the cooling jacket 27. Accordingly, the upper end of the annular cooling fluid passage is sealed by means of a sleeve 29 which surrounds the upper end of the cooling jacket 27 and the flanged collar 11. In the illustrated apparatus, the upper end of the cooling jacket 27 has a shoulder upon which the sleeve 29 is supported, and suitable O-rings 30, 31 are employed to form seals between the confronting faces of the sleeve 29, and the jacket 27 and flange 12. With this improved arrangement, the burner tube 10 can expand or contract with respect to the cooling jacket 27 without impairing the effectiveness of the fluid seal. The sleeve 29 is provided with one or more radial openings 32 serving as outlets for the water or other cooling fluid. It is preferable to form the burner tube 10 of copper or other material having good heat conducting characteristics. This facilitates transfer of the excess heat to the cooling water in the passage between the burner 10 and the cooling jacket 27.

Referring now to FIGURE 1, the burner assembly, generally designated by the numeral 33, may be conveniently mounted in vertical relation in a frame 34, so that the open upper end of the burner is directly upwardly, substantially in the same manner as indicated in FIGURE 2 for use in flame spraying. The frame 34 may be in the form of a housing, with one or more windows or openings 35 exposing the upper portion of the burner 33 to view. Mounted on the frame 34, directly above the burner 33, is an elongated cylindrical structure 36 which is open at its upper end and serves to confine the flames and combustion products issuing from the burner 33, as well as to muffle or deaden the noises produced during operation of the burner.

It will be understood, of course, that the burner installation illustrated in FIGURE 1 is purely exemplary, as it is contemplated that the burner may be installed, in a variety of ways or even arranged for portable manual use where desired. The installation illustrated in FIGURE 1 includes a work holder 37 comprising a chuck 38 and a threaded shaft 39 operated by a hand crank and adapted to support a workpiece 40 above the open end of the burner 33. With the illustrated apparatus, the workpiece 40 may be rotated and advanced longitudinally over the top of the burner 33 by appropriate manipulation of the shaft 39. This assures that all surfaces of the workpiece 40 are uniformly exposed to the action of the burner 33.

It is important to the proper operation of the burner assembly 33 when it is used for coating that it be provided with a continuous and uniform supply of powdered coating material. A feeder device for obtaining this uniform supply of coating material, is shown with a vertically elongated reservoir 41 (FIGURE 4) adapted to hold a supply of powdered coating material, and having an out-

let 42 at its lower end. Connected to the outlet 49 is a manually operable shutoff valve 43.

The outlet of the valve 43 is connected to the inlet end of a screw conveyor 44, turned by a suitable motor 45. The screw conveyor 44 is mounted on a plate 46 in upwardly inclined relation, so that the discharge end of the conveyor is substantially above the inlet end thereof. The upper or discharge end of the screw conveyor 44 opens into a downwardly extending duct 47, leading to a fluidizing chamber 48. This fluidizing chamber 48 may be of more or less conventional construction, having fluid inlet means therein whereby the powdered material flowing into the chamber is permeated with gaseous fluid and caused to assume a fluid-like condition. Advantageously, the fluidizing gas is fuel gas of the type used in the burner assembly 33, the fluidizing gas being brought into the chamber 48 through conduit means 49, 50 and through a valve 51. The lower end of the fluidizing chamber 48 is connected through suitable fittings 52 to the conduit 26 leading to and communicating with the powdered material discharge tube 25 of the burner assembly 33. A pressure equalizing conduit 55 is preferably provided from the fitting 52 on the bottom of the fluidizing chamber to the top of the reservoir 41.

When the feeder is in operation, the motor 45 is energized to rotate the screw conveyor 44 in a direction moving powdered material toward the upper end of the conveyor. The material, which is fed into the inlet end of the conveyor 44 moves through the conveyor 44 at a rate determined by the speed of the motor 45, and is carried through the fluidizing chamber 48 at a predetermined controllable rate. Speed of motor 45 is regulated by rheostat 45a which is representative of speed control means. The material reaching the fluidizing chamber 48 is permeated with gas, caused to assume a fluid-like condition, and then forced through the conduit 26 to the powder discharge tube 25 under the pressure of the fluidizing gas.

To avoid sticking of the powdered material in the reservoir 41, and to insure proper compacting of the material in the conveyor 44, a vibrator device 53 is attached to the conveyor 44 or to an adjacent part of the feeder, or both. The vibrator 53, which may be powered by pneumatic, mechanical, or other suitable means imparts a vibration to the feeder apparatus during operation, so that the flow of powdered material will take place in the desired manner. In this respect, it may be desirable to suspend a vibratory body (not shown) within the reservoir 41 and/or outlet 42 to avoid compacting and clogging up of the powdered material at this point.

The feeder apparatus may be mounted on the frame 34 or may be provided with legs 54 and set up at a position somewhat remote from the burner installation.

In an illustrative form of the invention, constructed substantially as hereinabove described, the burner chamber was one inch in diameter and eight inches long. The plate 16 was formed of a material such as copper or tellurium copper, and was approximately one inch in diameter and three-sixteenths inch thick. The center of the plate 16 was drilled to tightly receive the material feed pipe 25, in the form of a tube having a 1/4 inch outside diameter and a 1/16 inch wall thickness. At a radius of approximately 0.22" a plurality (10) of 0.073" diameter holes were drilled for the reception of the oxygen passage tubes 22. At a radius of approximately 0.34" a similar number of 0.063" diameter holes were drilled to form passages for fuel gas. These holes or openings, which are designated by the numeral 21 in FIGURE 3, are spaced uniformly around the plate 16 in predetermined relation to the inner circle of larger openings. At a radius of approximately 0.41" a plurality (10) of 0.073" diameter openings are drilled in a uniformly spaced relation about the disc and in symmetrical relation to the previously described opening. As shown in FIGURE 3, when the tubular elements 22 are received

in the large diameter openings 20 the passages provided for the flow of oxygen are about equal in diameter to the fuel gas passages 21. The oxygen passages are greater in number, however, since as a general rule the rate of flow of oxygen will substantially exceed that of the fuel gas.

A burner of this construction, using city gas (48% CH₄) or natural gas (93% CH₄), as a fuel gas, was operated by supplying fuel gas at a pressure of from about 5 to 50 p.s.i.g. with a corresponding flow of from about 300 to 1350 s.c.f.h. while oxygen was supplied at a pressure of from 10 to 50 p.s.i.g. with a corresponding flow of from 500 to 1500 s.c.f.h. The oxygen enters the burner chamber 14 through the plurality of elongated tubes 22, while the fuel gas enters directly through the small diameter opening 21 in the apertured plate 16. The streams of gas enter the chamber 14 at substantial velocity, and are thoroughly intermixed to promote proper combustion. During combustion, the pressure within the burner chamber 14 may be as much as 35 p.s.i.g.

The range of gas flows referred to above corresponds for the most part to commercially or readily available fuel gas pressures usually encountered. The actual useful operating range of the burner, of course, is not limited to these pressures or to such ranges of flows, but the burner may be employed at any desired higher flow rate where a suitable source is available. Burners constructed in the manner hereinabove described have been operated over the flow ranges indicated and at greatly higher flow rates with highly satisfactory stability. When a burner of the above construction is operated under conditions of 3,000 s.c.f.h. oxygen flow at 120 p.s.i.g. and 2,000 s.c.f.h. fuel gas flow at 80 p.s.i.g., the velocity of the oxygen entering the combustion chamber through the tubular elements 22 is in the order of 1,100 feet per second, while the velocity of the fuel gas was somewhat less. As the gases enter the combustion chamber, there is substantial turbulence and eddying immediately downstream of the plate 16 so that the plate acts as a flame holder as well as a manifold for separately admitting the fuel and oxygen gases.

In a further illustrative embodiment of the burner, the combustion chamber had a diameter of $\frac{1}{2}$ inch and a length of $\frac{7}{8}$ inch. The manifold plate having a $\frac{1}{2}$ inch diameter was $\frac{1}{8}$ inch thick. The feed pipe for delivery of a powdered coating material consisted of a tubing having an outside diameter of 0.085" and a wall thickness of 0.006". In an inner circle of a radius of approximately 0.11" was provided a series of six equally spaced openings of 0.0595" diameter in which the ends of oxygen tubes were tightly received as above described. In an intermediate circle of a radius of 0.164" were arranged a series of six equally spaced openings of 0.042" in diameter for fuel gas. An outer circle of a radius of 0.19" contained six openings of 0.0595" diameter for receiving further oxygen tubes. As in the previous burner, the oxygen tubes were such as to provide openings of substantially the same size as the fuel ports. The positions of the openings in the respective concentric circles were staggered with respect to one another.

Using natural gas (93% methane) this burner was operated at a fuel gas pressure range of 5-35 p.s.i.g. with a fuel gas flow of 100-375 s.c.f.h. Oxygen pressure was from 10-60 p.s.i.g. with oxygen flow rates of 200-400 s.c.f.h.

In a further embodiment, a burner such as the type herein described was provided with a combustion chamber $1\frac{1}{2}$ inches in diameter and $7\frac{1}{2}$ inches in length. The manifold end plate of $1\frac{1}{2}$ inch diameter was $\frac{5}{16}$ inch thick. The central pipe for the delivery of a coating material had an outside diameter of $\frac{1}{4}$ inch and a wall thickness of $\frac{1}{16}$ inch. An inner circle having a radius of 0.312" consisted of an arrangement of six equally spaced holes having a diameter of 0.096" for receiving the ends of oxygen delivery tubes. An intermediate circle having a

radius of approximately 0.375" consisted of six openings having a diameter of 0.071" for delivery of fuel gas. The outer circle having a radius of 0.562" consisted of twelve openings of 0.096" diameter for further oxygen delivery tubes. The series of openings in the respective circles are staggered in the same manner as in the burner described above and the openings of the oxygen tubes were substantially the same size as the fuel gas ports.

This $1\frac{1}{2}$ inch burner was operated using natural gas (93% methane) in the range of approximately 150-3,000 s.c.f.h. Oxygen flow rates were delivered in the range of about 300-10,000 s.c.f.h. These flow rates correspond to fuel gas pressures of from 5-80 p.s.i.g. and oxygen pressures of from 8-120 p.s.i.g.

Another construction embodying the features of the present invention was provided with a combustion chamber of 3 inch diameter and 16 inches in length. The manifold plate constructed in substantially the same manner described hereinabove was 3 inches in diameter and $\frac{3}{8}$ inch thick. A tube for the introduction of fluidized powdered material was centrally disposed in the plate and had an outside diameter of $\frac{1}{2}$ inch and a wall thickness of $\frac{1}{16}$ inch. Six holes having a diameter of 0.25" were arranged around an inner circle of a radius of 0.437" to receive the ends of oxygen delivery tubes. A middle circle having a radius of 0.750" consisted of a series of six equally spaced openings for fuel gas having a diameter of 0.312". Twelve equally spaced holes having a diameter of 0.375" were arranged around an outer circle having a radius of 1.125" for receiving ends of further oxygen delivery tubes. The openings were arranged substantially in a pattern employed in the previous burner. The openings of the oxygen tubes arranged in the inner circle were substantially of 0.1875" diameter and the openings of the tubes in the outer circle were substantially of 0.305" diameter.

This burner was operated using natural gas (93% methane) at flow rates in the range of 600-24,000 s.c.f.h. and using oxygen at flow rates of 1,000-50,000 s.c.f.h. The corresponding fuel pressures were within the range of 50-80 p.s.i.g. while the corresponding oxygen pressures were within the range of 8-120 p.s.i.g.

When combustion is taking place within the burner combustion chamber 14, the powdered material may be supplied to the interior of the chamber 14 through the conduit 26 and material feed tube 25. As the powdered material enters the combustion chamber it is picked up by the turbulent accelerating combustion gases, and the particles are passed through both the primary and the secondary combustion zones of the burner. The particles are thus heated to a high temperature and projected from the nozzle 10 at a very high velocity. If an article is placed in front of the burner opening, the coating particles will be impinged upon the surface thereof and caused to tightly adhere thereto to form a surface layer having characteristics determined by the nature of the resulting coating material.

By varying the pressure and rate of flow of the fuel gas and oxygen the burner combustion characteristics may be varied throughout a substantial range. Thus, by providing an excess of either oxygen or fuel gas, the environment of the combustion chamber may be of an oxidizing or reducing nature. This is sometimes desirable for the formation of special surface coatings. Moreover, burner conditions may be greatly varied to suit particular requirements by regulating the total flow of gases to the burner. Experience has shown that the new burner will operate in a satisfactory manner over a range of gas pressures starting at almost zero gauge pressure and extending to the blow-out pressure, or the pressure at which the gases enter the burner at a velocity greater than the rate of turbulent flame propagation.

Although it is contemplated that various forms of nozzles may be used in connection with the new burner apparatus, it is believed that a straight bore nozzle is

superior to other designs, when powdered materials are fed through the burner. The straight bore nozzle is advantageous in that there is little or no tendency for powder deposits to build up within the nozzle.

While the burner has been described at length with reference to the novel surface coating process, it is to be understood that it has many uses other than the coating process and need not be used in conjunction with powdered materials. A rocket type burner of this type provides an exceptionally versatile heat source of great stability. It is capable of use over a wide range of gas flows and gas mixture ratios. It is characterized by its ability to transfer large quantities of heat to a space or to a workpiece rapidly and reliably without danger of flame blow-away. It is also characterized by its ability to maintain a stable and useful flame at both the fuel rich and oxygen rich ends of the combustible range of gas mixtures. As a result it provides the solution to many heating problems. When used without the passage of powders therethrough the pattern and velocity of the exhausting products of combustion may be controlled by the use of varying nozzle shapes.

One of the most common uses for the new burner apparatus is in the coating of such materials as mild steel, drill rod, etc., with materials having different surface properties. The desired properties of the coating material for this purpose are that it be capable of bonding well to the base material, that it be resistant to thermal shock, resistant to oxidation at high temperatures, and substantially impervious. A composition having the best quality in the desired properties is a blend of chromium, nickel, aluminum and magnesium in the form of a mixture of metal powders. In the new composition, chromium is present in the range of from about 47 percent to 77 percent, nickel is present in the range of 20 to 32 percent, aluminum is present in the range of 6 to 10 percent, and magnesium is present in the range of from 3 to 5 percent. A highly satisfactory standard composition is a blend of 62 percent chromium, 26 percent nickel, 8 percent aluminum, 4 percent magnesium, and 1 percent finely powdered graphite. The graphite is added to make the powdered mixture flow more freely through the feeding apparatus and system.

It will be noted that the new mixture utilizes aluminum and magnesium in powdered form, rather than in oxide form. This is desirable for two reasons: first, it is likely that the molten droplets resulting from the melting of powdered particles in the flame exert a fluxing action on the surface of the base metal; second, these metals, when applied as heretofore described, are unaffected by thermal shock incidental to the coating operation but are later converted to refractory oxides upon exposure to oxidizing atmospheres at elevated temperatures. Thus, a refractory type coating of desirable characteristics may be produced when the coated article is placed in service.

By way of example of the effectiveness of the new coating composition applied in accordance with the method of the invention, a number of mild steel specimens were provided with a partial coating of 0.003-0.009" in thickness. The specimens were then heated in air to a temperature of 2000° F. for several hours. After removal from the heating chamber, the specimens showed substantial oxidation on uncoated portions, while the coated portions appeared substantially unoxidized, and revealed no change in dimension. One specimen was exposed to air at 2000° F. for a total of 24 hours, during which the uncoated portion of the specimen was reduced to approximately one-half its original size, while measurement of the coated portion indicated no change in dimension. Other specimens were exposed to moving air at 1800° F. for 500 hours with equally good resistance to oxidation. The resistance to thermal shock of the new coating was demonstrated by quenching the specimens immediately after spraying, and while still red-hot, in a stream of cold water. Upon subjection to such

treatment, the new coating remained intact and did not spall or chip.

The new coating method may be carried out quickly and efficiently and with equipment of a relatively simplified nature. For example, with the apparatus heretofore described, approximately 10 square inches of surface can be coated with a layer 0.010" thick, in approximately one minute. No remelting or post-heating for fusion is required, since the coating particles are propelled from the burner in a continuous stream of combustion products and the object being coated is heated sufficiently to cause fusion of the coating material during the coating process.

One of the outstanding advantages of the new coating method resides in the control which may be exercised over the residence time and velocity of the coating particles. Thus, a large variation in the residence time of the powder particles in the combustion chamber may be achieved by varying the gas flows and/or changing the length of the main combustion flames. Both of these factors may be adjusted for control of particle temperature, the temperature gradient within each particle and the particle size. Particle impingement velocity may also be varied by changing the gas flow or combustion chamber characteristics to increase or decrease the combustion chamber operating pressure.

One example of how this exclusive property of the present coating system may be advantageously employed is in the surface coating of molybdenum. Because of the rapid oxidation of molybdenum at elevated temperatures and the evaporation of the volatile oxide thus formed, as well as the fact that at about 1800° F. recrystallization of the base metal takes place it is obvious that ordinary coating techniques are not satisfactory. In accordance with the present invention the oxygen-fuel gas ratio may be adjusted to a low, fuel rich value of the order of 1 to 3, oxygen to fuel gas. With the burner operating in this manner the specimen is protected against oxidation and excessive elevation of the temperature while a coating of metallic aluminum is applied with aluminum powder. The aluminum coating is preferably applied with a coating thickness of from 0.002 inch to 0.005 inch. Following this an overlay of metallic chromium and aluminum consisting of 75% chromium and 25% aluminum may be applied having a thickness of from about 0.006 inch to 0.010 inch, giving a total coating thickness in the range of from about 0.008 inch to about 0.015 inch. Such a coating exhibits good adherence and corrosion resisting properties because the aluminum forms a good bond by diffusion of molybdenum through the interface at elevated temperature and because the chromium combines with the molybdenum during the diffusion process to form a stable molybdate which, it is believed, constitutes an effective protective component of the complex coating structure resulting from exposure of this system to oxidizing conditions, at high temperature. By using a molybdenum alloy containing 0.5% titanium as the base material the recrystallization temperature is elevated to about 2400° F., 600° F. above that of the pure metal. The aforementioned coating process can be carried out at workpiece temperatures below 1800° F. in accordance with the present invention.

The new method permits of the effective use of powdered coating materials, rather than wire or stick form materials. This has been impractical heretofore as the difficulty in controlling the particle temperature, particle velocity, etc. The new rocket type burner technique permits of coordinated control over all phases of the coating operation, so that powdered coating materials may be conveniently employed. It will be understood, however, that wire or rod materials may be used if desired by feeding them into the burner in the primary combustion zone in much the same manner as the powder.

In accordance with the invention, the new coating method hereinabove described is advantageously carried out

by employing the novel improved burner device hereinabove described which possesses a number of important design features particularly adaptable to the coating process. Thus, for example, the burner is characterized by a high degree of stability; the powdered coating material is delivered in the form of a fluidized stream at a controlled rate to the combustion chamber, whereby an extremely effective control of heating and propelling of these particles is obtained; and the material is carried through both the primary and combustion zones of the turbulently mixed gases. Further, by warrant of introduction of the powdered coating material through the inner end wall of the combustion chamber rather than the side wall thereof, a more advantageous operation is obtained; the build-up of deposits on otherwise present irregularities in the wall of the chamber is avoided; and burner maintenance is reduced.

Although it is to be understood that the new method and apparatus may be employed in the application of coatings of various types, it has been found that a certain composition or mixture of materials has outstanding advantages for use as a coating material in the new method. The new composition is a mixture of chromium, nickel, aluminum, and magnesium. These elements are combined in the percentages heretofore stated to produce a composition which, when applied to mild steel, for example, provides a coating of considerable hardness (Rockwell "C" 13), exhibits good wear resistant properties, is resistant to thermal shock, and is effective in preventing oxidation of the base material at high temperatures.

Since many of the specific features heretofore described may be altered without departing from the clear teachings of the invention, the foregoing should be considered illustrative only, and reference should be made to the following appended claims in determining the full scope of the invention.

This application is a continuation-in-part of our copending application Serial No. 612,203, filed September 26, 1956, and now abandoned.

What is claimed is:

1. A gas burner comprising an elongated combustion chamber open at one end and terminating at a terminal surface at an end opposite said one end, a plate closing the chamber at said end opposite said one end, said plate having a face forming said terminal surface of the chamber at said opposite end, said plate having a first group of separate passages therethrough for introducing streams of combustion supporting gas into the chamber, said plate having a second group of separate passages therethrough for introducing streams of fuel gas into the chamber, the separate passages of each group being spaced from one another and, from the passages of the other groups, all of said passages having their axes substantially parallel so that eddies from the streams flow into the space between the streams, to provide a combustible gas mixture forming stabilizing or anchoring flames and the streams issuing from the passages merge into one another gradually as they travel away from the plate and toward the open end of the chamber, separate means for supplying said combustion supporting gas, and additional separate means for supplying fuel gas under pressure to the respective groups of passages.

2. The gas burner described in claim 1 in which said combustion supporting gas is oxygen and in which the combustion chamber is cylindrical and has a wall that extends from said face of the plate to seal the streams of gas against aspiration of gas or air from beyond the perimeter of the plate, and the chamber has a ratio of length to diameter greater than one to one.

3. The burner described in claim 2 and in which the length of the combustion chamber is correlated with the spacing of the oxygen and fuel gas passages so as to obtain turbulent mixing of the gas streams throughout the cross-section of the chamber at any velocity of the gas streams.

4. The burner described in claim 3 and in which there are means for controlling the pressure and rate of flow of the oxygen, and other means for controlling the pressure and rate of flow of the fuel gas independently of the pressure and rate of flow of the oxygen.

5. The gas burner described in claim 2 and in which the passages for the oxygen are next to passages for the fuel gas at a number of different regions distributed across the area of the plate to provide a plurality of spaces where eddy currents of the oxygen and fuel gas streams mix and burn as low-velocity stabilizing flames behind a main combustion flame of the burner located toward the open end of the burner where the oxygen and fuel gas streams have merged and mixed.

6. The gas burner described in claim 5 and in which the passages of each group are substantially symmetrical about the longitudinal axis of the combustion chamber, and individual oxygen passages alternate with individual fuel gas passages in their location around said axes.

7. The burner described in claim 6 and in which the oxygen passages are at angularly-spaced locations around a circle, and the fuel gas passages are at angularly-spaced locations around another circle.

8. A method of producing a stable flame within an elongated combustion chamber terminating at one end at a terminal surface substantially in a single plane formed by a face of an apertured plate, which comprises admitting fuel gas to said chamber through said apertured plate as a first plurality of substantially uniformly distributed high velocity fuel gas jets substantially parallel to the axis of said combustion chamber and admitting combustion supporting gas to said chamber through said apertured plate as a second separate plurality of high velocity combustion supporting gas jets substantially parallel to the axis of said combustion chamber, dispersed substantially uniformly among said fuel gas jets and spaced therefrom by an amount to create therebetween a plurality of stable low pressure mixed gas zones which, when ignited, act as stable ignition sources for the mixed gases in the turbulent higher pressure main combustion zone formed within said combustion chamber downstream of said sources of ignition.

9. The method of producing a stable flame within an elongated combustion chamber closed at one end by an apertured plate, which method comprises admitting fuel gas to said chamber through said apertured plate as a first plurality of substantially uniformly distributed high-velocity fuel gas jets substantially parallel to the axis of said combustion chamber and admitting combustion-supporting gas to said chamber through said apertured plate as a second separate plurality of high-velocity combustion-supporting gas jets substantially parallel to the axis of said combustion chamber, dispersed substantially uniformly among said fuel gas jets and spaced therefrom by an amount to create and maintain therebetween, at a region substantially immediately adjacent said closed end of said chamber and substantially independently of the rates of flow of said fuel gas jets and said combustion-supporting gas jets, a plurality of stable low-pressure mixed gas zones wherein the combustion of mixed gases occurs adjacent to the unburned, high-velocity gas jets admitted through said closed end of said chamber and acts as a stable ignition source for the high-velocity gas jets in a turbulent relatively high-pressure main combustion zone formed within said combustion chamber downstream from said sources of ignition over a range of flow of said high-velocity gas jets exceeding the normal mixed gas flame propagation rate thereof.

10. An internal combustion burner comprising an elongated combustion chamber open at one end and closed at the other end by an apertured plate, means for admitting fuel gas to said combustion chamber through certain of said apertures uniformly distributed about the surface of said plate to form within the combustion chamber a plurality of fuel gas jets substantially parallel to the axis

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of said chamber, and means for admitting combustion supporting gas to said combustion chamber through the remainder of said apertures to form within the combustion chamber a plurality of combustion supporting gas jets substantially parallel to the axis of said chamber whereby said fuel gas and combustion supporting gas form a flame stabilized combustible gas mixture within said combustion chamber, said chamber comprising an elongated, tubular member of heat-conductive material, said tubular member having flange-forming means at one end, and including a second tubular member surrounding said first tubular member in co-axial relation and defining therewith an annular chamber for cooling liquid, said second tubular member extending toward said flange-forming means and terminating in space relation thereto, and a sleeve received about said flange-forming means and second tubular member and forming a seal therebetween, said sleeve adapted for limited sliding movement with respect to at least one of said last-mentioned parts to accommodate unequal expansion and contraction thereof.

11. In the gas burner described in claim 2, means for introducing a substantially continuous supply of projectable material into said chamber adjacent to the closed end of said chamber.

12. A method of producing a surface coating on an object which comprises admitting fuel gas into the interior of an elongated burner chamber, said chamber terminating at one end at a terminal surface formed by a face of an apertured plate, said fuel gas admitted to said chamber through said apertured plate as a first plurality of substantially uniformly distributed high velocity fuel gas jets substantially parallel to the axis of said combustion chamber, admitting combustion supporting gas to said chamber through said apertured plate as a second separate plurality of high velocity combustion supporting gas jets substantially parallel to the axis of said combustion chamber, dispersed substantially uniformly among said fuel gas jets and spaced therefrom by an amount

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to create therebetween a plurality of stable low pressure mixed gas zones which, when ignited, act as stable ignition sources for the mixed gases in the turbulent higher pressure main combustion zone formed within said combustion chamber downstream of said sources of ignition, maintaining substantially continuous combustion of said fuel gas in said main combustion zone of said chamber whereby to provide high temperature products of combustion flowing at high velocity from said chamber, introducing coating material into said burner chamber adjacent to the closed end of said chamber to be heated and carried from said chamber by said products of combustion, and directing the flow of coating material and products of combustion onto a surface of said object.

13. A method of producing a stable flame within an elongated combustion chamber terminating at one end by an apertured plate as set forth in claim 8, further comprising cooling said chamber with a coolant contained in a jacket surrounding at least part of said elongated combustion chamber.

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