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G. H. SMITH ET AL

2,920,001

JET FLAME SPRAYING METHOD AND APPARATUS

Filed July 11, 1955

3 Sheets-Sheet 1

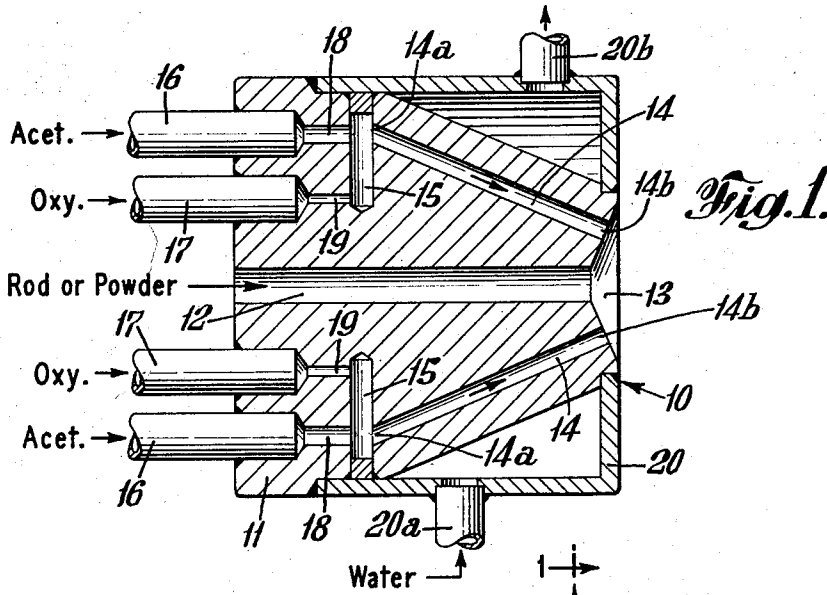


Fig. 2.

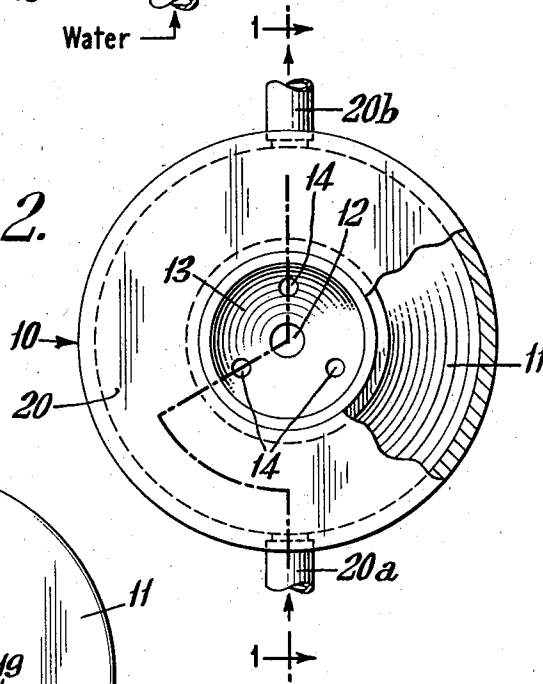
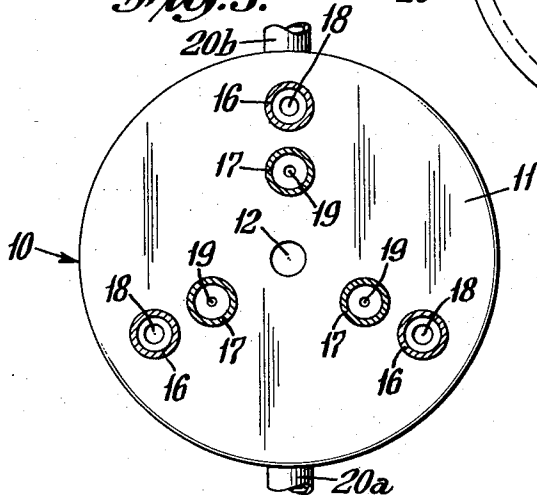


Fig. 3.



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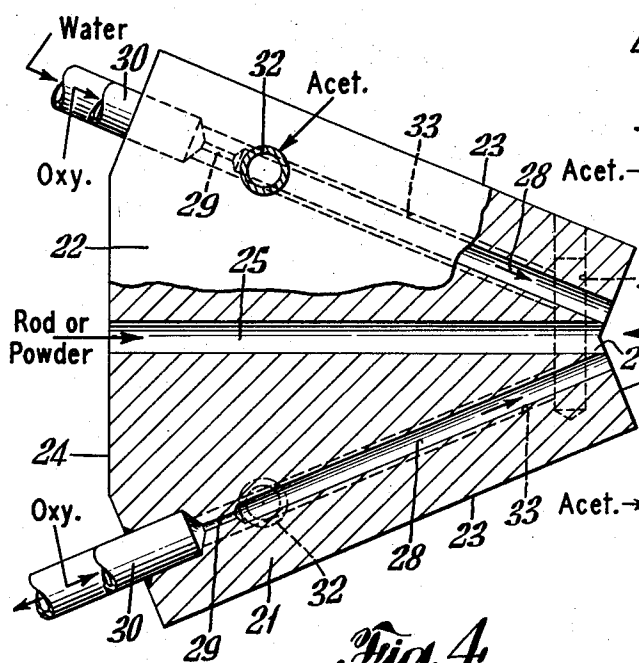
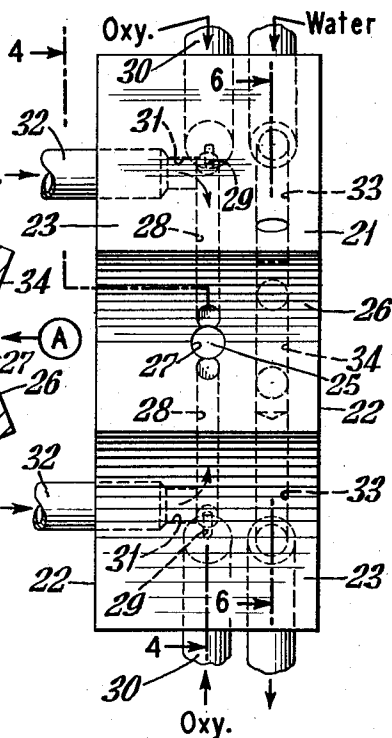
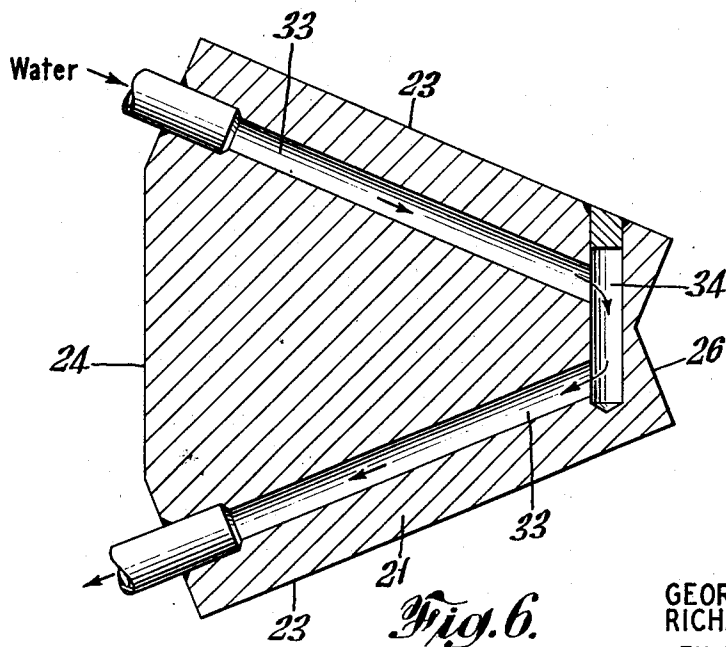
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3 Sheets-Sheet 2

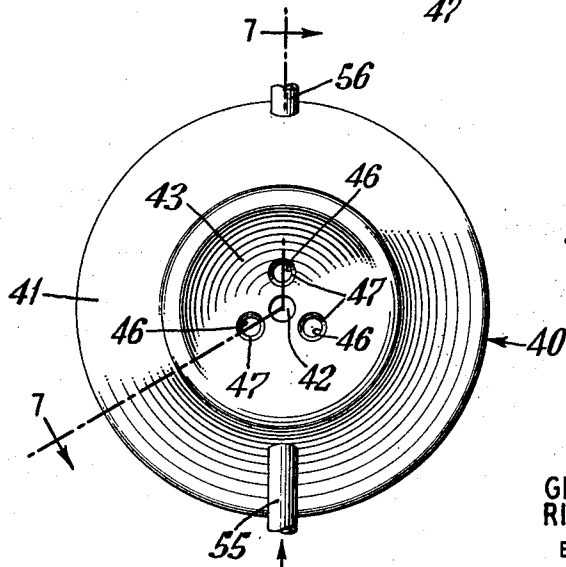


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JET FLAME SPRAYING METHOD AND APPARATUS

3 Sheets-Sheet 3



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JET FLAME SPRAYING METHOD AND APPARATUS

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13 Claims. (Cl. 117-21)

The present invention concerns the application of improved surface coatings to objects and particularly relates to new and improved methods of and apparatus for flame spraying, which are especially advantageous for applying surface coatings of low porosity to articles.

For some time now, it has been common practice to provide an object with a protective coating by spraying the object with an atomized and melted material that would adhere to a pre-cleaned surface of the object. Surface spraying has been accomplished by introducing the coating material, usually in the form of a rod or powder, into the flame of a gas torch in order to melt the material and by thereafter projecting the melted material against the surface to be coated by a blast of air or inert gas. Heretofore, such spraying has been limited in the main to the application of coatings of low melting point metals, and these coatings leave much to be desired in porosity and adherence characteristics.

One of the difficulties experienced with prior practices was the failure to keep the coating particles at sufficiently high temperatures prior to and at the time of deposition. The air or gas blast required to project the particles onto the surface to be coated had a pronounced cooling effect on the heated particles and, if air was used, also had an undesirable oxidizing effect. This resulted in a return of the melted particles to a less plastic and even solid state prior to deposition on the workpiece. Moreover, the gas velocities available in spray guns of the prior art are insufficient to impart to the coating particles the high velocities needed for producing a firm adherence and a non-porous layer on the workpiece surface. Because of these drawbacks, it was exceedingly difficult to flame spray coating materials of high melting points and also to obtain a substantially non-porous coating with low melting point materials. Moreover, in order to achieve a satisfactory bond with low velocity flame spraying processes, it was generally necessary to prepare the surface to be coated specially as by rough machining.

The general purpose of the present invention is to provide an apparatus for and method of spraying coating material on a workpiece surface at such temperatures and with such velocity that the coating particles will flow and bond together and to the workpiece in such manner that a substantially non-porous layer having high strength characteristics will be formed.

A more particular object of the invention is to provide a flame-spraying gun which is capable of applying surface coatings of relatively low porosity, and which is preferable in many cases to known spraying guns in both simplicity and compactness in construction and in improved operating characteristics.

Still another object of this invention is to make practical the use of lower grade fuels in flame spraying.

According to the present invention, there is provided

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a method of flame spraying a surface coating on objects, which includes advancing a body of solid coating material along a selected path, providing at least one hot continuous flame jet having a substantially constant linear velocity greater than 2000 feet per second intersecting said path at a predetermined point therealong for separating and heating particles from said body, and directing said flame jet in the direction of the object to be coated so as to propel heated particles onto such object at high linear velocity. In the preferred practice of this invention, there are provided a plurality of continuous flame jets which converge and intersect the path of movement of the body of coating material at a focal point therealong.

The steady, hot and high velocity flame stream formed by the converging flame jets not only imparts a high thermal energy to the coating particles but also concomitantly imparts high constant thrust to the particles without diminishing its thermal energy. The applied thrust accelerates the particles and propels them toward the workpiece at high velocity and with high kinetic energy which, upon impact, is converted to thermal energy, thereby raising substantially the thermal energy level of the particles at a critical time. Moreover, with proper control of the nature of the fuel and oxygen-fuel ratio, a protective atmosphere can be provided by the flame for the particles carried therein; this reduces objectionable oxidation and decarburization.

According to an important feature of this invention, the high velocity and temperature of the flame jet required for carrying out the principles of this invention are achieved by the provision of a novel spray gun having means for delivering a body of solid coating material along a predetermined path and at least one internal combustion chamber into which a continuous stream of a fluid combustible mixture is introduced and ignited and from which a flame jet of burning gases having a linear velocity greater than 2000 feet per second is discharged through a passage extending at such an angle to such path that the flame jet intersects the path immediately after discharge from the gun so as to heat, separate and propel particles from such body of material toward the surface to be coated.

The body of coating material may be constituted, for example, by either a rod or a powder made up of finely divided solid coating material. The invention preferably utilizes an embodiment of a "throat combustion" chamber disclosed in a copending application Serial No. 212,547, filed February 24, 1951, by G. H. Smith. For purposes of this invention, a "throat combustion" burner may be defined as a throat element constituted by a confined space unobstructed from inlet to outlet wherein a fluid combustible mixture received through such inlet at one end of the confined space is ignited within the passageway, passed through the confined space and then discharged from the confined space through such outlet at the other end of the confined space as a stream of hot burning gases to produce a flame jet having a high heat transfer intensity, a high velocity and substantial thrust. However, other internal combustion chambers producing a high velocity flame, one of the order of 2000 feet per second or more, may also be used. For example, a chamber having an enclosed combustion space from which burning gases are discharged through a jet nozzle can be used to carry out the principles of the present invention. For best results, it is advantageous to employ two or more flame jets, preferably three, which intersect in the zone of discharge from the chamber at a focal

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point along the path of movement of the body of coating material. It should also be understood that a single annular flame jet directed convergently toward the path of the body is a practical form for the practice of this invention.

The high temperatures to which the particles can be raised by being heated and entrained in the flame jet or jets and the appreciable temperature increase corresponding to kinetic energy expended upon impact of the high velocity particles upon the surface of the work to be coated make it possible to melt even high melting point materials (or at least the lowest melting point constituent of such materials) sufficiently to insure a firm mechanical bond with the surface of the body to be coated. The high velocity imparted to the particles at these temperatures causes them to deform sufficiently upon impact to weld to other particles in the coating so as to form a substantially non-porous coating. Moreover, the protective atmosphere afforded the particles by the flame jet in which they are carried to the workpiece minimizes oxidation and permits control of decarburization characteristics, a factor which influences the quality of the coatings when certain coating materials are being used.

These and other features, objects and advantages of this invention will become apparent from the following detailed description of the accompanying drawings, wherein:

Figure 1 shows a longitudinal section of a spray gun adapted for the practice of this invention, taken along line 1—1 of Figure 2;

Figure 2 is an end elevation, partly broken away, showing the discharge end of the spray gun of Figure 1;

Figure 3 is an end elevation showing the back end of the same gun;

Figure 4 is a vertical longitudinal section of a modified form of spray gun within the invention, taken along line 4—4 of Figure 5;

Figure 5 is an end elevation as seen looking in the direction of arrow A and showing in dashed lines internal passages;

Figure 6 is a vertical longitudinal section of the same gun, taken along line 6—6 of Figure 5;

Figure 7 is a longitudinal section of still another embodiment of a gun within this invention, taken along line 7—7 of Figure 8; and

Figure 8 is an end elevation looking at the discharge end of the spray gun shown in Figure 7.

The method of this invention will now be described in detail in connection with three illustrative embodiments of spray guns adapted for the practice of this invention.

With reference now to Figures 1—3, the spray gun, indicated generally at 10, comprises a solid body 11, preferably made of copper, having an outer surface that tapers toward the discharge end forward of the gun from a right cylindrical section remote from the discharge end. Body 11 has an axial bore 12 extending longitudinally therein for passage of solid coating material and a recessed front face 13 at the tapered end thereof which is constituted by a conically concave surface symmetrically surrounding the bore 12. Coating material may be delivered to the discharge end of the gun through bore 12 either in the form of a rod or a powder. The body 11 is also formed with three longitudinally extending bores 14 which are arranged circumferentially about axial bore 12 and each spaced 120° relative to one another. Bores 14 serve as elongated throat elements of internal combustion throat burners of the kind disclosed in the copending Smith application, supra. Fuel and oxygen are supplied to the rear inlet ends 14a of the bores 14 through closed radial bores 15, which cross the respective bores 14 at their rear ends and are connected with fuel and oxygen supply conduits 16 and 17 through drilled orifices 18 and 19, respectively. The bores or throat elements 14 extend forwardly and inwardly from their rear

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inlet ends 14a and terminate in outlets 14b which open into the sloped surface of recess 13 at the discharge end of the gun body and through which burning gases are discharged in high velocity flame jets. The axes of the bores or throat elements 14 are so inclined to the axis of the axial bore 12 that they intersect the latter axis at a point slightly in front of the burner.

For satisfactory results it is essential that conditions during combustion be maintained such that K is between 75 and 750 in the equation:

$$K = \frac{A_i^2 P_i^2}{A_o P_o W}$$

wherein:

A_i = cross-sectional area of said stream of fluid combustible material at the point of introduction thereof to said confined space, in square inches.

A_o = cross-sectional area of said stream of burning combustible material at the point of discharge from said confined space, in square inches.

P_i = pressure at the point of introduction of said stream of fluid combustible material into said confined space, in pounds per square inch absolute.

P_o = pressure at the point of discharge of said stream of burning combustible material from said confined space, in pounds per square inch absolute.

W = weight of fluid combustible material consumed, in pounds per second.

It will be understood that the combustible mixture is first ignited outside of the nozzle, and flashback of the flame into the combustion chamber 14 is obtained by proper control of the fuel and oxygen supply pressures. In order to secure such flashback, the minimum diameter of the throat outlet 14b should not be substantially smaller than 0.02 inch.

Fuel, such as acetylene, is supplied through lines 16 at high pressure, preferably greater than 15 pounds per square inch gauge, to throat chambers 14 via orifices 18 and radial bores 15. A combustion supporting agent is delivered at a pressure at least as high as the fuel pressure to throat combustion chambers 14 through orifices 19 and radial bores 15. The fuel and oxygen mix intimately in passing into the entrances of the throat combustion chambers 14 and burn almost immediately upon mixing. The burning gases pass through bores 14 and are discharged in flame jets directed forwardly and inwardly toward the axis of the coating material supply passage 12. The velocity of the gases rapidly increases as they approach the outlet 14b.

Coating material, either in the form of a rod or in a spray of finely divided powder, is fed into the axial passage 12 of the burner for delivery at the forward end of the gun into the intersecting jet flames emanating from bores 14. If the material is in rod form, any suitable positive driving means may be used to move the rod through passage 12. For example, a pair of power driven oppositely rotating rollers engaging opposite sides of the rod may be employed for this purpose. If the material is in powder form, the powder may be (1) fed into passage 12 and drawn through by the aspirating action of the jets, (2) entrained in a stream of a carrier gas, such as hydrogen, for example, or (3) preferably sintered or cemented together into a coherent mass. In the latter preferred method, the coating particles are held momentarily in the jet before being accelerated; this gives higher particle temperatures which result in better binding of the coating. A thermally decomposable cement can be conveniently used for cementing the particles together.

As the material moves into the flame, its temperature is raised to at least the fusion temperature of the lowest melting point component thereof, and it is propelled forward toward a coating surface by the thrust imparted to it by the high velocity flames. It will be seen that from the moment the coating material enters the zone

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of high temperature until it impinges upon the workpiece surface, it is entrained in the protective atmosphere of the flames.

In order to protect the gun body 11 against overheating, an annular water jacket 20 is provided around the forward portion of the body 11 and has an inlet 20a and an outlet 20b for receiving and discharging cooling fluid to be circulated through the jacket.

Figures 4, 5 and 6 illustrate an embodiment of the invention similar in many respects to that shown in Figures 1 to 3. Here, a generally wedge-shaped gun body 21, including two opposing parallel, triangular-like longitudinal sides 22, two opposing rectangular longitudinal sides 23 extending between the tapered edges of sides 22 and a back side 24, has a centrally disposed bore 25 extending longitudinally therethrough for the free passage of solid coating material. The gun body 21 also has a V-shaped recess 26 at its front tapered end into which bore 25 opens centrally, as at 27, and two longitudinally extending bores 28 that are disposed symmetrically on opposite sides of bore 25 in the plane thereof that lies parallel to sides 22.

Bores 28 serve as throat combustion chambers in the same manner as those described in Figure 1. Oxygen is supplied to bores 28 through drilled orifices 29 opening into the back ends of bores 28 and having connection with an oxygen supply line 30. Fuel is supplied to bores 28 through laterally extending drilled orifices 31 that open into the back end of bores 28 adjacent orifices 29 and that are connected with fuel supply lines 32.

In this embodiment wherein only two throat burners are employed, the bores 28 constituting the combustion-throat elements are so inclined to the axis of the material delivery bore 25 that they intersect the forward part of passage 25 at the front end of the gun body. In this way the flame jets issuing from the burners enter the body of coating material emanating from passage 25 as they converge to a point of intersection located on the axis of passage 25.

In this embodiment cooling fluid is circulated through the gun body 21 in bores 33 extending longitudinally alongside the bores 28 which serve as combustion throat elements. Bores 33 open exteriorly at the back side 24 and extend to a point near the front end of the gun body. There they are interconnected by a plugged cross bore 34 so that water may be introduced into the gun body 21 through one bore 33 and discharged out of the body through the other bore 33.

In the modification shown in Figures 7 and 8, the spray gun 40 comprises a substantially frusto-conically shaped body 41 having an axial bore 42 therein for free passage of solid coating material and a recessed front face 43 at the tapered end thereof which consists of a surface symmetrically surrounding bore 42 and sloping angularly outwardly from the bore axis. As in the other embodiments, the coating material may be passed through bore 42 either in the form of a rod or finely divided material. Body 41 is also provided with three longitudinally extending combustion chambers 44 arranged circumferentially about bore 42 and spaced angularly 120° relative to one another. Chambers 44 are provided rearwardly with a restricted central injector throat 45 which forms an entrance to the combustion chamber 44, whose walls extend forwardly and converge inwardly at a forward part of body 41 to a throat 46 of a divergent discharge nozzle 47 opening into the surface of the front end face 43.

The injector throat 45 is formed in an injector member 48 which is threadedly received into the rear open end of combustion chamber 44 and has at its end remote from the combustion chamber a bore 49 having a tapped cylindrical portion into which an adapter 50 is threaded and a forward conical portion, the walls of which slope convergently toward the injector throat 45. Fluid fuel is delivered at a high pressure, preferably greater than 15 pounds per square inch gauge, to the combustion chamber 44 through an eccentrically arranged supply duct 53 in

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adapter 50, the forward portion of bore 49 and throat 45. A combustion supporting agent is concomitantly but separately delivered at a pressure at least as high as the fuel pressure through throat 45 into combustion chamber 44 by a nozzle 51 which is threaded into a supply duct 52 in adapter 50 and which projects into the forward portion of bore 49 in axial alignment with throat 45.

The fuel and oxygen are supplied continuously and mix intimately together in passing through the throat 45, and the mixture burns vigorously in chamber 44, producing large volumes of flaming combustion gases which are discharged at high velocity, in excess of 2000 feet per second, through nozzle 47 in a directed jet flame. The combustion chambers 44 are so angularly inclined to the bore 42 that their axes converge and intersect the axis of the bore at a point slightly forward of the discharge end of bore 42. In this way the hot flames jointly transmit a high degree of heat to the coating material and a forward thrust which propels the heated material forwardly toward a surface to be coated.

The gun body 41 is cooled by a cooling fluid that is circulated through an annular water jacket 54 formed around the group of combustion chambers within the periphery of body 41. Jacket 54 has an inlet 55 adjacent the discharge end of the gun and an outlet 56 at a rearward portion of the gun.

It will be seen that each of the above-described guns can provide flame jets having the high velocities and high temperatures required by the method of this invention to separate and propel coating particles from a body of coating material onto a surface to be coated at velocities and temperatures needed for producing a non-porous, well-bonded coating. The temperature of the flame jets, as well as its composition, can be controlled by the nature of the fuel and the oxygen-fuel ratio. It is desirable to employ fuels with high flame temperatures and, where practical, to use oxygen-fuel ratios that produce maximum flame temperatures. However, the oxidation potential of the burning gases' atmosphere is an important factor in both the selection of the fuel and the oxygen-fuel ratio, for in the use of many coating materials, it has a decisive effect on the composition and quality of the coating. Acetylene, which has particularly high flame temperatures at fuel-oxygen ratios producing desirable flame composition, has been found to be especially suitable for the practice of the present invention. However, other fuels which can meet the temperature and composition requirements are also suitable. Oxygen, as used herein, is intended to include air, oxygen-enriched air and high purity oxygen. However, when plating higher melting point materials, the higher purity oxygen is preferred because of the higher flame temperatures obtained with its use.

The particle velocity obtained in a spray gun of the nature described is roughly proportional to the velocity of the flame jet. Since the supply pressure is the primary determinant of the velocity of the burning gases, the pressure which can be used becomes an important factor in selection of a fuel. The higher the supply pressure capable of being used with a particular fuel, the higher the attainable flame velocity. It has been found that a fuel supply pressure of about at least 15 pounds per square inch gauge is required to produce the high gas velocities needed for the practice of the present invention. Higher particle velocities effectively add thermal energy to the particle. This results from the increased temperature rise upon release of kinetic energy on impact of the coating particles against the workpiece surface. Thus fuel permitting higher supply pressures and high gas velocities may have lower flame temperatures and yet still be practical in the practice of the flame plating method of this invention. The hardness and porosity of the coating are dependent to a considerable extent upon particle velocity.

The advantages of high particle velocity and high particle temperature made available by the present invention are apparent whenever a non-porous, well-bonded coating

is desired. These benefits are not limited to any particular coating material. Although the invention is especially suitable for coating with materials of high melting points, it is also adapted for coating surfaces with any of a wide variety of metals, alloys, metallic compounds, plastics, ceramics and minerals. Materials sprayed by this invention include copper, aluminum, zinc, tin, steel, Inconel, chromium, and a cobalt-chromium-tungsten composition. Base surfaces, which may be pre-cleaned in any suitable manner but do not require the rough machining of prior art processes, may also be of a wide variety of materials. Materials coated included graphite, wood, paper, glass, sapphire and many metals.

The advantages of continuous flame jets are also apparent in flame plating, for it makes it possible to impart substantially constant thrust and constant thermal energy to the coating particles. In this way it is much easier to achieve uniformity over the entire coating.

It will be understood that the new features of process operation and gun construction herein disclosed may be employed in ways and forms different from those of the preferred embodiments described above, without departing from the spirit and scope of the invention, as defined in the appended claims.

What is claimed is:

1. A method of applying a surface coating to an object which comprises conducting solid coating material to a predetermined point along a fixed path, continuously blowing at least one steady, relatively constant velocity, hot flame jet having a linear velocity greater than 2000 feet per second into said path in the zone of said predetermined point to take up and heat particles of solid coating material, and directing the flame jet toward the object to be coated so as to propel heated particles entrained by said jet onto the surface of such object at high linear velocity.

2. A method as described in claim 1, wherein the solid coating material is in the form of a rod.

3. A method as described in claim 1, wherein the solid coating material is in the form of a stream of comminuted solids.

4. A method of applying a surface coating to an object, which comprises: conducting solid coating material to a predetermined point along a fixed path, blowing a plurality of continuous hot flame jets convergently toward a focus in said path in the zone of said predetermined point to take up and heat particles of solid coating material and to form substantially a single jet stream to be directed toward a surface of the object to be coated, and maintaining the velocity of the flame jets greater than 2000 feet per second for propelling the particles entrained in said jet stream onto such surface at high linear velocity.

5. A method of applying a surface coating to an object, which comprises: blowing a plurality of continuous streams of hot combustion gases each having a linear velocity greater than 2000 feet per second in one general direction toward a surface of an object to be coated, directing the streams convergently toward a predetermined focal point to form substantially a single stream to be directed toward the surface to be coated, and conducting a body of solid coating material to the zone of said focal point whereby said gases take up and heat particles of solid coating material and propel them onto such surface to deposit there and build up a coating thereon.

6. A spray gun for applying solid coating material to a surface, which comprises a gun body having a forward discharge end, a plurality of high discharge velocity type internal combustion chambers in said body each having inlet means for receiving a combustible mixture and outlet means for discharging burning gases in a flame jet, said outlets being oriented to direct the flame jets toward a point of convergency just forward of said discharge end, and means for feeding solid coating material into the jet flame in the zone of said point of convergency.

7. A spray gun for applying a solid coating material to a surface of an object, which comprises a gun body having a central passage extending longitudinally therein for delivering solid coating material to a discharge end forward of the gun body, a plurality of longitudinally extending passages arranged circumferentially about said central passage and spaced equi-angularly relative to one another, each of said circumferentially arranged passages having an inlet for receiving a combustible mixture and an outlet for discharging burning gases and being formed therebetween as a throat combustion chamber having an unconstricted cross-sectional area from inlet to outlet, said throat combustion chambers extending forwardly and inwardly toward said discharge end of the gun body so that the flame jets issuing forwardly from the chamber outlets converge toward a focal point forward of the front end of said central passage and on the axis of said central passage, thereby taking up particles of material delivered through such passage, and heating and propelling such particles forward to a surface of an object to be coated.

8. A spray gun for applying a solid coating material to a surface of an object, which comprises a gun body having a central passage extending longitudinally therein for delivering solid coating material to a discharge end forward of the gun body, a plurality of longitudinally extending reaction combustion chambers arranged circumferentially about said passage and spaced equi-angularly relative to one another, each of said chambers having an inlet for a fluid combustible mixture and a jet nozzle opening at said discharge end for discharging burning gases from the chamber in a flame jet, the axes of said nozzles converging forwardly and intersecting the axis of the central passage at a point forward of the front end of the central passage so as to take up particles of material delivered through such passage and to heat and propel such particles forward to a surface of an object to be coated.

9. A spray gun for applying a solid coating to an object, which comprises a solid body having a central bore therein for free passage of solid coating material and a forward surface symmetrically surrounding said bore including a recessed portion at said bore having a surface sloping angularly to the axis of the bore, said body also having a plurality of longitudinally extending bored passages arranged circumferentially about said central bore and equi-angularly relative to one another, each of said bored passages having an inlet remote from the forward surface for receiving a combustible mixture and an outlet opening into a sloping surface of said recessed portion in close relation to the axial passage for discharging burning gases, each of said bores being formed between such inlet and outlet as a throat combustion chamber unconstricted from inlet to outlet, said bored passages extending forwardly and convergently toward a focal point forward of the front end of said central bore so that flame jets issuing from said bored passages take up particles of material delivered through the central passage for heating and propelling them forward to a surface of the object to be coated.

10. A spray gun as defined in claim 9 wherein there are two longitudinally bored passages, said recessed portion being substantially V-shaped and said outlets opening oppositely to each other in opposing surfaces of said recessed portion.

11. A spray gun as defined in claim 9 wherein there are more than two longitudinally bored passages, said recessed portion being substantially concave.

12. A spray gun as defined in claim 9, including means for passing a coolant in heat exchange relation with said bored passages.

13. A spray gun as defined in claim 9, wherein said body has other longitudinally extending bores extending alongside said bored passages and fluid connections with

said other bores for circulating a coolant therethrough
for maintaining the body at safe temperatures.

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