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Melton, Jr. et al.

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[45] **Oct. 28, 1975**

[54] **METHOD AND APPARATUS FOR APPLYING PARTICULATE COATING MATERIAL TO A WORK PIECE**

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[22] Filed: **Oct. 26, 1973**

[21] Appl. No.: **409,962**

Related U.S. Application Data

[62] Division of Ser. No. 198,806, Nov. 15, 1971, Pat. No. 3,801,346.

[52] **U.S. Cl.** **239/81**; 239/85; 239/101; 117/22; 117/105

[51] **Int. Cl.²** **B05B 1/24**; C23C 7/00

[58] **Field of Search** ..... 239/79–81, 239/85, 70, 99, 101; 117/22, 105, 105.1, 105.2, 46 FS

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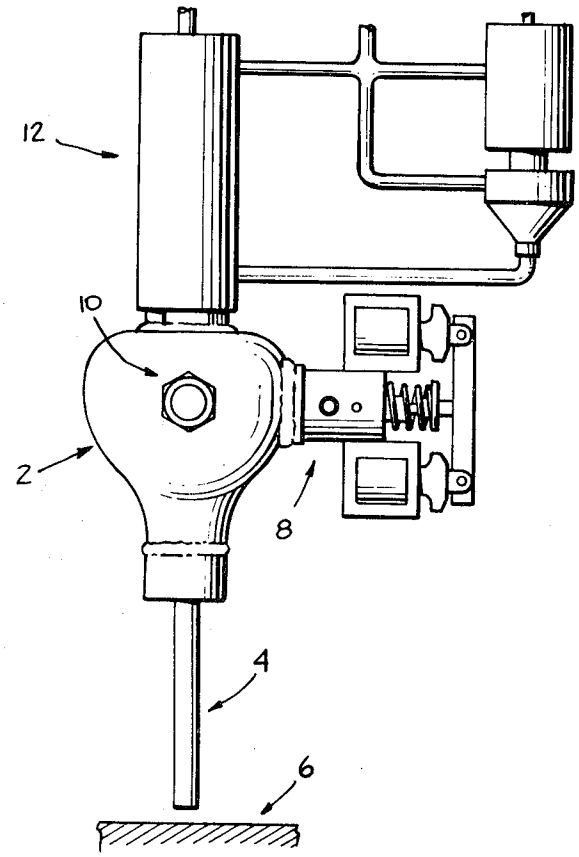
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Primary Examiner—Robert S. Ward, Jr.
Attorney, Agent, or Firm—Hubbard, Thurman, Turner & Tucker

[57] **ABSTRACT**

A system for applying particulate coating material to a work piece in which the particulate material is directed against the work piece in a series of pulses. Each pulse includes an initial step of feeding a charge of combustible gaseous mixture into a combustion chamber provided with an outlet nozzle. The combustible mixture is ignited and the outflow of gaseous mixture through the nozzle is constricted sufficiently to cause a rapid pressure rise during combustion to a peak value, followed by a period of falling pressure during continued outflow of the combusted mixture through the nozzle. A charge of the particulate coating material is injected into the combustion chamber for a brief period which terminates while the pressure in the chamber is at least a substantial proportion of the peak pressure. The outflow of combustion mixture and entrained particulate material is directed through the nozzle at high velocity against the work piece to cause the particulate material to form a coating on the work piece.

7 Claims, 10 Drawing Figures



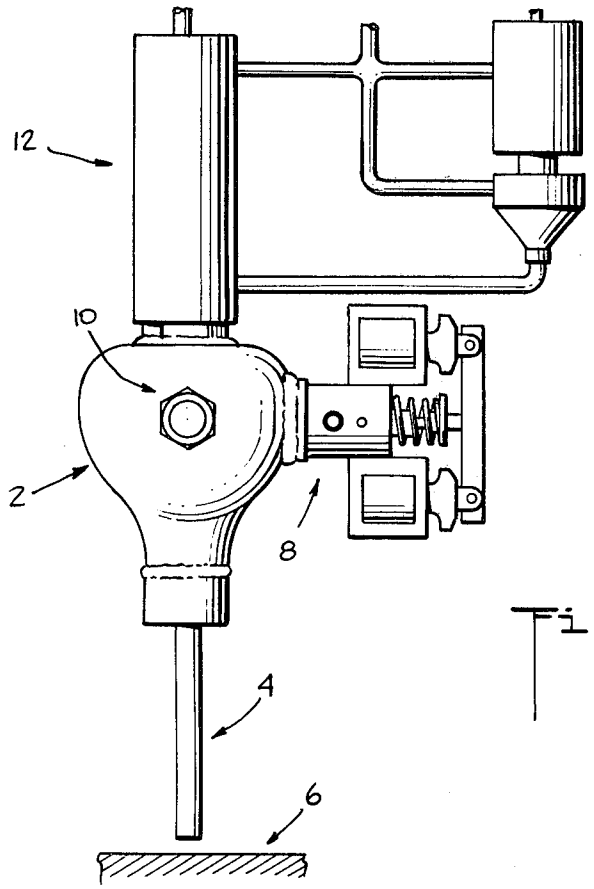

12
10
2
8
4
6

Fig. 1.

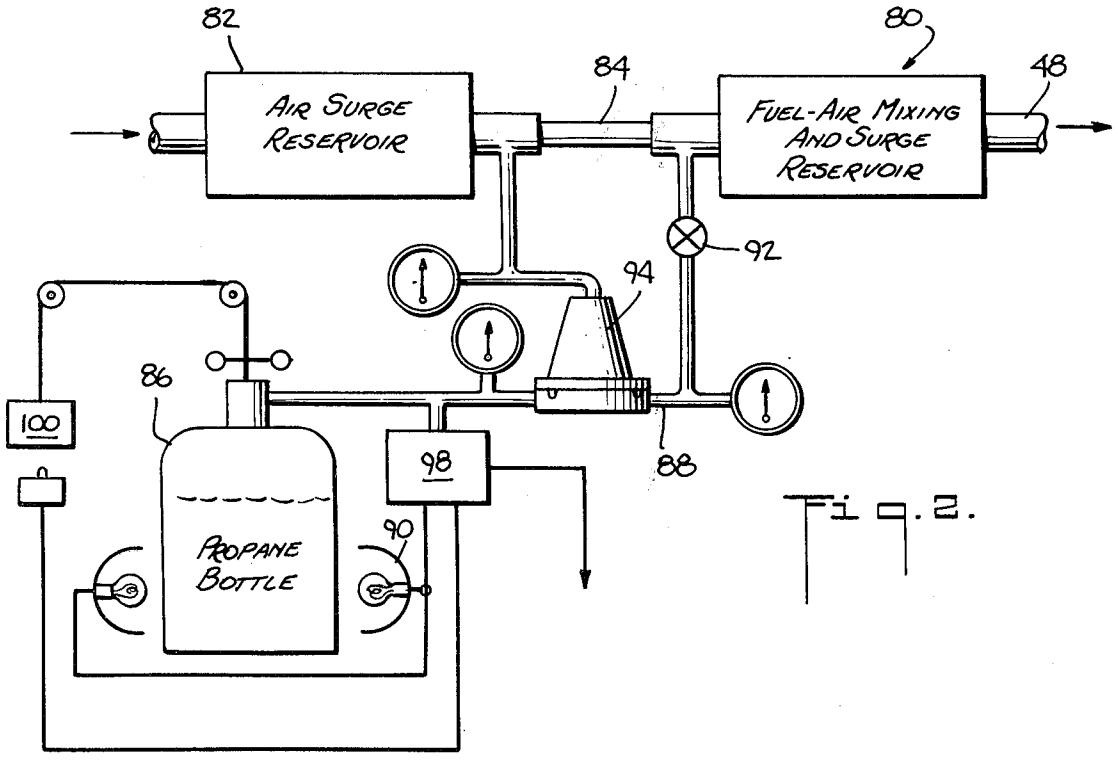

82
AIR SURGE RESERVOIR
84
80
FUEL-AIR MIXING AND SURGE RESERVOIR
48
92
94
86
100
98
88
PROPANE BOTTLE
90

Fig. 2.

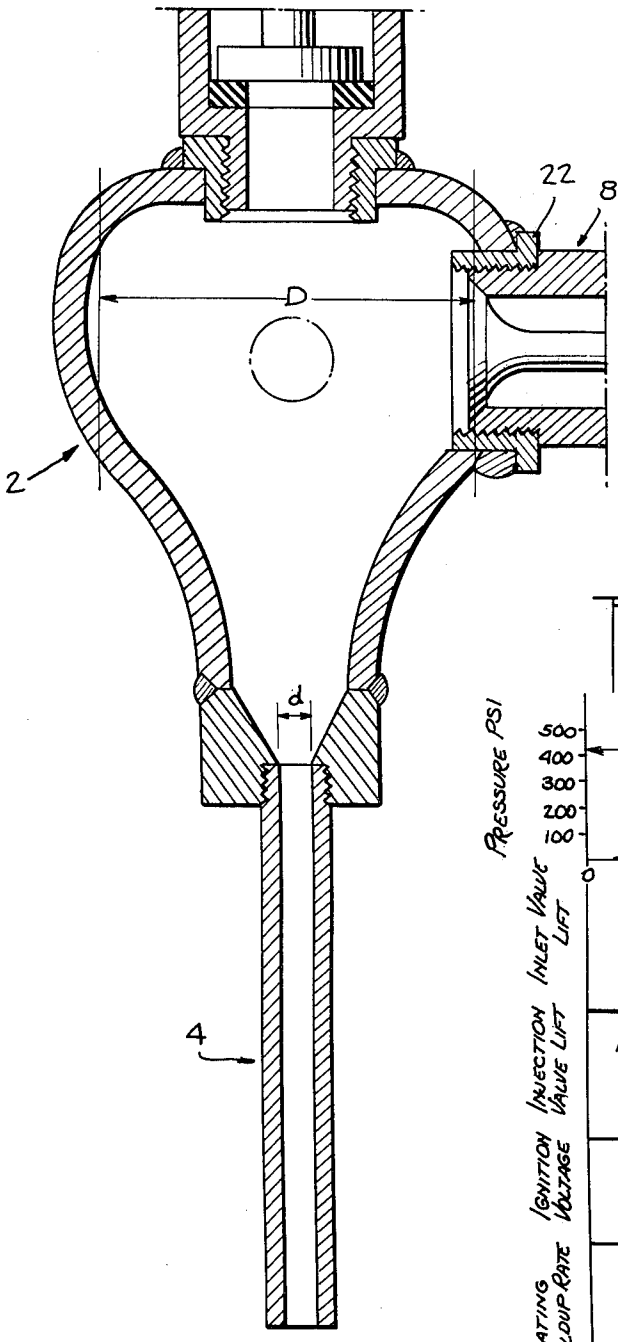


Fig. 3.

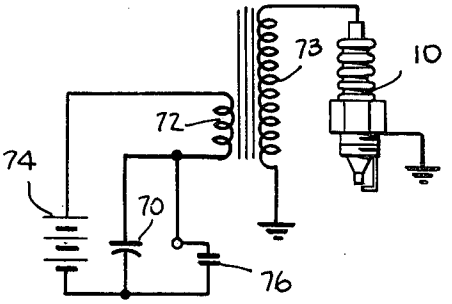
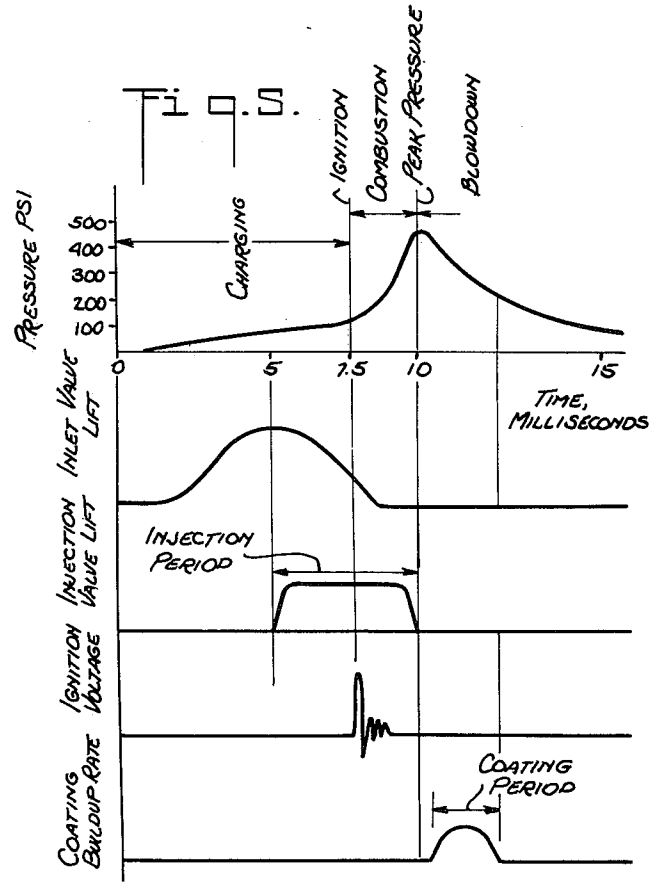


Fig. 4.

Fig. 5.



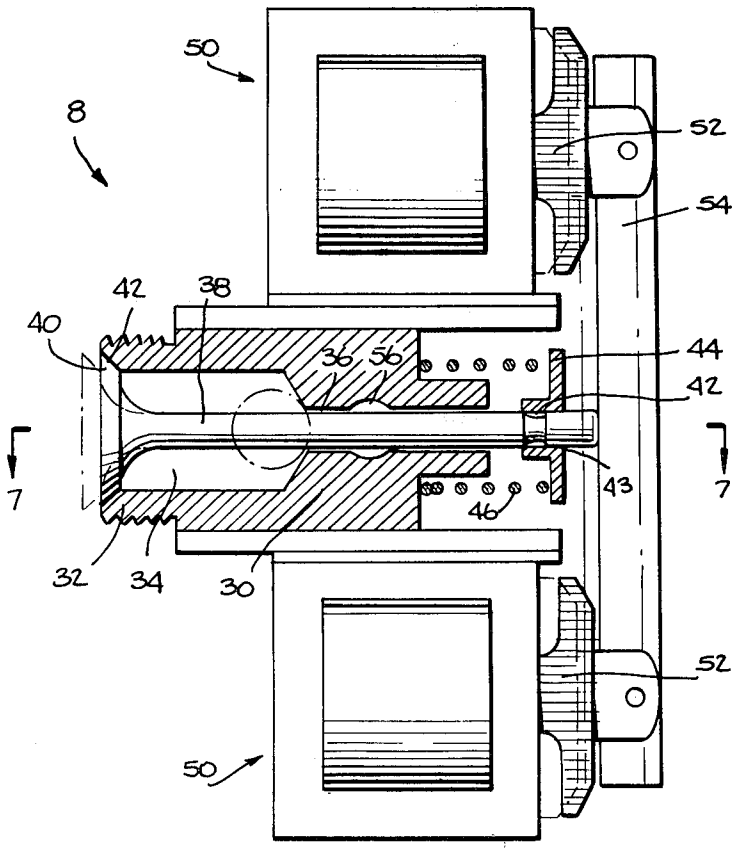

50
8
52
54
42
38
40
36
56
44
42
7
43
7
46
32
34
30
52
50

Fig. 6.

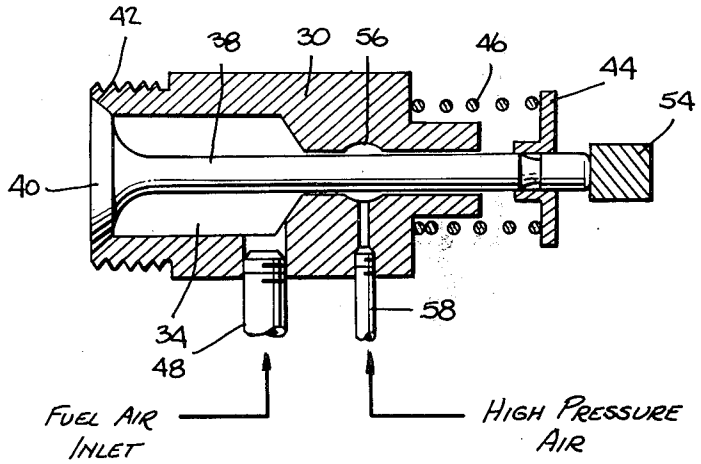

42
38
30
56
46
44
54
40
58
34
48
FUEL AIR INLET
HIGH PRESSURE AIR

Fig. 7.

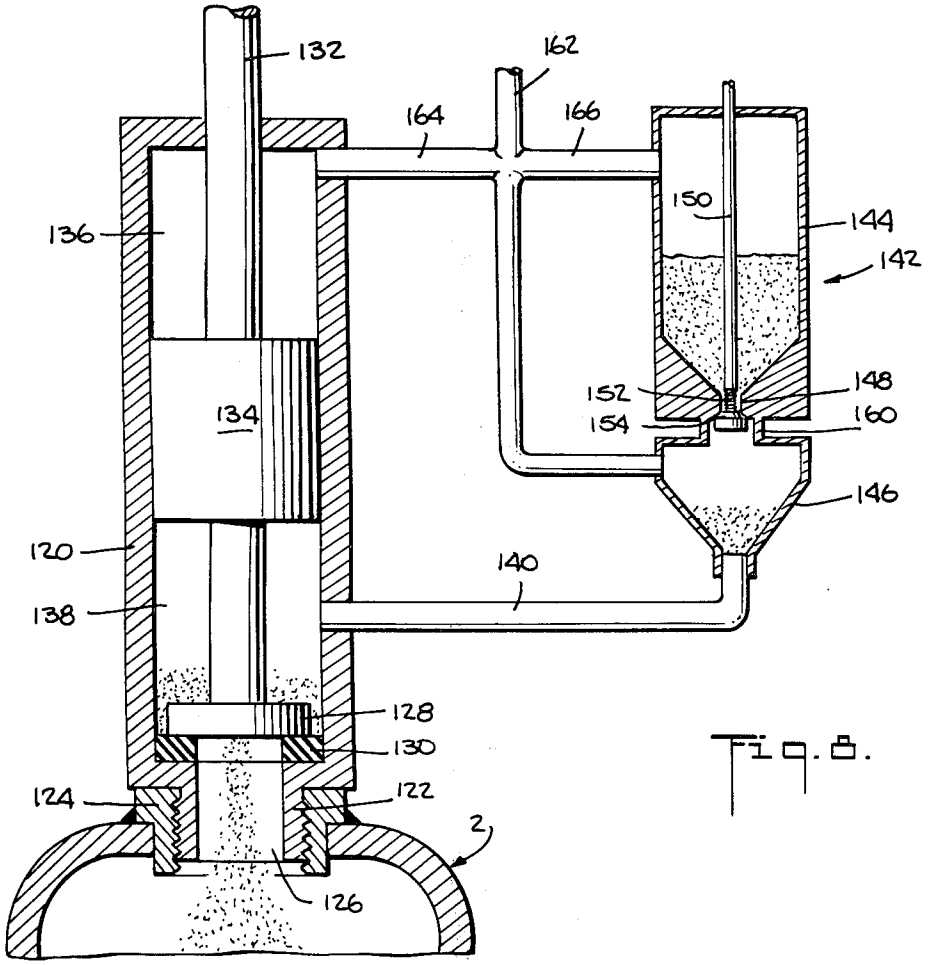


Fig. 8.

Fig. 9A.

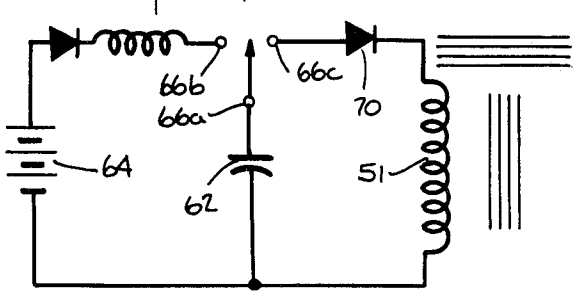
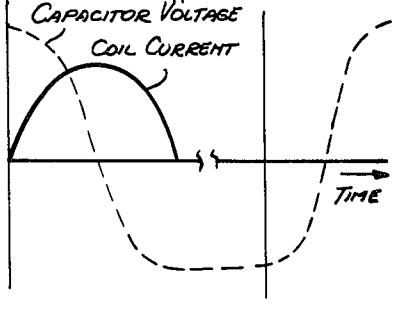


Fig. 9B.



METHOD AND APPARATUS FOR APPLYING PARTICULATE COATING MATERIAL TO A WORK PIECE

RELATED APPLICATION

This is a divisional application of copending application Ser. No. 198,806, filed Nov. 15, 1971, now U.S. Pat. No. 3,801,346.

This invention relates to a method and apparatus for applying particulate coating material to a work piece, and in particular to a system in which the coating material is directed intermittently against the work piece in a heated condition in a high velocity gas stream.

In applying coating materials, it is advantageous with certain materials in view of their high melting points, non-galvanic properties or for other reasons, to direct the coating material in particulate form against a work piece in a high velocity gas stream at an elevated temperature. If the conditions are carefully chosen, the particles of coating material become flattened and weld to each other and to the work piece to produce a hard, non-porous coating.

In performing a coating process of this general nature, it has been found that at least three variables are of critical importance, the rate at which material is deposited, the velocity at which the particles hit the surface and the temperature at impact of the particles which is a function both of the temperature to which they are raised in the gas stream and their kinetic energy on impact which is converted into an additional temperature rise. Various prior coating systems have therefore been devised intended to provide a suitable degree of control over these coating process variables.

For example, one prior coating system utilizes a tubular housing fed with continuous streams of acetylene, oxygen, and a carrying gas (which may also be oxygen) containing powdered coating material. The gases are ignited continuously within the tubular housing and directed down a water-cooled barrel to impinge upon the work piece in a continuous stream at a velocity of at least 2,000 feet per second. Although such a system may be generally satisfactory for the purpose for which it is intended, certain problems may arise under particular conditions. For example, a continuously operating system subjects the work piece to a large uninterrupted stream of very hot burnt gases which could easily overheat the work piece and subject it to severe thermal erosion or distortion. In addition, such a system operating continuously at velocities in the order of 2,000 feet per second would tend to deposit coating material at a very high rate and on certain types of small work pieces this rate of coating build-up might not allow heat to escape from the work piece sufficient rapidly, thereby further contributing to thermal distortion of the work piece. Another problem with such a system may be inefficient utilization of fuel as a continuous gas flow system usually requires that the proportion of powder in the combustion gases be about 5–10% of gas mass as high concentrations would supply material so rapidly as to even further compound the heat dissipation problems just described. To avoid these potential hazards, it would be preferable to emply a pulsed system allowing time between applications of coating material in which sufficient heat dissipation from the work piece could occur to avoid distortion. Additionally, the need for a water cooled barrel to prevent the barrel from melting during continuous operation may render the apparatus unduly heavy and cumbersome.

It may sometimes be desirable, therefore, to utilize an intermittant or pulsed coating system. In one such prior system, a combustible gaseous mixture is ignited in a combustion chamber at the upstream end of a gun barrel which is sufficiently long to permit a supersonic detonation wave to be established in and travel down the barrel. Downstream of the combustion chamber particulate coating material is fed into the gun barrel so that the particles are carried down the barrel at high velocity and directed against a suitable work piece. Again, although generally satisfactory for its intended use, a prior device of this second type may also be unsatisfactory under certain conditions. For example, the need to have a sufficiently long barrel on the device to sustain a supersonic detonation wave may make the device unnecessarily lengthy for installation at locations where space is at a premium. Additionally, by injecting the powder at a location downstream of the combustion zone, the opportunity to heat the powder directly in the combustion zone is lost. Also, by the time the detonation wave reaches the powder injection zone downstream of the combustion zone, some of the peak pressure attained in the combustion zone has necessarily already been dissipated.

SUMMARY OF THE INVENTION

The present invention provides a method and apparatus for applying particulate coating material to a work piece, which is intended to obviate or minimize problems of the type previously described.

In more detail, the method of the present invention directs particulate coating material, e.g. tungsten carbide, a gainst a work piece in a series of pulses. Each pulse includes an initial step of feeding a charge of gaseous combustible mixture into a combustion chamber provided with an outlet nozzle. The combustible mixture is ignited and the outflow of gaseous mixture through the nozzle is constricted sufficiently to cause a rapid pressure rise during combustion of the mixture to a peak value followed by a period of falling pressure during continued outflow of the combusted mixture through the nozzle. A charge of the particulate coating material is injected into the combustion chamber for a period commencing just prior to ignition or, alternatively, approximately at the time the pressure in the combustion chamber reaches its peak value and terminating while the pressure in the chamber is still a substantial proportion of the peak pressure. The outflow of combusted mixture and entrained particulate material is directed through the nozzle against the work piece at high velocity to cause the particulate material to form a coating on the work piece.

It will be appreciated that by using a pulsed system, the rate of application of material to the work piece is reduced sufficiently to permit the work piece to dissipate some of the heat between successive applications of coating material thereby minimizing the possibility of distortion. Pulse operation also provides more effecient use of fuel as the wastage of combusted gases occurring during a continuous flow against the work piece is avoided. By terminating the entry of particulate material into the chamber while the pressure is still a substantial proportion of the peak pressure, it is insured that almost all the particulate material is applied to the work piece while the velocity of the outgoing stream is

still sufficiently high to form a satisfactory coating. Thus, by the time the velocity of the stream has dropped below an adequate level substantially all the coating material in the charge has already been applied.

It may be noted that the conditions of pressure and velocity contemplated by the present invention are a peak pressure as attained in the chamber of approximately 400 psi, and a velocity of outflow of the combusted gases of about 3,000 feet per second with the entrained particulate material traveling at about 1,500 feet per second.

BRIEF DESCRIPTION OF THE DRAWINGS

An apparatus for applying particulate coating material to a work piece, constructed in accordance with one preferred embodiment of the invention, is illustrated in the accompanying drawings in which:

FIG. 1 is a side view of an apparatus for applying particulate coating material, constructed in accordance with the preferred embodiment of the invention, showing certain principal elements of the apparatus including a combustion chamber, a fuel inlet unit, and a powder injector,

FIG. 2 is a schematic view of a source of combustible gaseous mixture for supplying the apparatus shown in FIG. 1,

FIG. 3 is a cross-sectional side view of the combustion chamber shown in FIG. 1,

FIG. 4 is a schematic circuit diagram of an ignition circuit for a spark plug connected with the combustion chamber shown in FIG. 1,

FIG. 5 is a timing diagram showing the relative periods of operation of various of the principal elements shown in FIG. 1,

FIG. 6 is a cross-sectional side view of the fuel inlet unit shown in FIG. 1,

FIG. 7 is a cross-sectional top view of the fuel inlet unit shown in FIG. 6 taken along the lines 7—7 therein,

FIG. 8 is a cross-sectional side view of the powder injector shown in FIG. 1,

FIG. 9A is a schematic electrical circuit diagram showing the electrical connections to an electrical solenoid forming a part of the fuel inlet unit shown in FIG. 6; and

FIG. 9B is a schematic graph of current and voltage versus time for the electrical circuit shown in FIG. 9A.

Referring now to the drawings, and particularly to FIG. 1 of the drawings, an apparatus for applying particulate coating material, constructed in accordance with the preferred embodiment of the invention, is shown.

The components of the unit include a combustion chamber 2 shaped generally like an inverted bulb and a downwardly directed nozzle 4 through which particulate coating material entrained in a high velocity gas stream is directed in intermittent pulses at an underlying work piece 6. Associated with the combustion chamber 2 are, a fuel inlet unit 8 for periodically feeding a charge of combustible gaseous mixture into the combustion chamber 2, a spark plug 10 mounted on the combustion chamber projecting into its interior to ignite the charge of combustible mixture and a powder injector unit 12 for feeding in a charge of the particulate material. Many particulate materials may be used including higher melting point coating materials such as tungsten carbide, as well as flaked metal coatings and other coatings. A separate description of these components follows.

The combustion chamber 2, which is formed of steel or similar material, is configured generally as an inverted bulb with a flattened, enlarged upper end region of mean diameter D (FIG. 3) tapering down to a reduced neck portion. Welded to the free lower extremity of the neck of the combustion chamber 2 is a block 20 which is threaded to receive the correspondingly threaded upper end of the previously mentioned nozzle 4 which is a short pipe aligned concentrically with the vertical axis of the combustion chamber 2.

A horizontal bushing 22 extends through the wall of the combustion chamber 2 into its interior in the upper, enlarged region of the combustion chamber. The bushing 22 is threaded internally and mounts correspondingly threaded portions of the previously mentioned fuel inlet unit 8. Periodically (as will be described hereinafter) the fuel inlet unit 8 injects a charge of combustible gaseous mixture, which in the preferred embodiment is a mixture of propane gas and air, into the interior of the combustion chamber 2.

The mixture is then ignited by the previously mentioned spark plug 10 (FIG. 1) which is tapped through the wall of the combustion chamber 2 projecting into its interior. The spark plug is positioned centrally of the enlarged upper portion of the combustion chamber displaced 90° from the inlet unit 8. Other locations may be chosen for the spark plug. The spark ignition plug 10 is a conventtional automobile spark plug which, when it is energized, initiates a flame front that extends through the charge of combustible mixture.

In an important aspect of the invention, combustion within the chamber is by deflagration as opposed to detonation, by which it will be understood that the flame front proceeds through the mixture in the combustion chamber at a subsonic velocity, which is about 75 feet per second. In the preferred embodiment it is contemplated that the combustion of the mixture occurs entirely by deflagration.

In an alternative embodiment of the process, however, the chamber 2 may be so dimensioned that the pressure rise during deflagration is so rapid that, for a final unburnt portion of the combustible mixture in the chamber, which may be referred to as the end gas, the last part of combustion is by auto-ignition in which spontaneous ignition of the end gas at substantially all the points in it occurs simultaneously.

An important characteristic of the chamber in attaining a sufficient pressure rise during combustion to provide a satisfactory coating is the ratio between the diameter of the upper, enlarged portion of the combustion chamber 2 and the diameter of the outlet nozzle 4. In the preferred example the combustible propane air mixture is admitted to the chamber 2 at about 100 psi and it is necessary to achieve a pressure rise to a peak value during combustion of about 400 psi. If the outlet nozzle 4 has too large an internal diameter, too much gaseous mixture may escape through the nozzle before the pressure has built up sufficiently. To achieve such a pressure it has been found that the ratio of the mean internal diameter D of the combustion chamber of the enlarged upper region to the internal diameter of the nozzle 4 (*d* in FIG. 3) should be at least 5 to 1 and preferably somewhat greater. For example in the preferred embodiment where the internal diameter *d* of the nozzle 4 is one-third inch, the chamber diameter D in its

enlarged region is about 2½ inches providing a ratio of D/d of 7½. Stated in another way, the ratio V/d^2 should exceed about 50 where V is the volume of the chamber in cubic inches and d is the diameter of the opening. Of course if a length of the chamber becomes significantly greater than the diameter of the chamber, the time required for the flame to propagate through the chamber may become so great as to materially reduce the pressures reached in the chamber because of the escape of gas through the open nozzle during the period of deflagration. The combustion chamber pressures and dimensions described result in a gas velocity through the nozzle of about 3,000 feet per second with the velocity of the entrained powder being about 1,500 feet per second.

Another important characteristic of the combustion chamber **2** is its overall cubic capacity in relation to the cross-sectional area of the nozzle **4**. The cubic capacity of the chamber **2** should be sufficiently large to provide for a period of outflow of gas through the nozzle which lasts sufficiently long to enable the period of injection of the charge of particulate material (which will be described hereinafter) into the combustion chamber to be completed while the pressure in the combustion chamber still remains at a high level. Thus, in the preferred embodiment, wherein the injection period of the powder can be accomplished in about 5 milli-seconds, the period of gas outflow (sometimes called the blow down) during which gas escapes from the nozzle, should be several times longer. For example, a ¼ inch internal diameter nozzle requires a chamber volume of at least 8 cubic inches giving a blow down period of about 10 milli-seconds and in practice a chamber capacity of 12–14 cubic inches is provided. With these dimensions, powder can be injected and substantially eliminated from the combustion chamber **2** before the pressure in it has dropped to a value which is too low to project the coating material against the work piece with a sufficient velocity for satisfactory coating.

Various considerations affect the nozzle length. Nozzle length is determined by required powder impact velocity, powder particulate size, and firing pressure, for a given velocity being proportional to particle size and inversely proportional to firing pressure. The required velocity is that which will hammer particles into a dense, well-bonded coating; too much velocity will break up in-place coating or even remove substrate material while insufficient velocity leaves the coating porous. Temperature plays a subordinate role by softening particles to facilitate impact deformation but temperature is primarily gained from exposure of the powder to hot gas by injecting across the combustion space, with relatively little additional heating occurring in the nozzle. Relatively high firing pressure (related to available fuel and air supply pressure) permits high velocity from a short nozzle; the nozzle could be made much shorter than described here by proportionately increasing firing pressure, or vice-versa, by manipulating powder size and/or fuel air supply pressure. For example applying a coating of tungsten carbide in the −325 mesh +15 micron size range, a satisfactory coating was obtained, using a nozzle of 4 inches length, having an amorphous structure with a Knoop hardness of approximately 1,200, with adhesion in excess of 11,000 pounds per square inch using standard tests.

Important advantages obtained by using a relatively short nozzle are that the relative significance of wall friction and wall heat losses are substantially reduced. By contrast, a "soda straw" nozzle, e.g., one having a length to diameter ratio in excess of 30, has a large amount of wall surface area in relation to its cross-sectional area with the result that wall friction appreciably slows down gas flow during passage through the nozzle and there is an additional relatively high heat loss. Additionally, the ability to function with a short nozzle facilitates installation of the apparatus in locations where space is at a premium. By conducting combustion through a process of deflagration in the present invention rather than by detonation causing a supersonic shock wave, it is possible to avoid the need for a nozzle length sufficiently long to sustain a detonation wave.

The process occurring in the combustion chamber with reference to the pressures and dimensions of the preferred embodiment described are depicted graphically in FIG. **5**. Starting a pulse or a flow at zero time, combustible mixture at 100 psi commences admission to the chamber through the inlet unit **8** (as will be described in more detail hereinafter) for about 8 milliseconds. At about 5 milli-seconds, a charge of the particulate coating material is injected into the chamber and injection of the coating continues until it terminates at about 10 milli-seconds. About midway through the powder injection, after 7.5 milli-seconds have elapsed, the spark plug **10** ignites the mixture causing a rapid rise in pressure within the combustion chamber to a peak value of about 400 psi attained at about 10 milli-seconds after commencement of the cycle.

This injection of the powder ceases at approximately the time the pressure in the chamber is at its peak value. At about that time the first particles injected have travelled out of the combustion chamber **2** and through the nozzle **4** to impact the work piece, thus starting a coating period which continues for about 2 milli-seconds. The coating period is shorter than the injection period because the later particles injected catch up with the earlier particles in the nozzle due to the pressure build-up in the chamber. By the end of the coating period substantially all the particulate material has been blown out of the combustion chamber **2** with the result that by the time the pressure in the combustion chamber eventually falls below that necessary to sustain an adequate velocity for coating, all the particulate charge has already been applied.

It will be appreciated that the pressures, times and dimensions described for the preferred embodiment can be selectively varied, if so desired, to facilitate the use of larger or smaller coating apparatuses following this invention. In addition the timing of the coating material injection period can be selected to commence after, rather than before, ignition for applications in which it is desirable to introduce the powder into an atmosphere in which all the oxygen has already been combusted, to reduce particle oxidation.

The previously mentioned fuel inlet unit **8** (FIGS. **6** and **7**) includes a cylindrical inlet housing **30** having a reduced, threaded boss **32** at its forward end which threadedly engages the previously described bushing **22** in the side of the combustion chamber **2**. Extending rearwardly into the inlet housing **30** from its forward end is an inlet passage **34** which terminates at about the midpoint of the inlet housing. Extending rearwardly from the inlet passage **34** through the remainder of the inlet housing is a second passage **36**, of relatively

smaller diameter, which slidably receives a valve stem **38** carrying a valve head **40.** The valve head **40,** which is beveled along its rim, seats on a correspondingly beveled valve seat **42** on the inlet housing body **30** and closes off fluid communication between the inlet passage **34** and the combustion chamber **2** in a closed position of the valve head.

To hold the valve head in its closed, seated position, the rearward end of the valve stem **38,** which projects rearwardly beyond the inlet housing **30,** is provided with an undercut, annular groove **42** providing a forwardly facing shoulder **43** which is engaged by a circular collar or spring retainer **44.** A circular compression spring **46** spaced concentrically around the valve stem **38** extending between the inlet housing **30** and the collar **44** is just sufficiently strong to hold the valve head **40** closed against the pressure exerted by the incoming supply of combustible gas which is delivered continuously to the interior of the inlet passage **34** through a conduit **48** (FIG. **7**).

To move the valve head **40** forwardly off its seat, thus placing the inlet passage **34** in fluid communication with the interior of the combustion chamber, two electrical solenoids **50** are fixedly mounted on the exterior of the inlet housing **30** on opposite sides thereof. The solenoids **50** are of conventional construction, each having an electromagnetic coil **51** (FIG. **9A**) with a plunger **52** mounted for axial reciprocation forwardly into the coil when the coil is energized. Connected to and carried by the plungers **52** is a transverse yoke **54** (FIG. **6**) in continuous abutting contact with the free rearward end of the valve stem **38.**

In a de-energized condition of the solenoids **50,** the biasing spring **46** urges the valve stem **38** to move the yoke **54** rearwardly so that the plungers **52** are in an extended rearward position when the valve head **40** is seated. Energizing the solenoids **50,** which causes the plungers **52** to move into the solenoids, carries the yoke **54** forwardly (to the dotted line position shown in FIG. **6**) carrying the valve stem **38** forwardly and raising the valve head **40** off its seat. At this time the combustible mixture, which is at a pressure of 100 psi in the preferred embodiment, starts to feed into the combustion chamber **2.** The solenoids **50** are de-energized at approximately the time the spark plug **10** is fired. The rapid pressure build-up that then occurs in the combustion chamber **2** during charging allows the spring **46** to return the valve head **40** to its seat rapidly closing off the combustion chamber **2** from the inlet passage **34** before the advancing flame front can reach the mixture in the inlet passage.

To prevent leakage of the combustion mixture outwardly of the inlet housing along the stem **38,** which could create a fire hazard, an annular recess **56** in the inlet housing **30** surrounds the valve stem at approximately the midpoint of the second passage **36** (FIG. **7**). Air is delivered to the passage **56** through a conduit **58,** at a higher pressure than the pressure at which the combustible mixture is supplied to the inlet passage **34.** As a result, any leakage of gas between the stem **38** and the second passage **36** is in a direction from the recess **56** towards the inlet passage **34,** preventing escape of combustible mixture rearwardly into the atmosphere. Additionally, in an alternative embodiment of the invention in which the particulate material is introduced into the chamber **2** through the fuel inlet valve by entraining it in the fuel gas supply, the flow of gas introduced through the recess **56** is very important for preventing powder from filling the passage around the valve stem and jamming its swift movement between the open and closed positions.

To energize and de-energize the solenoids **50** for pulsed or cyclical feeding of mixture into the combustion chamber the electrical circuit shown in FIG. **9A** is employed. The preferred rate of operation is at a pulse rate in the region of 5–25 pulses per second although this may be varied. The coil **51** of the solenoid **50** is connected in series with a capacitor **62** which is charged by a high voltage (300 volts) power supply indicated by battery **64** when switch contacts **66***a* and **66***b* are closed. When switch contacts **66***a* and **66***c* are closed the capacitor **62** discharges through the coil **51** of the solenoid moving the associated plunger **52** forwardly. When the switch contacts **66***a* and **66***b* are remade the capacitor **62** is recharged through coil **66** from power supply **64.** A rectifying diode **70** is included in the circuit to the solenoid coil **51** to prevent reverse current flow when the capacitor charge swings in its opposite polarity (FIG. **9B**), insuring that the solenoid experiences only a single current pulse. This circuit minimizes the electrical energy drain on the system.

Similarly to energize the spark plug **10** (FIG. **4**) a capacitor **70** and a primary coil **72** of a standard ignition transformer, having its secondary coil **73** connected to the spark plug **10,** are connected in series with a battery **74.** A pair of switch contacts **76** are connected across in parallel with the capacitor **70.** The switch contacts **76** are opened and closed by movement of the valve stem **38.** When the valve stem moves to open the valve head **40** the points **76** close, starting current build-up in the primary coil **72.** As the valve stem closes the valve head **40,** the points **76** reopen, initiating a voltage change across the coils of the transformer which causes the ignition spark. Although a system utilizing only one spark plug has been disclosed, it will be appreciated that the ignition system may be readily modified to energize two of the spark plugs **10** located on opposite sides of the combustion chamber **2.**

As previously mentioned, a supply of combustible mixture is supplied through the conduit **48** to the inlet passage **34** in the inlet unit **8.** The supply of combustible mixture is from a source system shown in FIG. **2** which includes a fuel air mixing tank **80** connected to the conduit **48,** in which air and propane gas are mixed at a pressure of approximately 100 psi to provide the combustible mixture. When the inlet valve head **40** opens, the mixture flows through the conduit **48** and the inlet passage **34** into the combustion chamber **2** which, after completion of the preceding pulse, is at a pressure substantially lower than 100 psi.

Air is supplied to the mixing tank **80** from an air surge tank **82** connected to a high pressure source of air, such as an air line, operating at 100 psi. The air surge tank **82** is connected through an intervening conduit **84** to the mixing tank **80.**

Propane gas is supplied to the mixing tank **80** from a bottle **86** containing liquified propane, through connecting conduits **88.** Positioned outside the propane bottle **86** are electrical heating lamps **90** which raise the temperature of the liquid propane so that it boils off. The heating of the liquid propane creates a supply of propane gas at about 120 psi and it passes through a variable restrictor **92,** interposed in the conduit **88,** which controls the supply of propane into the mixting

tank **80**. Connected in the conduit **88** with a branch connection to the air conduit **84**, is a slave regulator **94** which automatically regulates the supply pressure of the propane gas to that of the air pressure.

Two safety features are included. A pressure sensor **98** in fluid communication with the propane gas in the conduit **88** is connected with the electrical supply to the heating lamps **90** for the propane bottle, so that if an excessive pressure rise is detected by the unit **98** it automatically turns off the heating lamps. It is also necessary to turn off the heating lamps **90** when the liquid propane in the bottle **86** has been exhausted and for this purpose a weight-sensor indicated schematically as **100**, is also connected with the propane bottle. The weight-sensor **100** cuts off the electrical supply to the lamps **90** whenever the weight of the bottle **86** and its contents drops below a predetermined level.

The mixing tank **80** and the air surge reservoir **82** are of very much larger volumetric capacity than the combustion chamber **2** to minimize variations in supply pressure of the combustible mixture during flow of the gas into the combustion chamber.

Although a source utilizing liquified propane gas has been disclosed, it will be understood that, by appropriate modification, a liquid fuel or mist can be mixed with air and supplied to the combustion chamber to provide the combustion mixture.

The previously mentioned powder injector unit **12** (FIG. **8**) includes a vertical, closed hollow cylindrical injector housing **120**. The housing **120** has a threaded boss **122** at its lower end which engages a threaded bushing **124** welded to and extending through the wall of the combustion chamber **2** at its upper end. A vertical passage **126**, extending through the boss **122**, places the interior of the injector housing **120** in fluid communication with the interior of the combustion chamber **2**. The passage **126** is normally closed, however, by an injector valve head **128** which seats on an annular neoprene sealing ring **130** mounted in the lower end of the injector housing. The injector valve head **128** may be lifted vertically off its seat **130** by an injector valve stem **132** extending upwardly and outwardly through the upper end of the injector housing **120**. The upper end of the injector housing includes a conventional pressure type seal (not shown) permitting vertical sliding motion of the stem **132** without loss of pressure within the housing.

Fixedly secured to the stem **132**, adjacent the midpoint of the housing, is a piston **134** which divides the interior of the housing into an upper chamber **136** and a lower chamber **138**. The piston **134** guides the valve stem for vertical sliding motion to insure that the valve head moves vertically off and onto its seat **130**.

Particulate material is periodically fed into the lower chamber **138** through a horizontal conduit **140** connected to and extending through the sidewall of the housing **120**. At its opposite end the conduit **140** communicates with the lower end of a dispenser unit **142** comprising an upper, storage container **144** containing a supply of the coating material and a lower, hopper **146**. The storage container **144** is a closed, vertical hollow cylinder having a cone-shaped bottom wall leading into a narrow throat **148**. Passing centrally through the storage unit **144** is a vertical shaft **150** having a threaded region **152** at its lower end positioned in the throat **148**, spaced from the walls thereof. A valve head **154** is threadedly secured to the bottom of the shaft **152** and has an upwardly directed conical portion which seats on a correspondingly shaped seat at the lower end of the throat **148**.

Normally, flow through the throat into the underlying hopper **146**, which is connected to the storage unit **144** by an intervening neck **160**, is prevented by the valve head **154**. However, the shaft **150** may be selectively moved downwardly so that particles can pass through the throat **148** into the hopper **146**. In addition, the threads **152** at the lower end of the shaft **150** help to carry particulate material downwardly into the lower hopper. From the hopper **146** the particles pass through the intervening conduit **140** into the lower chamber **138**.

By the use of both a storage unit and a hopper, the quantity of material fed into the powder injector housing **120** on each charge can be controlled. Moreover, by providing the hopper **146**, it is insured that a volume of particulate material mixed with a relatively larger volume of air is fed through the conduit **140**, thus avoiding clogging of the conduit **140** as might occur if it were attempted to feed directly from the mass of material in the storage unit into the conduit without an intervening hopper.

As the particulate material must be fed into the combustion chamber during a period in which the pressure in the chamber rises to a peak of about 400 psi, it is necessary to insure that the pressure in the interior of each of the injector housing **120**, the storage unit **144** and the hopper **146** are all at a still higher pressure. For this purpose, a supply of air from a conventional higher pressure source at about 1,000 psi (not shown) is connected through a supply conduit **162** feeding branch conduits **164, 166** and **168** which are connected to the upper chamber **136**, the interior of the storage unit **144**, and the interior of the hopper **146**, respectively.

To inject the material in the lower chamber **138**, the stem **132** is raised vertically, lifting the valve head **128** off its seat. The high pressure within the lower chamber **138** injects the particles into the combustion chamber in a direction toward the nozzle **4**. By injecting the particles at the side of the combustion chamber remote from the nozzle **4**, the particles are given a sufficient residence time in the combustion chamber **2** to provide a necessary degree of preheating before they enter the high velocity combusted gas stream through the nozzle **4**.

Return of the valve to its closed position thereafter is assisted by the high pressure on the upper side of the valve head **128** which gives a particularly rapid and effective valve closing action.

The valve stem **132** may be raised and lowered by the use of a solenoid and associated switching circuit, similar to one of the solenoids **50** and associated circuits, previously described in connection with the fuel inlet unit. Thus, it will be appreciated that the fuel inlet solenoids, the powder injector solenoid and the spark plug are each energized in response to operation of the switches in their respective associated electrical circuits. As previously discussed, the make and break points for the spark plug **10** are mounted on the inlet valve mechanisms so that timing of the spark at the desired interval after opening of the inlet valve is achieved automatically. Similarly, the opening of the powder injector valve in the timed relation previously described is achieved by arranging the switch contacts to the powder injector solenoid to close approximately

3 milli-seconds after the fuel inlet valve head **40** commences to open. This can be achieved by mounting cams on a common rotating shaft controlling the operation of the switches controlling the inlet valve and the powder injector plunger in the desired timing relation. Other conventional timing circuits could alternatively be used.

In an alternative embodiment of the invention, the coating material instead of being introduced into the chamber separately from the combustible mixture, may be introduced into the chamber already mixed with the combustible mixture. This may advantageously be done by introducing the coating material into the line **48** between the fuel/air source and the fuel inlet valve or, alternatively, by introducing the coating material into the chamber **34** within the fuel inlet valve **8** via a suitable conduit. In either event the coating material enters the combustion chamber with the combustible mixture.

What is claimed is:

1. An apparatus for applying particulate coating material to a work piece comprising:

a combustion chamber having a gas inlet and a restrictive gas outlet,

valve means in the gas inlet for blocking flow of gas from the chamber out through the gas inlet during combustion in the combustion chamber,

the combustion chamber having a cross sectional area substantially larger than that of the gas outlet such that a major portion of the gases will be retained in the combustion chamber by the restrictive gas outlet while the combustible gaseous mixture is deflagrated whereby the pressure within the combustion chamber will rise sharply as a result of such deflagration,

fuel feed means for forming a combustible gaseous mixture in the chamber by forcing gases through the gas inlet into the combustion chamber,

ignition means for igniting a combustible gaseous mixture in the combustion chamber,

particle feed means for injecting a predetermined quantity of particulate coating material into gases of combustion in the combustion chamber, and

control means for the valve means, fuel feed means, ignition means and particle feed means for respectively forming a combustible gaseous mixture in the combustion chamber, igniting the combustible gaseous mixture to produce a sharp increase in pressure in the combustion chamber, and injecting a predetermined quantity of particulate material into the chamber while a substantial portion of the gases of combustion are still in the combustion chamber, whereby the particulate material will be heated by the gases of combustion and accelerated by the gases of combustion issuing from the gas outlet for impact against a work piece.

2. The apparatus of claim **1** wherein the fuel feed means comprises:

fuel-air carburetor means for producing a combustible mixture of fuel and air,

a source of air at a super atmospheric pressure, and

means connecting the source of air at super atmospheric pressure to the carburetor and the output of the carburetor to the gas inlet of the combustion chamber, and wherein

the valve means controls the admission of a fuel-air mixture from the carburetion means to the combustion chamber.

3. The apparatus of claim **2** wherein the fuel feed means has sufficient pressure capacity to force gas into the combustion chamber at a rate greater than the rate at which the gas escapes through the gas outlet to achieve a pressure substantially greater than atmospheric in the combustion chamber prior to combustion of the gases.

4. The apparatus of claim **2** wherein the fuel-air carburetion means comprises:

a source of liquified natural gas,

a mixing tank in fluid communication with said internal passage in said inlet valve housing,

an air surge tank in fluid communication with a source of air under pressure and with said mixing tank for delivering air under pressure thereto,

conduit means connecting said source of liquified propane gas and said mixing tank; and

flow control means connected with said conduit means and with said air surge tank for regulating the proportions of air and propane gas fed to said mixing tank.

5. The apparatus of claim **1** wherein the particle feed means comprises:

an injector housing having a closed injector chamber therein,

an outlet port in said injector housing placing one end of said injector chamber in fluid communication with the interior of said injector chamber in fluid communication with the interior of said combustion chamber,

an injector valve having,

an injector valve head which in a closed position thereof closes said outlet port,

actuating means connected with said injector valve head extending outwardly of said injector housing for selective movement of said injector valve head to an open position exposing said outlet ports;

dispenser means connected with said injector housing for delivering a charge of the particulate material to said injector chamber in the region of said valve head; and

pressure means in fluid communication with said injector chamber for supplying gas thereto at a pressure in excess of the peak pressure developed in said combustion chamber, whereby when said valve head is raised off said outlet port the pressure within said injector chamber is sufficient to inject the particulate material within said injector chamber into said combustion chamber.

6. The apparatus of claim **1** wherein the gas outlet is formed by an elongated nozzle of substantially constant diameter for accelerating the particulate material.

7. The apparatus of claim **6** wherein said combustion chamber and said nozzle are of generally circular cross section with the ratio of the internal diameter of said combustion chamber to the internal diameter of said nozzle being at least 5 to 1.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 3,915,381

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INVENTOR(S) : Rosser B. Melton, Jr.; John M. Clark, Jr.; Ronald J. Mathis; William D. Weatherford, Jr.; Charles D. Wood, III.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 12, line 42, "ports" should be --port--.

Signed and Sealed this

Second Day of November 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks