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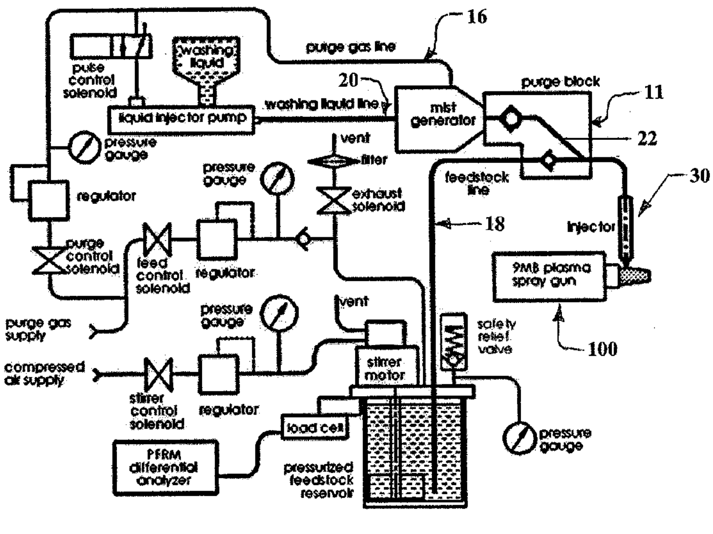
(54) Title: PRESSURE BASED LIQUID FEED SYSTEM FOR SUSPENSION PLASMA SPRAY COATINGS

FIG. 1



(57) **Abstract**: Apparatus (1) for injecting a liquid in an area of a thermal spray gun (100). The apparatus (1) includes an injector cleaning device (10) having an inlet connectable (19) to at least one feedstock supply line (18), an inlet connectable (17) to at least one gas supply line (16), and an inlet connectable (21) to at least one liquid medium supply line (20). An injector (30) orifice is coupled to the injector cleaning device (10) and is adapted to at least one of inject a liquid jet into a hot stream created in the area of the thermal spray gun (100) and receive feedstock, gas and liquid passing into the inlets.

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PRESSURE BASED LIQUID FEED SYSTEM FOR SUSPENSION PLASMA SPRAY COATINGS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The instant application is an International Application based on U.S. provisional application No. 61/423,428, filed December 15, 2010, the disclosure of which is hereby expressly incorporated by reference hereto in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Work resulting in the instant invention was partially supported by funding from the National Institute of Standards and Technology under Advanced Technology Program number 70NANB7H7009.

REFERENCE TO A COMPACT DISK APPENDIX

[0003] Not applicable.

BACKGROUND OF THE INVENTION

[0004] The thermal spray process has been widely used to deposit coatings for industrial applications, including aerospace, automotive, petroleum and petrochemical, biomedical, etc. See Mateyja D., *Plasma spraying of metallic and ceramic coatings.* 1989, New York: John Wiley & Sons, the disclosure of which is hereby expressly incorporated by reference in its entirety. Thermal spray ceramic coatings are usually made from a powder feedstock. However, individual ultrafine particles (usually <5μm) cannot be thermally sprayed using conventional powder feeding methods. A high carrier gas flow rate is required for the ultrafine particle penetration within the plasma jet. Such a cold gas flow rate will drastically perturb the plasma jet. See Fauchais, P., et al., *Parameters controlling liquid plasma spraying: Solutions, sols, or suspensions.* Journal of Thermal Spray Technology, 2008 17(1): p. 31-59, the disclosure of which is hereby expressly incorporated by reference in its entirety. On the other hand, these ultrafine particles would clog the hoses and fittings during delivery from the powder feeder to the thermal spray torch. See Lima, R.S. and B.R. Marple, *Thermal spray coatings engineered from nanostructured ceramic agglomerated powders for structural, thermal barrier and biomedical applications: A review.* Journal of Thermal Spray Technology, 2007 16(1): p. 40-63 and Chen, Z., et al., *Air-plasma spraying colloidal solutions of nanosized ceramic powders.* Journal of Materials Science, 2004 39(13): p. 4171-4178, the disclosure of each of these documents is hereby expressly incorporated by reference in its entirety.

[0005] Recently, a suspension plasma spray (SPS) process has been developed for the deposition of nanostructured coatings. See Chen, Z., et al., *Air-plasma spraying colloidal solutions of nanosized ceramic powders.* Journal of Materials Science, 2004 39(13): p. 4171-

4178, Fauchais, P., et al., *Suspension and solution plasma spraying of finely structured layers: potential application to SOFCs.* Journal of Physics D-Applied Physics, 2007 40(8): p. 2394-2406, Burlacov, I., et al., *Induction plasma-sprayed photocatalytically active titania coatings and their characterisation by micro-Raman spectroscopy.* Surface & Coatings Technology, 2006 201(1-2): p. 255-264, Tomaszek, R., et al., *Microstructural characterization of plasma sprayed TiO2 functional coating with gradient of crystal grain size.* Surface & Coatings Technology, 2006 201(1-2): p. 45-56, Toma, F.L., et al., *Nanostructured photocatalytic titania coatings formed by suspension plasma spraying.* Journal of Thermal Spray Technology, 2006 15(4): p. 587-592, Berghaus, J.O., B. Marple, and C. Moreau, *Suspension plasma spraying of nanostructured WC-12Co coatings.* Journal of Thermal Spray Technology, 2006 15(4): p. 676-681, Fauchais, P., et al., *Understanding of suspension DC plasma spraying of finely structured coatings for SOFC.* Ieee Transactions on Plasma Science, 2005 33(2): p. 920-930, Wittmann-Teneze, K., et al., *Nanostructured zirconia coatings processed by PROSOL deposition.* Surface & Coatings Technology, 2008 202(18): p. 4349-4354, Chen, D.Y., E.H. Jordan, and M. Gell, *Microstructure of Suspension Plasma Spray and Air Plasma Spray Al2O3-ZrO2 Composite Coatings.* Journal of Thermal Spray Technology, 2009 18(3): p. 421-426, and Chen, D.Y., E.H. Jordan, and M. Gell, *Suspension plasma sprayed composite coating using amorphous powder feedstock.* Applied Surface Science, 2009 255(11): p. 5935-5938, the disclosure of each of these documents is hereby expressly incorporated by reference in its entirety. In SPS, the ultrafine or nanosized particles are dispersed in a liquid medium such as water or ethanol to form a suspension and then the suspension is injected into the plasma torch. The suspension droplets will undergo liquid evaporation, particles melting process in the plasma jet and form the coatings upon impacting the substrate. Chen, D.Y., E.H. Jordan, and M. Gell, *Microstructure of Suspension Plasma Spray and Air Plasma Spray Al2O3-ZrO2 Composite Coatings.* Journal of Thermal Spray Technology, 2009 18(3): p. 421-426 and Chen, D.Y., E.H. Jordan, and M. Gell, *Suspension plasma sprayed composite coating using amorphous powder feedstock.* Applied Surface Science, 2009 255(11): p. 5935-5938, used the molecularly mixed amorphous powder as feedstock and prepared phase homogeneously distributed ceramic coatings using the suspension plasma spray process. Waldbillig, D. and O. Kesler, *The effect of solids and dispersant loadings on the suspension viscosities and deposition rates of suspension plasma sprayed YSZ coatings.* Surface & Coatings Technology, 2009 203(15): p. 2098-2101, the disclosure of which is hereby expressly incorporated by reference in its entirety, studied the effect of solids and dispersant loading on the deposition rate of suspension plasma sprayed YSZ coatings. In the reported suspension plasma spraying process, home-made delivery systems with a peristaltic pump were used to deliver the suspension to the plasma jet.

[0006] While liquid jet injection into plasma was well observed and studied (see P. Fauchais and G.Montavon, *Latest Developments in Suspension and Liquid Precursor Thermal Spraying*. Thermal Spray 2009: Proceedings of the ITSC, 2009, ASM International: p.136-149, R. Etchart-Salas, V. Rat, J.F. Coudert and P. Fauchaus, *Parameters controlling properties of coatings sprayed by suspension plasma spraying*. Procedings of the ITSC, 2008: p.506-511, C. Marchand, C. Chazelas, G Mariaux and A. Vardelle, *Liquid precursor plasma spraying: observation of liquid feedstock break-up.* Procedings of the ITSC, 2008: p.512-516, and R. Vassen, H. Kassner, G. Mauer and D. Stover, *Suspension plasma spraying: Process Development and Applications.* Thermal Spray 2009: Proceedings of the ITSC, 2009, ASM International: p.162-167, the disclosure of each of these documents is hereby expressly incorporated by reference in its entirety), the propensity of suspensions to clog lines and injector orifice gained notoriety among researches and practitioners alike, and rendered the SPS process as highly unreliable and impractical. Combined with a high cost of sub-micron and nano-sized feedstock, any significant loss of material due to line flush or non-stop running further diminishes ROI and prospects of practical SPS process implementation. To make stable and robust coating deposition, there is a great need for the development of commercially available liquid delivery system for the suspension/solution thermal spraying.

SUMMARY OF THE INVENTION

[0007] With the above-noted background research in mind, a prototype of a liquid feedstock feeder that is based on the SULZER METCO 5MPE powder feeder platform was developed. TiO_2, Al_2O_3, ZrO_2 coatings were deposited through this liquid delivery system using a SULZER METCO 9MB plasma gun. The phase composition and microstructure of the as-sprayed coatings were investigated. A detailed discussion of this can be found in Article entitled "Pressure-Based Liquid Feed System for Suspension Plasma Spray Coatings" by Elliot M. Cotler, Dianying Chen, Ronald J. Molz printed in the Journal of Thermal Spray Technology Volume 20, Number 4, pages 967 – 973 in May 2011). The disclosure of this document is hereby expressly incorporated by reference in its entirety.

[0008] Research found that injector proximity to plasma plume makes it necessary to maintain thermal management at all times. Any clogging upstream of the injector diminishes the flow of suspension through the injector orifice and reduces the cooling effect of a feedstock on internal surfaces. The resulting rise in temperature boils out the liquid phase and leaves a crust of agglomerated solids that could be further sintered into a practically irremovable plug. With that in mind, attempts were made to keep the injector cool and clean by switching to gas purge when feedstock is not fed, especially during plasma gun start-ups and shut-downs. Surprisingly, while gas purging did keep injector clean during gas purge (soon after switch back to suspension feed) within a few seconds the injector orifice was consistently clogged. The autopsies of ruined injectors indicated that gas purge led to creation of dried agglomerated crust of solids on inside surfaces exposed to gas flow. The subsequent flow of feedstock material lifted up crust flakes from the walls and carried them down toward the injector orifice. The size and shape of these flakes promoted quick clogging of the injector. To overcome the problem of after-purge clogging, the newly developed purge system includes a mist purger whereby the injection of a small amount of liquid into a purge gas occurs before its entrance to the feedstock injector. This minute amount of liquid is introduced by a pneumatically driven plunger pump into a mist generating device, where small droplets of liquid were formed and mixed with purge gas. The produced mixture combines the advantages of high purge gas velocity with high cooling capacity of mist and with wetting and washing properties of liquid.

[0009] In accordance with one non-limiting aspect of the invention there is provided an apparatus for injecting a liquid in an area of a thermal or thermo (e.g., plasma or HVOF) spray gun. The apparatus comprises an injector cleaning device having an inlet connectable to at least one feedstock supply line, an inlet connectable to at least one gas supply line, and an inlet connectable to at least one liquid medium supply line. An injector orifice is in fluid communication with the injector cleaning device and is adapted to at least one of inject a liquid jet into in the area (e.g., a hot stream or plasma created in the area) of the thermal spray gun and receive feedstock, gas and liquid passing into said inlets.

[0010] In embodiments, the at least one feedstock supply line, the at least one gas supply line, and the at least one liquid medium supply line are located upstream of the injector orifice.

[0011] In embodiments, the apparatus further comprises a mounting arrangement adapted to couple the injector cleaning device to a portion of the plasma spray gun.

[0012] In embodiments, the injector cleaning device comprises a purge block section and a mist chamber section.

[0013] In embodiments, the injector cleaning device comprises a mist chamber section and the inlet connectable to at least one gas supply line and the inlet connectable to at least one liquid medium supply line are at least one of arranged on the mist chamber section and coupled to the mist chamber section.

[0014] In embodiments, the injector cleaning device comprises a purge block section and the inlet connectable to at least one feedstock supply line is at least one of arranged on the purge block section and coupled to the purge block section.

[0015] In embodiments, the apparatus further comprises a mounting arrangement adapted to couple the injector cleaning device to a discharge end of the plasma spray gun.

[0016] In embodiments, the mounting arrangement comprises a gun mount securable to the plasma spray gun.

[0017] In embodiments, the mounting arrangement comprises a gun mount removably securable to the plasma spray gun.

[0018] In embodiments, the mounting arrangement comprises at least one of a gun mount securable to the plasma spray gun, a mounting block, and a support plate adapted to connect the mounting block to the injector cleaning device.

[0019] In accordance with a non-limiting aspect of the invention there is provided an injector cleaning apparatus for a plasma spray gun. The apparatus comprises at least one feedstock supply line, at least one gas supply line, and at least one liquid medium supply line. The at least one feedstock supply line, the at least one gas supply line, and the at least one liquid medium supply line are located upstream of an injector orifice located in an area of the plasma spray gun.

[0020] In embodiments, at least one of the feedstock supply line, the gas supply line and the liquid medium supply line are removably connected to an injector assembly.

[0021] In embodiments, the at least one liquid medium supply line is connected to a liquid medium supply that contains a liquid medium.

[0022] In embodiments, the liquid medium is a rinsing agent.

[0023] In embodiments, the liquid medium is a liquid structured and arranged to clean an injector for injecting feedstock.

[0024] In embodiments, the feedstock supply line is connected to a hopper that contains a feedstock.

[0025] In embodiments, the feedstock is at least one of a suspension, a precursor and a solution.

[0026] In embodiments, the apparatus further comprises a mister that mists liquid medium prior to entry of the liquid medium into an injector for injecting feedstock.

[0027] In embodiments, the apparatus further comprises a purging arrangement having two switchable mode as follows; a first mode wherein liquid feed is fed to the injector orifice and a second mode wherein liquid medium is fed to the injector orifice.

[0028] In embodiments, the apparatus further comprises an injector cleaning device adapted to combine liquid medium and purge gas upstream of the injector orifice.

[0029] In embodiments, the apparatus further comprises a controller adapted to control flow of at least one of a feedstock, a gas, a liquid medium, and a purging fluid.

[0030] In embodiments, there is provided a system for injecting a liquid jet into plasma of a plasma spray gun, comprising a plasma spray gun and an injector cleaning apparatus of any of the types described above.

[0031] In embodiments, there is provided a method of injecting a liquid jet into plasma of a plasma spray gun comprising arranging the injector cleaning apparatus of any of the types described above on a plasma spray gun and discharging a liquid via the injector orifice.

[0032] In embodiments, there is provided a method of injecting a liquid jet into plasma of a plasma spray gun comprising arranging the injector cleaning apparatus of any of the types described above on a plasma spray gun and injecting, via the injector orifice, a liquid jet into a plasma created in the area of the plasma spray gun.

[0033] In accordance with another non-limiting aspect of the invention there is provided a method of using the apparatus or system of any one of the types described above. The method comprises at least one of; activating a flow of liquid cleaning fluid in a gas dispersant after a flow of liquid feedstock is stopped, automatically producing a flow of an atomized liquid cleaning fluid after shut down of a flow of liquid feedstock, and activating a flow of liquid cleaning fluid in a gas dispersant each time a flow of liquid feedstock is stopped or shut down. The activating or producing substantially prevents build-up of obstruction material or crust formation on at least one flow surface arranged upstream of the injector orifice.

[0034] In embodiments, preferably as little liquid as possible is used to purge or clean the system. Gas options include at least one of argon, nitrogen, helium, methane and other suitable gasses. Liquid medium options include water, alcohols, glycol, glycerin, organic liquids (for example kerosene) and other cleaning solvents. Examples of an amount of liquid medium per purge shot include: minimum about 0.001 cc to unlimited (resulting in an almost continuous or continuous flow), preferably about 0.01 to about 1 cc liquid. The minimum amount of liquid to be used is preferably to achieve at least the dew point of the gas that is used. Mist is preferred over liquid because liquid is too slow through orifice – the mist can be under greater pressure. Misting or other ways similar to misting may be used. Purge shots can range from about 1 to about 400 per minute, preferably about 20 to about 100 shots per minute. A gas atomizer can be used instead of misting and is another way of cleaning the injector. In a preferred embodiment, use of less liquid with higher frequency of shots is preferred.

[0035] Other exemplary embodiments and advantages of the present invention may be ascertained by reviewing the present disclosure and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0036] The present invention is further described in the detailed description which follows, in reference to the noted drawings by way of a non-limiting example embodiment of the present invention, and wherein:

FIG. 1 shows a schematic of an experimental prototype pressurized liquid feed system in accordance with the invention;

FIG. 2 shows a photograph of the experimental prototype schematically illustrated in FIG. 1;

FIG. 3 shows a chart describing a liquid feed delivery rate for de-ionized water at room temperature. The upper curve relates to 0.012" I.D. injector orifice while the lower curve relates to 0.008" I.D. injector orifice;

FIG. 4 shows a photograph of idle suspension jet mounted to a 9MB plasma spray gun in accordance with the invention;

FIG. 5 shows a perspective view of an injector feedstock cleaning apparatus which can be used with the pressurized liquid feed system of FIG. 1 and in accordance with the invention;

FIG. 6 shows a front view of FIG. 5;

FIG. 7 shows a perspective view of the injector cleaning device used in the apparatus of FIG. 5;

FIG. 8 shows a front view of the injector cleaning device of FIG. 7;

FIG. 9 shows a side cross-section view of section A-A in FIG. 8;

FIG. 10 shows a non-limiting method of using the apparatus of the invention in accordance with one exemplary mode of operation; and

FIG. 11 shows a non-limiting method of using the apparatus of the invention in accordance with another exemplary mode of operation.

DETAILED DESCRIPTION OF THE INVENTION

[0037] The particulars shown herein are by way of example and for purposes of illustrative discussion of the embodiments of the present invention only and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the present invention. In this regard, no attempt is made to show structural details of the present invention in more detail than is necessary for the fundamental understanding of the present invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the present invention may be embodied in practice.

[0038] A liquid feeder proof of concept prototype was successfully developed and tested. It demonstrated that continuous and stable operation of a liquid based feedstock feeder is possible. A novel approach to semi-automated injector cleaning was developed and showed robustness on a level necessary for industrial thermal spray applications.

[0039] The prototype feeding system was used to produce coatings with ultrafine splats from liquid feedstock suspensions of Alumina, Titania and YSZ. Analysis of the resulting coating structure and composition showed favorable results with potential for further optimization for specific applications.

[0040] FIG. 1 shows a principal schematic of the developed prototype system or arrangement in accordance with one non-limiting embodiment of the invention. In the system, a feedstock is contained in a pressurized feedstock reservoir that is mounted off a load cell connected to a Powder Feed Rate Meter (PFRM) differential analyzer. It displays an actual weight loss of the feedstock reservoir in either g/min or lb/hr as selected by operator.

[0041] A top cover of the reservoir has a built-in pneumatically driven stirrer motor that keeps the feedstock suspension mildly agitated to prevent sedimentation and to maintain the uniformity of solids concentration throughout. The stirrer operates by compressed air taken from a shop air supply line. It turns on or off via the stirrer control solenoid and allows for a speed adjustment. To facilitate this operation, the system utilizes a front panel pressure regulator. A pressure gauge reading serves as an indirect indicator of stirrer speed.

[0042] A single source of gas (argon or nitrogen) is used for both injector purge and feedstock feed functions. When the feed control solenoid is on, a pressure regulator adjusts the desired level of pressure applied to reservoir. The pressurized feedstock charges the feedstock line **18** and exits through injector **30** into the plasma plume. To stop feeding, a feed control solenoid turns off and a purge control solenoid and exhaust solenoid turns on allowing a purge gas line **16** to pressurize and the feedstock reservoir and feedstock line **18** to de-pressurize. A delay-on-break timer keeps purge and exhaust solenoids on to allow the reservoir to de-pressurize completely. Simultaneously, a recycling timer turns on and off a pulse control solenoid that supplies pressure pulses to a liquid injector pump. The amount of liquid delivered with each stroke can be adjusted from about 0 to about 0.1 cc by the adjustment screw that limits travel of pump plunger. A washing liquid from the pump reservoir charges washing liquid line **20** and enters mist generator where it mixes with purge gas and washes internal passages of feedstock injector. A check valve on the feedstock line **18** prevents the purge mix from entering and diluting feedstock.

[0043] The complete system created and used is shown on FIG. 2. All tests have been performed with feedstock reservoir of 2 liter capacity and 25feet (7.62 m) long feedstock line of

0.062" (1.6 mm) I.D. (inside diameter). The actual delivery rate depends greatly on feedstock viscosity and injector size and internal profile. FIG. 3 shows a baseline comparison between de-ionized water rates through injectors with orifice sizes of 0.008" (0.2 mm) and 0.012" (0.3 mm). A suspension jet from an injector **30** mounted off 9MB plasma gun nozzle is shown in FIG. 4.

Performance Testing of the System

[0044] The experimental prototype of liquid feed system of FIGS. 1 and 2 has shown a fairly robust performance for all tested suspensions. A novel purge system kept the injector clean and even allowed the feedstock line to be kept fully charged and waiting for 1- 1.5 hr without injector dismounting during short work breaks. For overnight breaks, the whole injector mount was taken off the gun and placed into a container filled with water. The next day it was ready to work right after mounting back onto the plasma gun nozzle. Longer periods of storage or changes between feedstock required full clean-up of the feedstock reservoir, lines and injector mount.

Injector Feedstock Cleaning Apparatus

[0045] A non-limiting injector feedstock cleaning apparatus which can be used with the non-limiting system of FIG. 1 is shown in FIGS. 5-9. The apparatus **1** is utilized for injecting a liquid in an area of a plasma spray gun **100** (see FIG. 1). As shown in FIG. 5, the apparatus **1** has three main components. A first component is an injector cleaning device **10** which includes an inlet (see FIG. 9) connectable to a connector **19** of at least one feedstock supply line **18**, an inlet connectable to a connector **17** of at least one gas supply line **16**, and an inlet connectable to a connector **21** of at least one liquid medium supply line **20**. Also includes is a mist chamber section **12** to which lines **16** and **20** are connected and a purge block section **11** to which line **18** is connected. An internal passage **22** (see FIG. 9) forms a fluid connection path between an internal space coupled to lines **16** and **20** and to an output passage in the purge block section **11** leading to an injector **30**. Lines **16** and **20** feed gas and liquid into an atomizing chamber **23**. Once the liquid from the line **20** is dispersed in the gas from line **16**, it can pass by a check valve **24** and then travel through passage **22**. The check valve **24** is a one-way valve that prevents backflow and specifically prevents any feedstock from passing into the chamber **23** when the feedstock is being fed out of the injector **30**. Line **18** feeds feedstock into a chamber containing another check valve **25** which then travels through passage containing a filter **26**, e.g., a final screen filter which can trap particles or contamination that capable of clogging the injector **30**. The check valve **25** is a one-way valve that prevents backflow and specifically prevents any fluid passing through passage **22** from passing into the feedstock line **18** when the dispersed cleaning fluid is being fed out of the injector **30**.

[0046] The injector **30** forms a second main component of the apparatus **1**. An elbow tubing connector **13** has connectors **14** and **15** which connect the output port of the purge block **11** to an input **31** of the injector **30**. In this way, feedstock and/or fluid passing out of the purge block **11** can pass through an injector body **32** and out of an injector orifice **33**.

[0047] A third component of the apparatus **1** is a mounting arrangement **40**. The mounting arrangement **40** couples the injector cleaning device **10** and injector **30** to a portion or discharge end of the plasma spray gun **100** (see FIGS. 1 and 2). The mounting arrangement **40** includes a gun mount **41** whose opening **48** slides over a portion of the plasma spray gun **100** and which is securable or removably clampable to the plasma spray gun **100**. A fastener **47** can be used to adjust the clamping force of and allow for removal of the gun mount **41**. The gun mount **41** is coupled to a mounting block **42** to which the injector body **32** is also mounted in a manner which maintains a desired or predetermined distance between the injector output or orifice **33** and the block **41**. A support plate **43** connects the mounting block **42** to the injector cleaning device **10** and, more specifically, to the purge block **11** of the device **10**. Fasteners **46** connect the plate **43** to the mounting block **42**. An adjusting device in the form of a fastener nut **45** adjustably connects the plate **43** to the purge block **11** while a slot **44** provides for sliding adjustability.

[0048] The modes of operation of the apparatus 1 will now be discussed with reference to FIGS. 1 and 5-9 and as exemplified in the non-limiting modes shown in FIGS. 10 and 11. In FIG. 10, the apparatus can be utilized in accordance with a method of cleaning and cooling the injector during intermittent shutdown of liquid feedstock while the gun is running, i.e., liquid feedstock passing through the injector **30** and arriving via conduit **18** is stopped and restarted without stopping a thermal spray gun. Additionally or alternatively, in cases where thermal spray gun has to be stopped and to prevent overheating of the injector, the mode described in FIG. 11 can be utilized. One should keep in mind, however, the problem of engaging liquid feedstock flow while the injector is hot because it can cause precipitation and clogging of the same.

[0049] More specifically, in the mode of FIG. 10, liquid feedstock passing out of injector **30** and through the cleaning device **10** after arriving via line **18** is stopped at stage **100**. Then, gas and cleaning liquid pass through the device **10** and out of the injector **30** after arriving via lines **16** and **20** in stage **200**. This can occur for a predetermined amount of time via a timer or by input from an operator. The device **10** ensures that the gas and liquid produce therein a purging mist which passes into and out of the injector **30** and keeps it clean and cool. After, the purging mist is stopped in stage **300** and the device **10** resumes the feeding of liquid feedstock into and out of injector **30** in stage **400**.

[0050] In the mode of FIG. 11, liquid feedstock passing out of injector **30** and through the cleaning device **10** after arriving via line **18** is similarly stopped at stage **1000**. Then, gas and cleaning liquid pass through the device **10** and out of the injector **30** after arriving via lines **16** and **20** in stage **2000**. The thermal spray gun **100** can then be shut down in stage **3000**. After shut down, the purging mist is stopped in stage **4000**. This can occur after a predetermined amount of time via the timer. The device **10** can then resume the feeding of liquid feedstock into and out of the injector **30** at a later time or date.

[0051] In one exemplary embodiment, the flow rate of fluid passing out of the orifice of the injector **30** is approximately 16 scfh (standard cubic feet per hour) utilizing a 0.012 inch orifice at 120 psi. In another exemplary embodiment, the flow rate of fluid passing out of the orifice of the injector **30** is approximately 7.2 scfh utilizing a 0.008 inch orifice at 120 psi. In still another exemplary embodiment, the flow rate of fluid passing out of the orifice of the injector **30** is approximately 1.8 scfh utilizing a 0.004 inch orifice at 120 psi. In embodiments, any liquid pump can be utilized to feed washing fluid to the mist nozzle provided it functions in the coating environment.

[0052] It is noted that the foregoing examples have been provided merely for the purpose of explanation and are in no way to be construed as limiting of the present invention. While the present invention has been described with reference to an exemplary embodiment, it is understood that the words which have been used herein are words of description and illustration, rather than words of limitation. Changes may be made, within the purview of the appended claims, as presently stated and as amended, without departing from the scope and sprit of the present invention in its aspects. Although the present invention has been described herein with reference to particular means, materials and embodiments, the present invention is not intended to be limited to the particulars disclosed herein; rather, the present invention extends to all functionally equivalent structures, methods and uses, such as are within the scope of the appended claims.

WHAT IS CLAIMED:

1. An apparatus for injecting a liquid in an area of a thermal spray gun, the apparatus comprising:

an injector cleaning device comprising:

an inlet connectable to at least one feedstock supply line;

an inlet connectable to at least one gas supply line; and

an inlet connectable to at least one liquid medium supply line,

an injector orifice in fluid communication with the injector cleaning device and being adapted to at least one of:

inject a liquid jet into the area of the thermal spray gun; and

receive feedstock, gas and liquid passing into said inlets.

2. The apparatus of claim 1, wherein the injector cleaning device comprises a liquid atomizing chamber adapted to disperse liquid into a gas stream upstream of the injector orifice.

3. The apparatus of claim 1, wherein the at least one feedstock supply line, the at least one gas supply line, and the at least one liquid medium supply line are located upstream of the injector orifice.

4. The apparatus of claim 1, further comprising a mounting arrangement adapted to couple the injector cleaning device to a portion of the thermal spray gun.

5. The apparatus of claim 1, wherein the injector cleaning device comprises at least one of:

a purge block section and a mist chamber section;

a mist block section comprising a gas/liquid mixing chamber arranged upstream of a check valve;

a purge block section comprising a check valve and a filter for preventing contaminates entrained in liquid or gas from passing out of the injector orifice; and

a purge block section comprising a passage in fluid communication with a check valve arranged downstream of the inlets of the liquid medium and gas supply lines and in fluid communication with another passage arranged downstream of the feedstock supply line.

6. The apparatus of claim 1, wherein the injector cleaning device comprises a mist chamber section and the inlet connectable to at least one gas supply line and the inlet connectable to at least one liquid medium supply line are at least one of:

arranged on the mist chamber section; and

coupled to the mist chamber section.

7. The apparatus of claim 1, wherein the injector cleaning device comprises a purge block section and the inlet connectable to at least one feedstock supply line is at least one of:

arranged on the purge block section; and

coupled to the purge block section.

8. The apparatus of claim 1, further comprising a mounting arrangement adapted to couple the injector cleaning device to a discharge end of the thermal spray gun.

9. The apparatus of claim 8, the mounting arrangement comprising a gun mount securable to the thermal spray gun.

10. The apparatus of claim 8, the mounting arrangement comprising a gun mount removably securable to the thermal spray gun.

11. The apparatus of claim 8, the mounting arrangement comprising at least one of:

a gun mount securable to the thermal spray gun;

a mounting block; and

a support plate adapted to connect the mounting block to the injector cleaning device.

12. An injector cleaning apparatus for a thermal spray gun, comprising:

at least one feedstock supply line;

at least one gas supply line; and

at least one liquid medium supply line,

wherein the at least one feedstock supply line, the at least one gas supply line, and the at least one liquid medium supply line are located upstream of an injector orifice located in an area of the thermal spray gun.

13. The apparatus of claim 12, wherein at least one of the feedstock supply line, the gas supply line and the liquid medium supply line are removably connected to an injector assembly.

14. The apparatus of claim 12, wherein the at least one liquid medium supply line is connected to a liquid medium supply that contains a liquid medium.

15. The apparatus of claim 14, wherein the liquid medium is a rinsing agent.

16. The apparatus of claim 14, wherein the liquid medium is a liquid structured and arranged to clean an injector for injecting feedstock.

17. The apparatus of claim 12, wherein the feedstock supply line is connected to a hopper that contains a feedstock.

18. The apparatus of claim 17, wherein the feedstock is at least one of a suspension, a precursor and a solution.

19. The apparatus of claim 12, further comprising a mister that mists liquid medium prior to entry of the liquid medium into an injector for injecting feedstock.

20. The apparatus of claims 12-19, further comprising a purging arrangement having two switchable mode as follows:

a first mode wherein liquid feed is fed to the injector orifice; and

a second mode wherein liquid medium is fed to the injector orifice.

21. The apparatus of claims 12-20, further comprising an injector cleaning device adapted to combine liquid medium and purge gas upstream of the injector orifice.

22. The apparatus of claims 12-21, further comprising a controller adapted to control flow of at least one of:

a feedstock;

a gas;

a liquid medium; and

a purging fluid.

23. A system for injecting a liquid jet into a hot stream or plasma of a thermal spray gun, comprising:

a thermal spray gun; and

the injector cleaning apparatus of claim 12.

24. A system for injecting a liquid jet into hot stream or plasma of a thermal spray gun, comprising:

a thermal spray gun; and

the injector cleaning apparatus of claim 1.

25. A method of injecting a liquid jet into hot stream or plasma of a thermal spray gun, comprising:

arranging the injector cleaning apparatus of claim 12 on a thermal spray gun; and

at least one of:

discharging a liquid via the injector orifice;

discharging each of a feedstock and a cleaning liquid via the injector orifice at two different points in time; and

discharging a feedstock via the injector orifice during a feedstock feed cycle and discharging a cleaning fluid via the injector orifice during a cleaning fluid cleaning cycle.

26. A method of injecting a liquid jet into hot stream or plasma of a thermal spray gun, comprising:

arranging the injector cleaning apparatus of claim 1 on a thermal spray gun; and

injecting, via the injector orifice, a liquid jet into a hot stream or plasma created in the area of the thermal spray gun.

27. A method of using the apparatus or system of any one of claims 1-24, comprising at least one of:

activating a flow of liquid cleaning fluid in a gas dispersant upon a flow of liquid feedstock is stopped;

automatically producing a flow of an atomized liquid cleaning fluid after shut down of a flow of liquid feedstock; and

activating a flow of liquid cleaning fluid in a gas dispersant each time a flow of liquid feedstock is stopped or shut down,

whereby the activating or producing substantially prevents build-up of obstruction material or crust formation on at least one flow surface arranged upstream of the injector orifice.

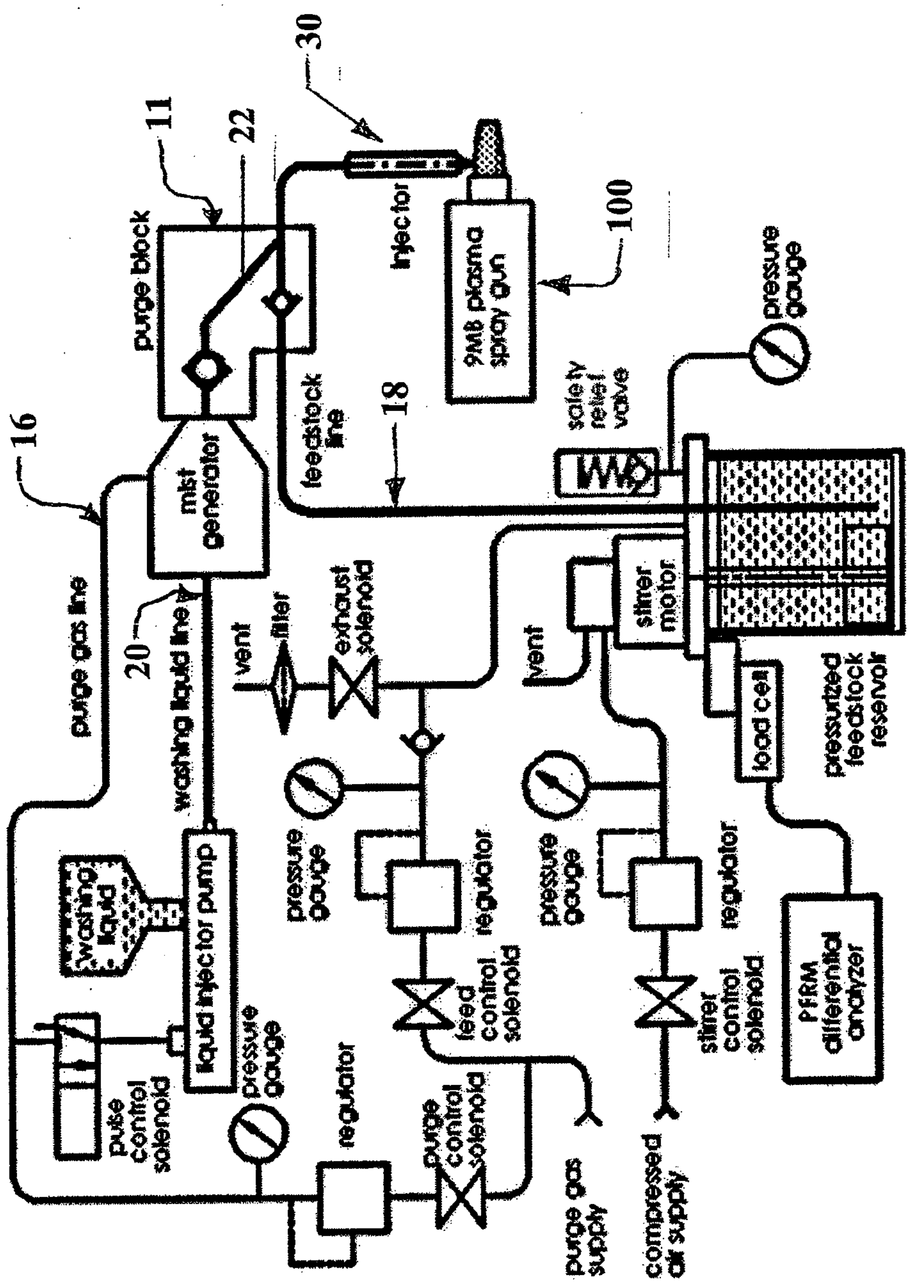
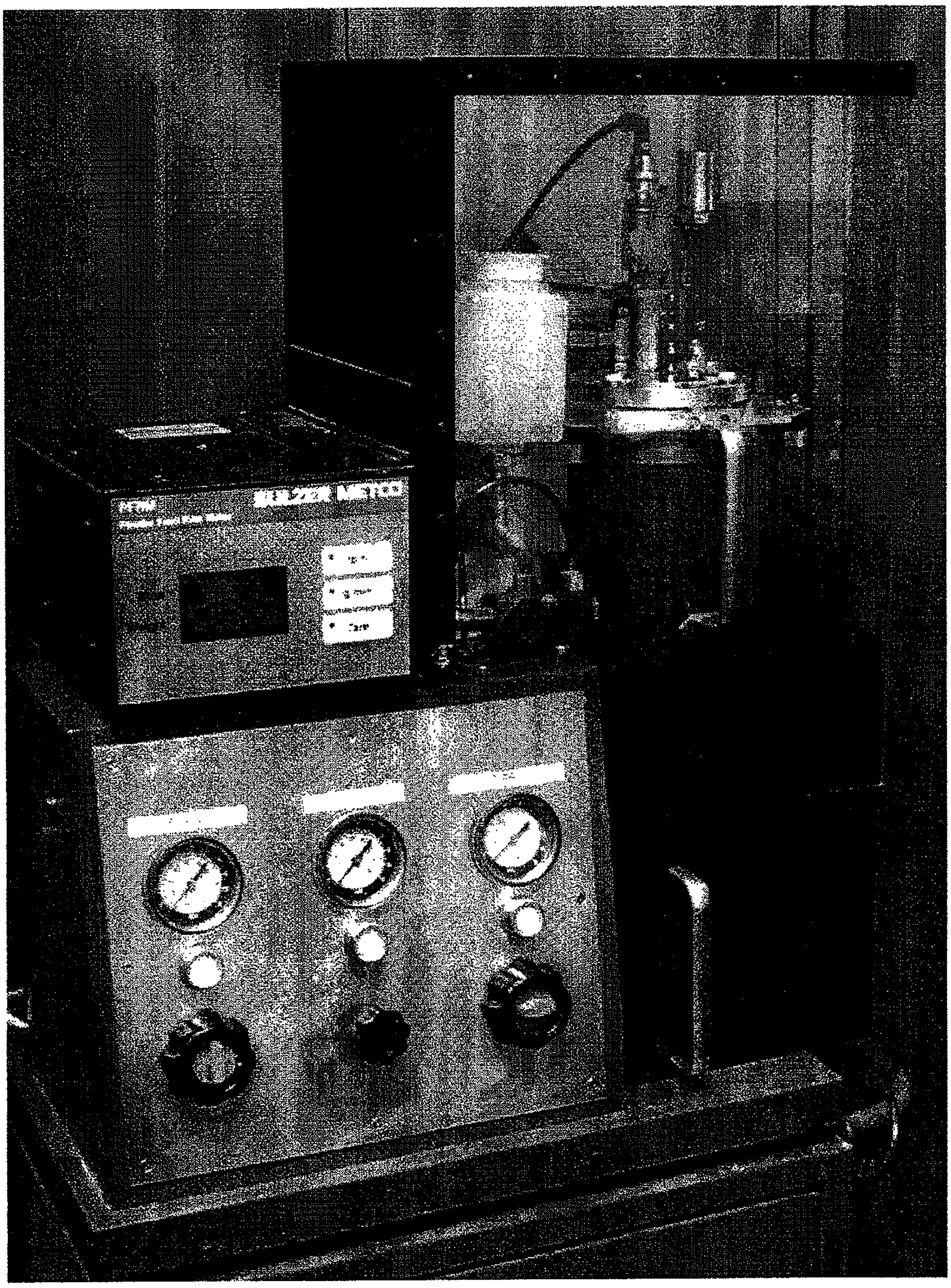

30
11
22
purge block
injector
100
9MB plasma spray gun
16
mist generator
feedstock line
18
safety relief valve
pressure gauge
purge gas line
20
washing liquid line
vent
filter
exhaust solenoid
vent
stirrer motor
pressurized feedstock reservoir
load cell
washing liquid
liquid injector pump
pressure gauge
regulator
pressure gauge
regulator
pulse control solenoid
pressure gauge
regulator
feed control solenoid
stirrer control solenoid
PFRM differential analyzer
purge control solenoid
purge gas supply
compressed air supply

FIG. 1

FIG. 2



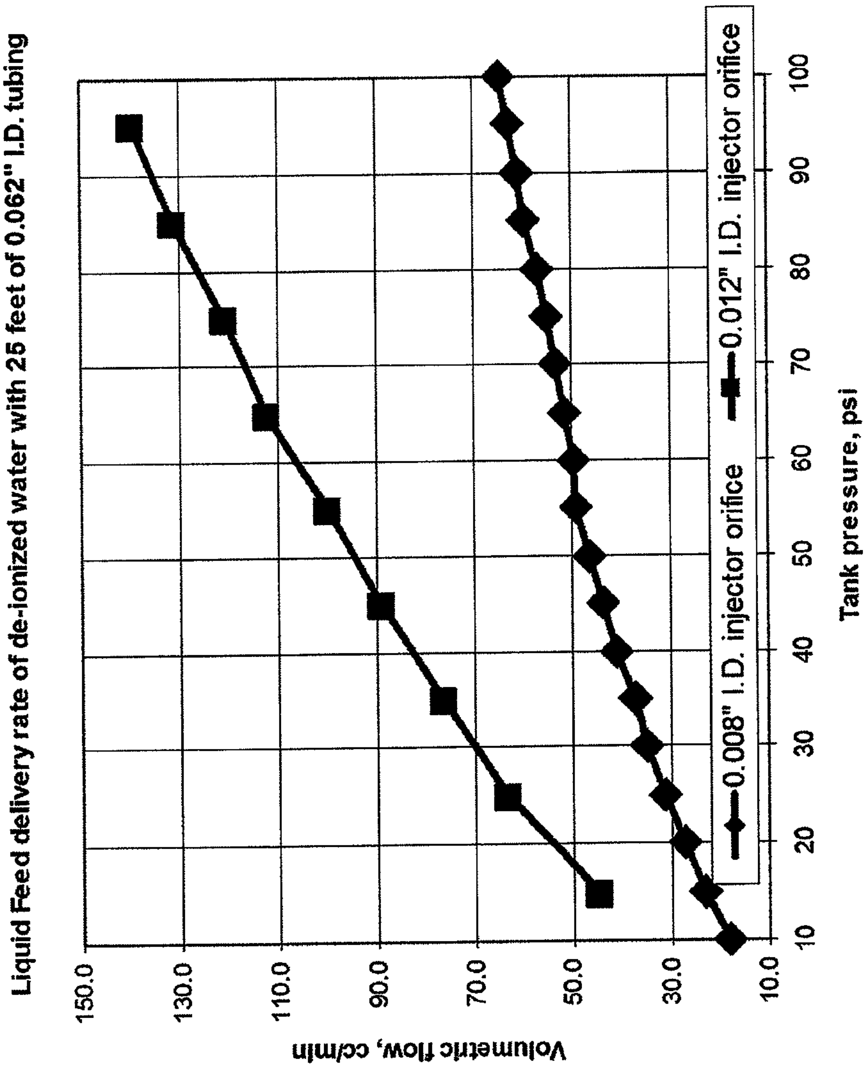

Liquid Feed delivery rate of de-ionized water with 25 feet of 0.062" I.D. tubing
Volumetric flow, cc/min
150.0
130.0
110.0
90.0
70.0
50.0
30.0
10.0
10
20
30
40
50
60
70
80
90
100
Tank pressure, psi
0.008" I.D. injector orifice
0.012" I.D. injector orifice

FIG. 3

FIG. 4

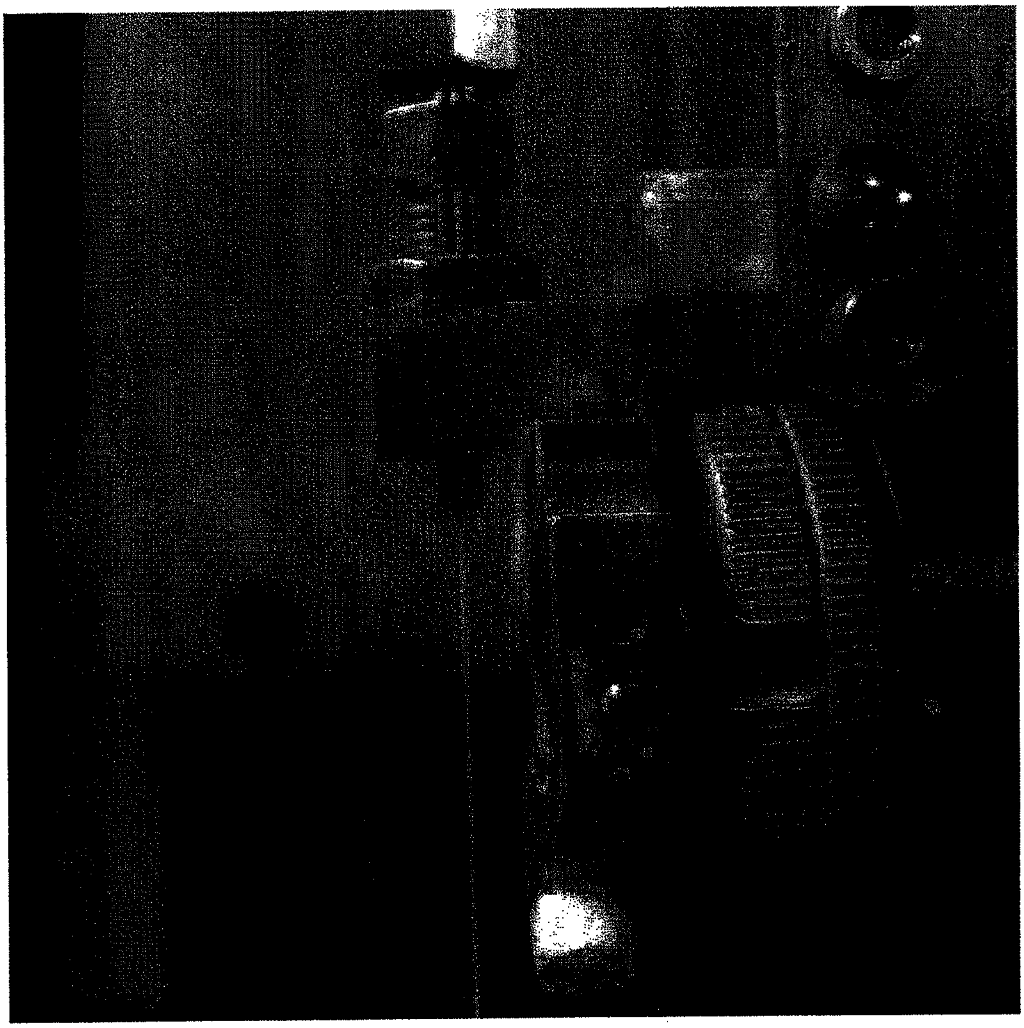


FIG. 5

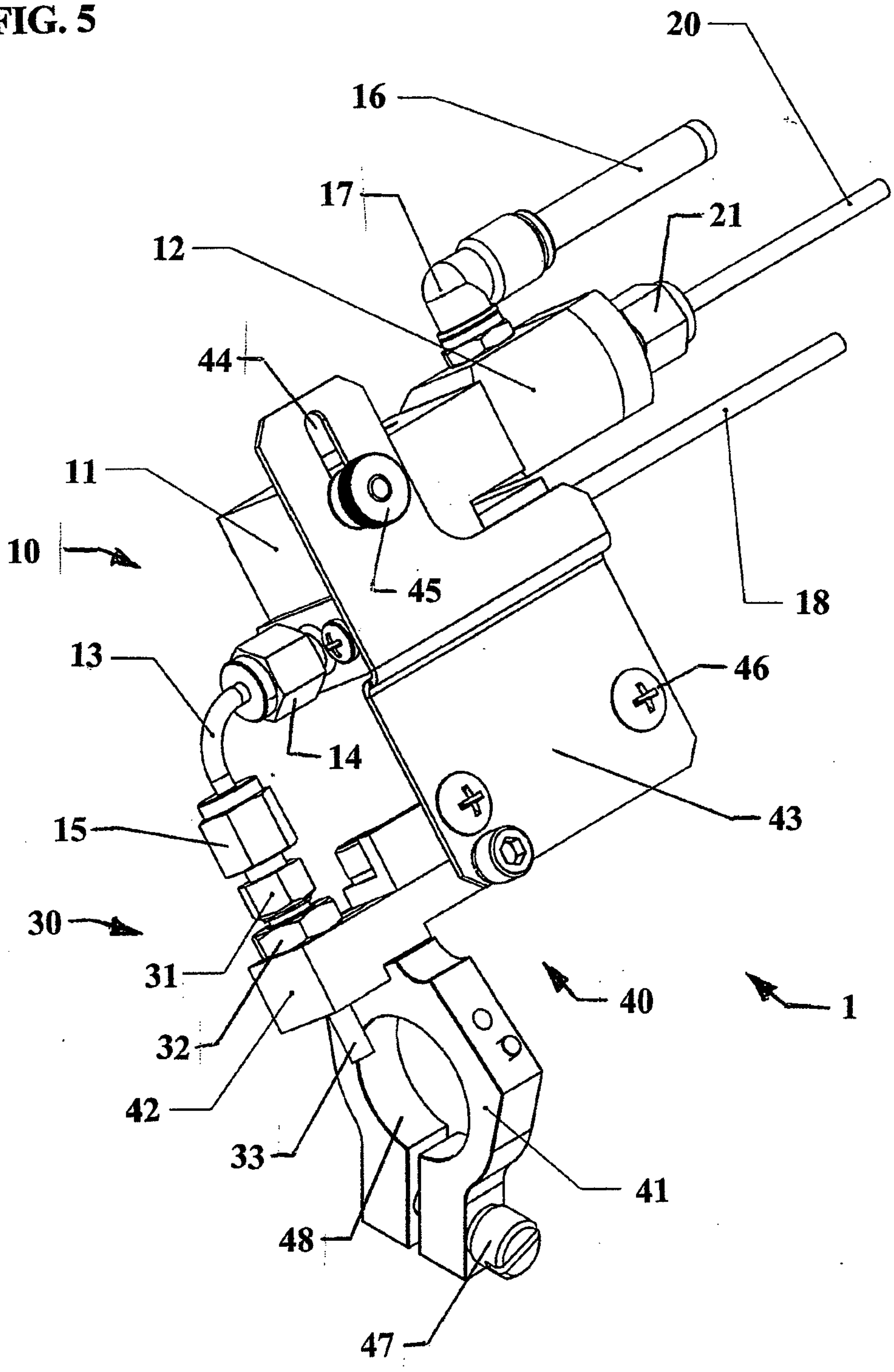
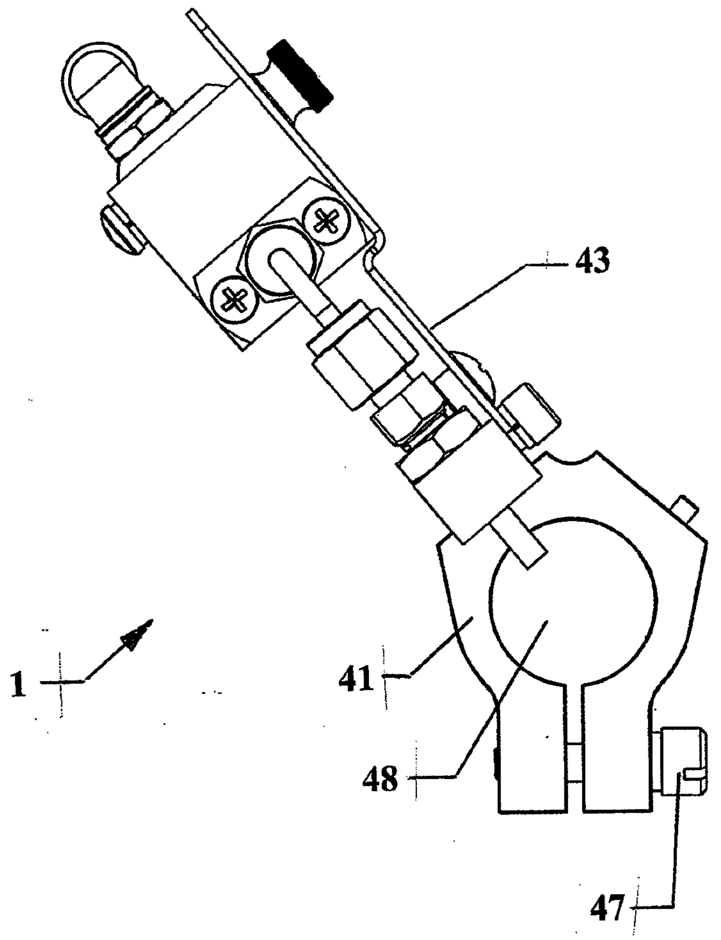


FIG. 6



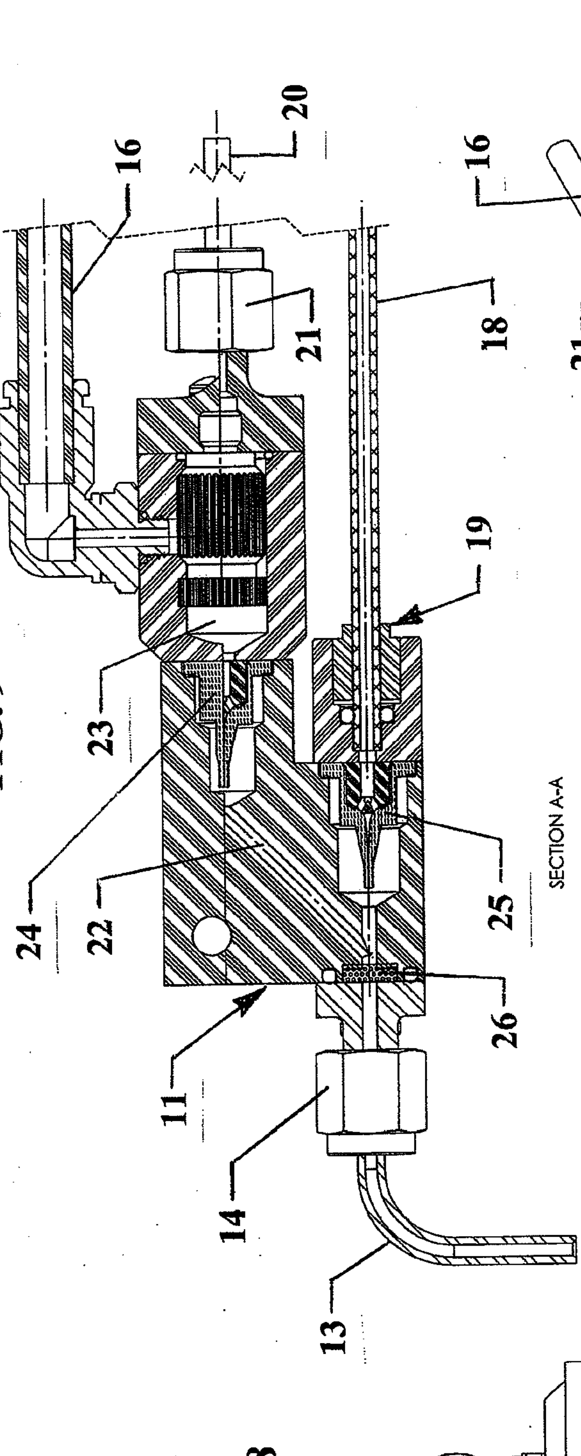


FIG. 9

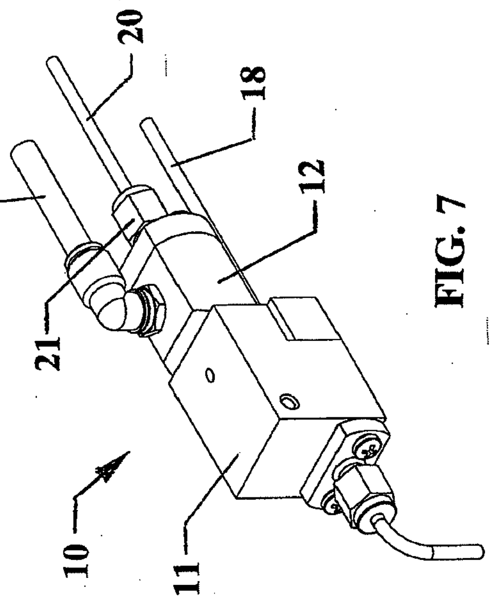


FIG. 7

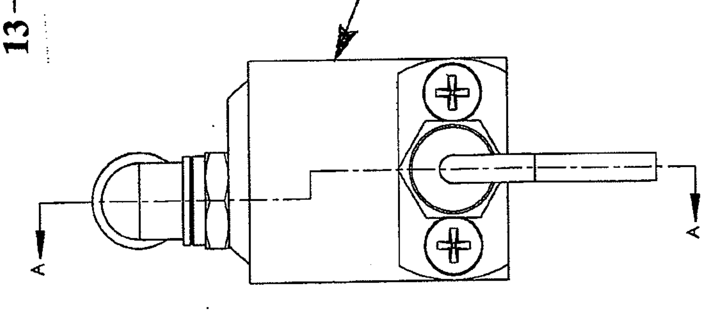


FIG. 8

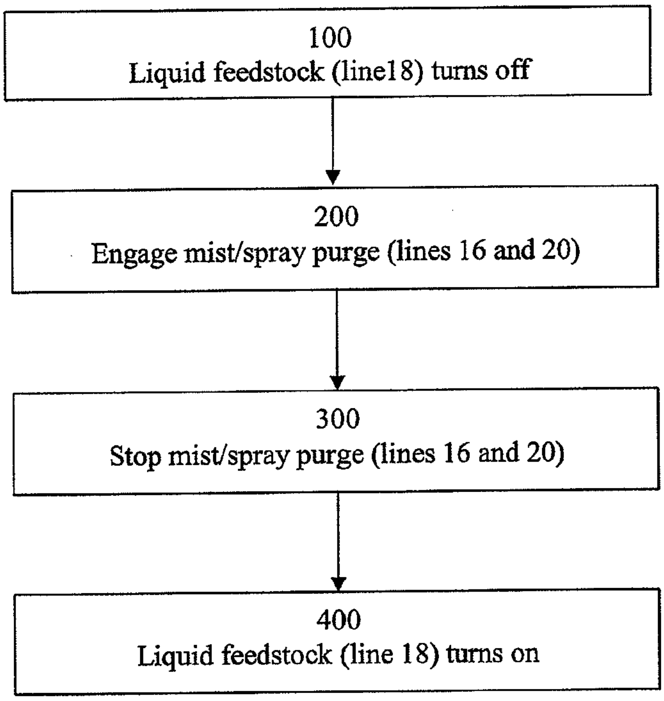

100
Liquid feedstock (line18) turns off
200
Engage mist/spray purge (lines 16 and 20)
300
Stop mist/spray purge (lines 16 and 20)
400
Liquid feedstock (line 18) turns on

FIG. 10

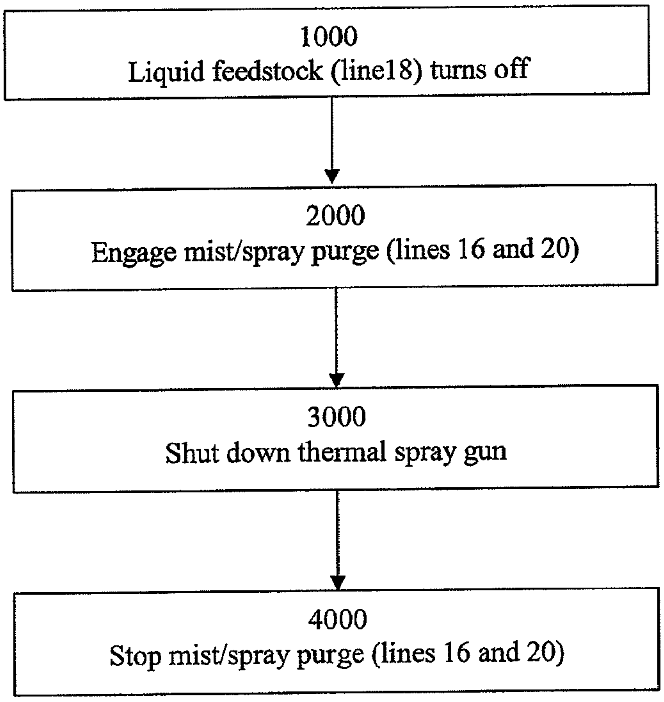

1000
Liquid feedstock (line18) turns off
2000
Engage mist/spray purge (lines 16 and 20)
3000
Shut down thermal spray gun
4000
Stop mist/spray purge (lines 16 and 20)

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2011/064919

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - C23C 16/00 (2012.01)
USPC - 219/121.5
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - B23K 9/00; C23C 4/04, 16/00 (2012.01)
USPC - 219/121.47, 121.5; 118/715

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
MicroPatent, Freepatentsonline, Google, Google Patents, Science Direct

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2004/0226508 A1 (MA et al) 18 November 2004 (18.11.2004) entire document	1-19, 23-26
Y	US 2006/0289405 A1 (OBERSTE-BERGHAUS et al) 28 December 2006 (28.12.2006) entire document	1-19, 23-26
A	US 2008/0090071 A1 (VALLE et al) 17 April 2008 (17.04.2008) entire document	1-19, 23-26

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 March 2012	17 APR 2012

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2011/064919

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 20-22, 27
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.