United States Patent

Roblin et al.

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[54] **APPARATUS FOR VAPORIZING MOLTEN METAL**

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[52] **U.S. Cl.**.....**266/34 R**, 117/107, 118/49

[51] **Int. Cl.**.....**C21c 7/00**

[58] **Field of Search**.....118/48, 49, 49.1, 49.5; 117/107, 107.1; 266/34 R, 39

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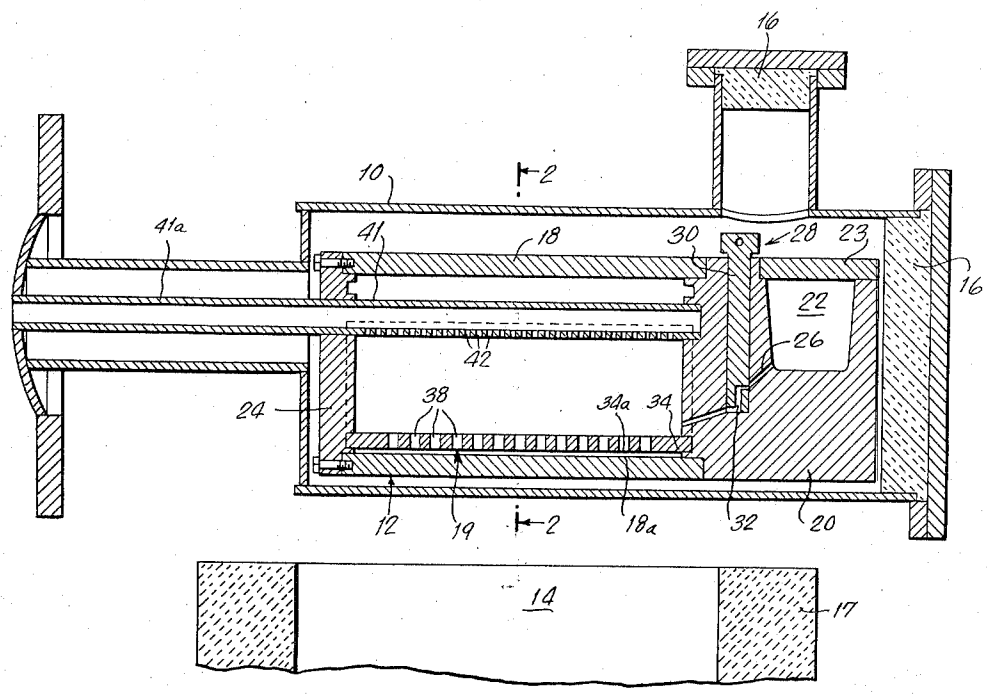
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[57] **ABSTRACT**

Apparatus and method for vacuum vaporization of molten metal without entrainment of liquid droplets includes charging a pool of molten metal into a first cylinder member which has its central axis disposed horizontally and has at least one passage therethrough. A second cylinder member, also having its central axis disposed horizontally, encloses the first cylinder member so as to receive molten metal through the passage. A thin semi-cylindrical shell of fluid metal is thus formed between the cylinder members. Heating the thin shell generates metal vapor. The metal vapor is passed through a tortuous path to remove any liquid droplets, and is discharged from an outlet nozzle for deposition upon a substrate.

In a modification the molten metal is contained in the lower portion of an evaporator member. A shelf with a passage therethrough divides the evaporator member horizontally while allowing generated metal vapor to pass to the upper portion of the evaporator member. There the vapor is passed through a tortuous path to remove any liquid droplets, thence proceeding to an outlet nozzle for deposition upon a substrate.

22 Claims, 9 Drawing Figures



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SHEET 1 OF 3

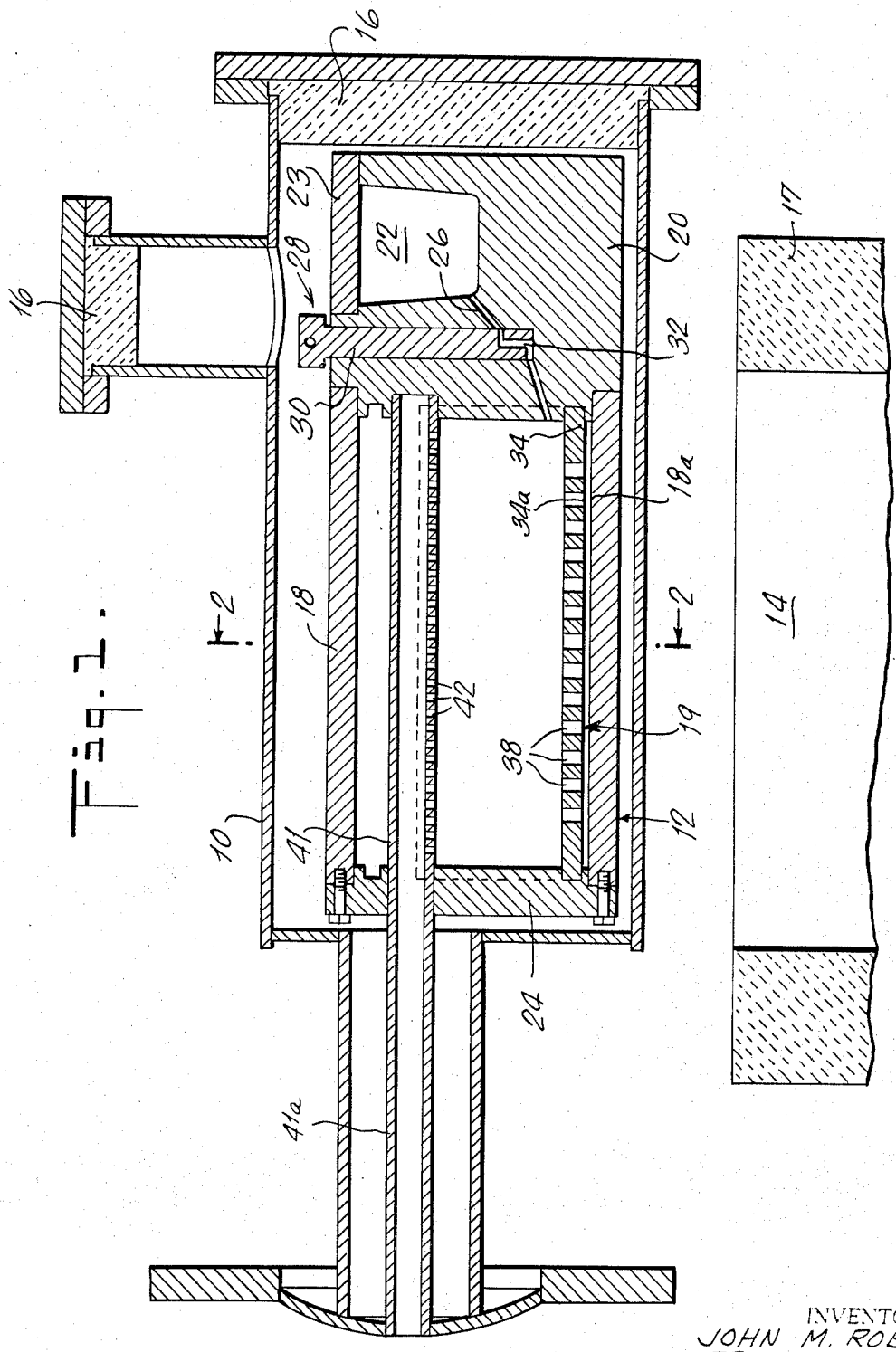


Fig. 1.

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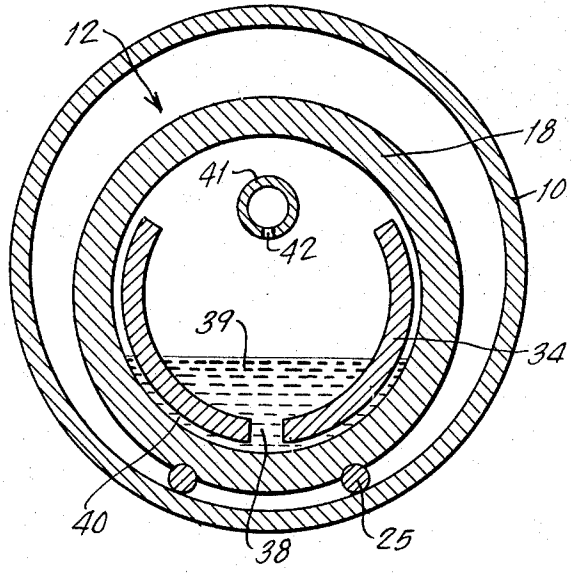


Fig. 2.

Fig. 7.

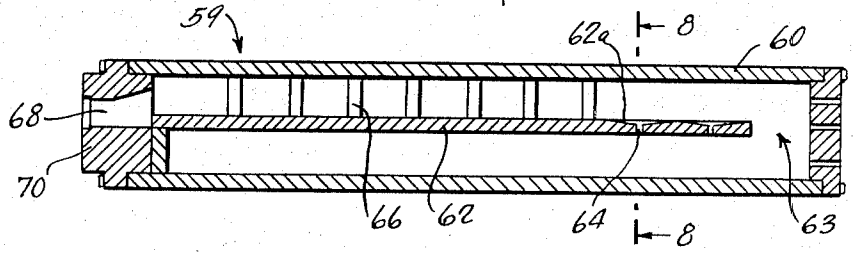


Fig. 8.

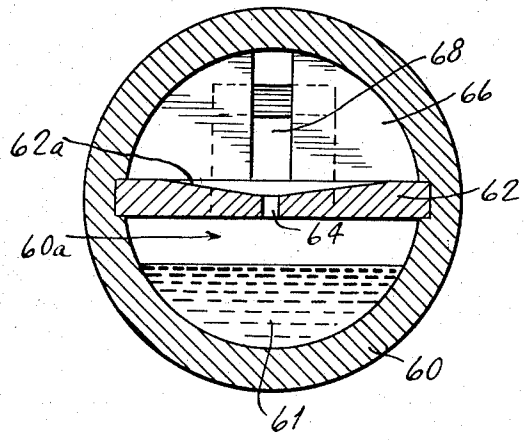
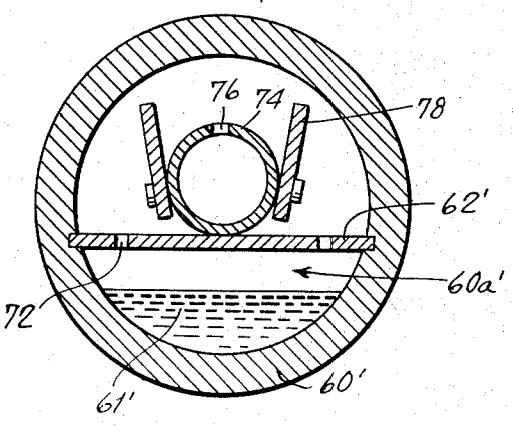


Fig. 9.



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Fig. 3.

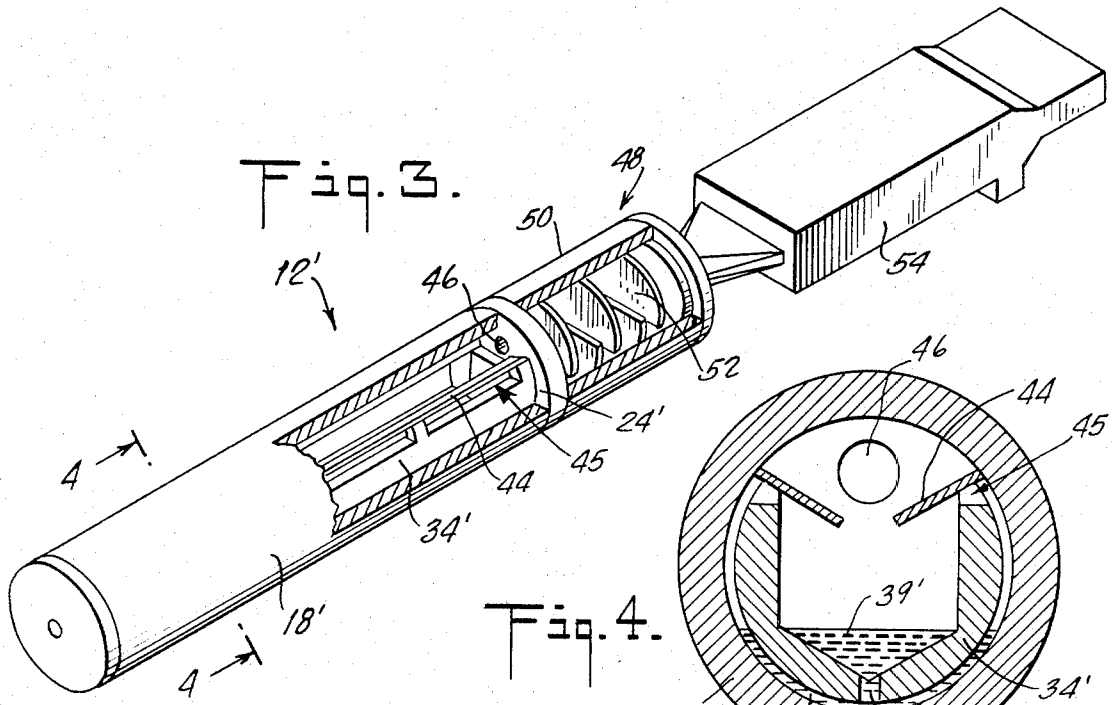


Fig. 4.

Fig. 5.

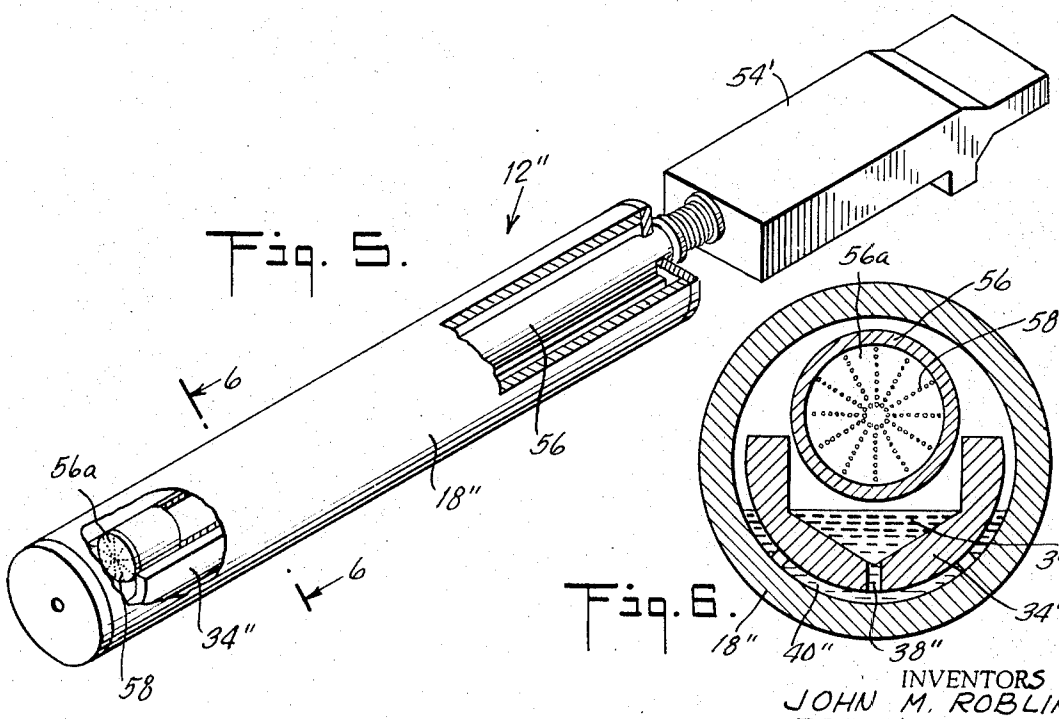


Fig. 6.

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APPARATUS AND METHOD FOR VAPORIZING MOLTEN METAL

BACKGROUND OF THE INVENTION

This invention relates to vaporizing molten metal, particularly zinc, while preventing liquid droplets from being entrained in the metal vapor.

Vaporized zinc coatings on steel offer many advantages over conventional electroplated zinc coatings and hot dip galvanized coatings. A smooth coating can be produced by vapor deposition while coating thickness can be varied by controlling the zinc evaporation rate and/or the speed of a moving steel substrate to be coated. A one-side coating can be easily produced by properly shielding the strip. Composite coatings, e.g., a thin aluminum coating over a thin zinc coating, can be produced by vapor deposition, the steel thus coated having excellent corrosion resistance. Production speed can be considerably faster for vapor deposition than for an electroplating line or a hot dip galvanizing line because the restrictions of current density and coating roll speed do not apply. There is no inherent limitation on the gage of steel that might be coated, and is unlike galvanizing lines where line speed must be lowered as thickness and/or width of the strip is increased in order to allow for increased heat demand on the galvanizing pot. Furthermore, the cost of vapor deposition is believed to be less than the cost of either electroplating or hot dip galvanizing.

Traditionally, metals have been evaporated from crucibles simply by heating the metal to a temperature above its vaporization point and then removing the vapor from the crucible, e.g., by vacuum methods. At a high rate of vaporization, solid or liquid particles may become entrained in the vapor. It is not necessary to distinguish between liquid and solid particles as both have the same deleterious effect when present in the form of splatter upon a substrate. Several methods of avoiding the splatter problem have been attempted in the past. Many prior art devices and methods, however, may not be successfully employed to generate metal vapor that is completely free of included particles nor to generate metal vapor at a controllable high rate suitable for commercial plating of steel strip, for example.

The following prior art patents are representative:

U.S. Pat. No.	Patentee(s)	Issued
3,400,241	Gloerson et al.	3 Sept. 1968
2,447,789	Barr	24 Aug. 1948
2,446,557	Schutz et al.	10 Aug. 1948
1,981,765	Weiss	20 Nov. 1934
1,265,863	Abbott, Jr.	14 May 1918
899,738	Kirkwood	29 Sept. 1908

SUMMARY OF THE INVENTION

It is an object of the present invention to provide apparatus and method for vaporizing molten metal with elimination of particles in the generated metal vapor.

Another object is to provide apparatus for coating a continuously moving substrate with metal vapor at a controllable and high rate of production. More particularly, an object of the invention is to provide apparatus for coating a moving steel strip with zinc vapor devoid of splatter.

To these and other ends, the present invention contemplates metal vaporizing apparatus and method in which molten metal is formed into a thin semi-cylindrical shell having a horizontally disposed central axis. The thin shell communicates with and is supplied from a body of metal. Heating the thin shell of molten metal under vacuum produces metal vapor. The metal vapor generated is directed against a substrate to be coated.

In one embodiment of the invention a first cylinder member is charged with a pool of molten metal. The first cylinder member has its central axis disposed horizontally and has at least one passage extending therethrough. A second or outer cylinder member with its central axis disposed horizontally encloses the first cylinder member and receives molten metal through the passage in the first cylinder member so as to form a thin semi-cylindrical shell of molten metal between the cylinder members. As the thin shell of molten metal remains fixed in size, there is always a constant supply of molten metal between the cylinder members for vaporization. Preferably, each of the cylinder members as well as the other elements of the system are fabricated of graphite when the molten metal is zinc, since graphite is not attacked (neither corroded by nor reactive with) by zinc.

The first or inner cylinder member is cut away in its top portion so that means defining a tortuous path for removing any particles in the generated vapor may be disposed in that area. An outlet removes the generated vapor after it has passed through the tortuous path and includes a nozzle for directing the vapor against a moving substrate to be coated.

In another embodiment of the invention an evaporator member defining an evaporation chamber is employed. The molten metal is disposed in the lower portion of the chamber where it is heated to generate metal vapor. A shelf extends horizontally across and divides the chamber, although the shelf is provided with a passage to allow the metal vapor to pass therethrough. In one form of this embodiment the shelf is tilted downwardly toward one end of the chamber and a portion of the shelf is recessed about an aperture to collect liquid droplets removed from the metal vapor and to direct them back to the pool of molten metal.

In the upper portion of the chamber above the shelf is located means defining a tortuous path to remove liquid droplets from the metal vapor. The tortuous path preferably includes plural baffles located between the passage in the shelf and the outlet from the chamber. These baffles may be either disposed longitudinally of the chamber or transversely thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional side view of representative apparatus in accordance with the present invention.

FIG. 2 is a sectional view taken along the line 2—2 of FIG. 1.

FIG. 3 is a perspective view of a modified form of representative apparatus in accordance with the present invention and similar to the apparatus of FIG. 1.

FIG. 4 is a sectional view taken along the line 4—4 of FIG. 3.

FIG. 5 is a perspective view of another form of representative apparatus in accordance with the present invention similar to the apparatus of FIG. 1.

FIG. 6 is a sectional view taken along the line 6—6 of FIG. 5.

FIG. 7 is a sectional side view of representative apparatus in accordance with another embodiment of the present invention.

FIG. 8 is a sectional view taken along the line 8—8 of FIG. 7.

FIG. 9 is a sectional view of another form of representative apparatus similar to the embodiment of FIG. 7.

DETAILED DESCRIPTION

Referring to FIG. 1 of the drawings, there is shown a shell 10 in which metal vaporizing apparatus 12 in accordance with one embodiment of the invention is disposed. The shell 10 is fabricated of stainless steel or the like and is maintained under vacuum during vaporization so that metal vapor may be produced under vacuum. The shell 10 is disposable within a furnace 14 so that the shell and hence the metal vaporizing apparatus 12 may be heated to a temperature sufficient to vaporize molten metal. In operation, the shell 10 should be capable of withstanding a vacuum of about 0.1 to 1.0 microns and a temperature of about 1,500° to 1,800° F. It should be understood that the furnace 14 may be of any suitable type, such as electrical resistance heating of graphite rods, furnace heater tubes enclosing burning gas, or the like. Insulation material 16 is preferably disposed at all openings into the shell 10, while the shell itself is surrounded by refractory material 17 comprising the furnace 14. Metal vaporizing apparatus 12 may substantially fill the volume of the shell 10.

Two major embodiments of the present invention are detailed in this application. More than one form of each embodiment is described. The embodiments have in common a cylinder member having its central axis disposed horizontally for containing a pool of molten metal. Means defining a tortuous path separated from the area of vaporization are included so that any liquid droplets may be removed from the generated metal vapor before leaving the evaporation chamber. The generated metal vapor exits from the chamber in a horizontal direction so that it may be readily deposited on a continuously vertically moving substrate to form a coating thereon.

FIGS 1 and 2

In a first embodiment of the present invention (see for examples FIGS. 1 and 2) metal vaporizing apparatus 12 includes an outer evaporator cylinder member 18 in which molten metal is vaporized in a vaporization area 19. At one end of the outer evaporator cylinder 18 is disposed a base 20 in which there is located a reservoir 22 which provides molten metal for vaporization. The outer evaporator cylinder 18 and the base 20 are the major exterior elements of metal vaporizing apparatus 12. The entire metal vaporizing apparatus 12 including the base 20 is preferably fabricated of graphite or the like when the molten metal is zinc. Although it is possible to transfer molten metal directly into the reservoir 22, especially in a commercial installation, it is presently contemplated to locate an ingot of metal or metal granules within the reservoir 22 so that upon heating of the shell 10 the ingot or granules will melt to form fluid metal. A cover 23 is provided to maintain the molten metal within the reservoir 22. The end of the cylinder 18 opposite the base 20 is sealed by a plate 24. Vapor and liquid leakage are thus prevented. As the outer evaporator cylinder 18 is cylindrical in shape, having its central axis disposed horizontally, a plurality of supporting elements 25 are provided between the cylinder 18 and the shell 10.

At the bottom portion of the reservoir 22 is a passage 26 extending through the base 20. After the metal has been melted, the molten metal contained in the reservoir 22 is permitted to flow through the passage 26 into the vaporization area 19 of the metal vaporizing apparatus 12. The passage 26, however, is blocked bya valve 28 which either allows or prevents molten metal from leaving the reservoir 22. Normally, the valve 28 is in closed position until the metal ingots or granules within the reservoir 22 have melted and until the temperature of the metal vaporizing apparatus 12 has reached the desired level. The valve 28 is variably controllable and may be of the type disclosed in Iezzi et al. application, Ser. No. 778,609, filed Nov. 25, 1968, entitled "Graphite Variable Control Valve" and assigned to the assignee of the present application. Thus, the valve 28 comprises a valve body 30, an operator structure (not shown) which may be either manual or automatic, and an aperture 32 in the valve body alignable with the passage 26 upon movement of the valve body 30 by the operator structure. In FIG. 1, the valve 28 is shown in open position. As the valve 28 is fabricated of a material non wetted by the molten metal, e.g. graphite when the molten metal is zinc, a liquid-to-liquid seal may be achieved about the valve body 30 so that there will be no liquid leakage through the various clearances about the valve components.

When the aperture 32 is aligned with the passage 26, molten metal may flow from the reservoir 22 through the passage 26 and the aperture 32 into the vaporization area 19 of metal vaporizing apparatus 12. The vaporization area 19 is defined by the outer evaporator cylinder 18 and an inner cylinder member 34 disposed within the outer evaporator cylinder 18. The upper portion of the inner cylinder 34 may be cut away so that it is substantially semi-circular in shape, for purposes explained more fully below. The inner cylinder 34 is also fabricated of graphite or the like when the molten metal is zinc. Graphite has been found to be a suitable material for fabricating the evaporator cylinders 18, 34 as well as the other elements of metal vaporizing apparatus 12 as it does not react with molten zinc, is easily fabricated, maintains its strength at high temperatures, and is efficient in conducting heat from the furnace 14 to the molten zinc to be vaporized. The inner cylinder 34 may be continuously charged with molten metal from the reservoir 22 so that a constant supply of metal vapor may subsequently be generated.

In the bottom portion of inner cylinder 34 are located a plurality of passages 38. Although a pool of molten metal 39 is formed in the inner cylinder 34, a portion of that pool of molten metal is permitted to flow through the passages 38 into the space between the cylinders 18 and 34. Thus, a thin semi-cylindrical shell of molten metal 40 forms between outer wall 34*a*

of the inner evaporator cylinder **34** and the inner wall **18***a* of the outer evaporator cylinder **18**. The depth of the molten metal in the thin shell **40** is generally the same as the depth of the pool of molten metal **39** remaining within the inner evaporator cylinder **34**. However, the thin shell of liquid boils, and the distinction between vapor and liquid phases as well as fluid level may be difficult to perceive. Providing a thin semi-cylindrical shell of molten fluid allows a uniform evaporation rate to be achieved as the volume of the thin shell of fluid metal may be substantially constant. Preferably, the passages **38** are uniform in size and extend in a single row along the bottom portion of the inner cylinder **34**. It is of course possible to use any combination or size of passages **38** so long as a thin shell of molten metal **40** may be readily formed between the walls of the cylinders **18, 34**.

Forming a relatively thin shell of fluid metal **40** in the space between the cylinder members has definite advantages in vaporizing the molten metal. First, the thinness of the shell reduces the size of vapor bubbles which form in the molten metal upon heating and consequently reduces the size of liquid inclusions or droplets in the vapor. Second, the efficiency of heat transfer is increased by the high velocity of bubble or fluid movement through the thin shell of fluid **40**. Thus, vaporization of the molten metal may occur at a high rate so that the apparatus may be used for commercial coating of continuously moving strip material or the like.

The vaporization rate of molten metal depends primarily on four factors. First, the most critical, is the temperature of the evaporator, as the vapor pressure of the metal depends on temperature. The second and third factors are the liquid-vapor interface area and the liquid-evaporator contact area. Generally, the higher the temperature of the vaporizing apparatus **12**, the higher the vaporization rate. However, although the vaporization rate remains constant for a period of time, it tends to decay when the amount of molten metal in the chamber **28** begins to fall, even though the temperature of the vaporizing apparatus **12** reaches an extremely high level, i.e., about 1,800° F., since the second and third factors are now influencing the evaporation rate. The fourth factor affecting the vaporization rate is the provision of adequate vapor transport from the vaporizing apparatus **12**. If excessive pressure drops exist in the vapor stream causing the pressure to rise in the evaporator, the temperature of the molten metal will rise and the evaporation rate will drop.

After the semi-cylindrical thin shell of fluid metal **40** has been heated to generate metal vapor by the furnace **14**, the metal vapor accumulates in the upper portion of the outer cylinder **18**. As the inner cylinder **34** has its upper portion cut away, any small amount of vapor generated upon direct heating of the pool of molten metal **39** contained therein also rises to the upper portion of the outer cylinder **18**.

Located within the upper portions of the two evaporator cylinders is a structure defining a tortuous path. The metal vapor generated passes through the tortuous path when exiting from the vaporizing apparatus **12** so that any droplets entrained in the metal vapor are removed therefrom. As shown in FIGS. **1** and **2**, the tortuous path structure for removing droplets entrained in the metal vapor in that embodiment comprises in part an outlet tube **41** which extends horizontally in the upper portions of the outer evaporator cylinder **18** and the semi-cylindrical inner cylinder **34**. The outlet tube **41**, which may also be fabricated of graphite when the molten metal is zinc, has a plurality of perforations **42** therein through which the vapor passes to be removed from the vaporizing apparatus **12**. Preferably, the perforations **42** are of uniform size and are formed in a single row at the bottom of the outlet tube **41**, although perforations may also be at the top of the tube. Generated metal vapor emanating from the thin shell of molten metal **40** must first rise past the top edges of the semi-cylindrical inner cylinder **34**, then flow downwardly past the exterior of outlet tube **41**, and finally flow upwardly through the perforations **42** into the outlet tube **41**, as best seen in FIG. **2**.

The outlet tube **41** also serves the function of a nozzle for directing the metal vapor after it has passed through the tortuous path horizontally from the vaporizing apparatus **12**. In this case the outlet tube **41** must be sufficient in size to permit ready transport of the vapor from the evaporator cylinders **18, 34**. The outlet tube **41**, which contains no perforations **42** along its length in the portion **41a** extending beyond the cylinder **18**, directs the metal vapor against a moving substrate (not shown — typically moving vertically) so that the vapor condenses to form a coating thereon. The shell **10** preferably encases the entire metal vaporizing apparatus **12** including the extension of the outlet tube **41** which serves as a nozzle, so that no pressure leakage will occur in the system. As the metal vapor is generated at a rapid and controllable rate, a coating of substantially equal thickness may be deposited about the surface area of the continuously moving substrate.

EXAMPLE 1

Using representative apparatus of the type shown in FIGS. **1** and **2**, a zinc ingot weighing 12 lbs. was disposed in the reservoir **22**. The metal vaporizing apparatus **12** was located in a stainless steel shell **10**, which was then placed in a furnace **14** of the gas burner type. The shell **10** was evacuated to a pressure of about 1 micron and heated to a control temperature of about 1,750° F. (The control temperature is actually the lowest temperature on the steel shell in the evaporation area.) A pressure below 30 microns is preferred to obtain a bright coating. The zinc ingot in the reservoir **22** reached a temperature of about 1,100° F. (1,200° F. temperature of the reservoir itself) which was sufficient to melt the zinc. When the valve **28** was opened, the molten zinc metal flowed into the inner evaporator cylinder **34** to form a pool of molten metal **39** therein. A ¼-inch thin shell of molten zinc metal **40** was subsequently formed between the inner and outer evaporator cylinders **18, 34**. In the run of the apparatus although the stainless steel shell **10** was heated to a control temperature of 1,750° F., the steady-state temperature of the vaporizing apparatus **12** before liquid zinc was introduced into the vaporization area **19** was also about 1,750° F., while the steady-state temperature of the vaporization area after the molten zinc metal was introduced was 1,680° F.

Five hundred feet of 6-inch wide steel strip were coated with the generated zinc vapor. Previously, however, the steel strip, which was 0.015 inches thick, had been cleaned with an alkali cleaner, pickled in a 5 percent hydrochloric acid solution and electroplated with a copper coating 5 to 7 micro-inches thick to promote adherence of the coating. The strip was maintained at a temperature of about 80° F. and a coating of about 1 mil in thickness was deposited thereon when the strip moved at a rate of about 60 to 75 ft. per minute. The outlet tube **41** was 1-inch in diameter. The average condensation rate upon the steel strip was 0.70 lbs. per minute, while the maximum condensation rate was 0.95 lbs. per minute.

It has been determined, however, that the maximum feasible temperature any place on the stainless steel shell **10** should be about 1,750° F. in order to avoid collapsing or weakening of the shell structure. Under these limitations a similarly prepared steel strip was coated. The control temperature of the stainless steel shell **10** was 1,480° F. and the average temperature about 1,530° F. The steady-state temperature of the vaporizing apparatus **12** before introduction of the molten zinc metal was about 1,480° F. while the steady-state temperature of the vaporizing apparatus **12** after introduction of the molten zinc was 1,420° F. The perforations **42** in the outlet tube **41** faced toward the bottom of the outer evaporator cylinder **18**. In this run the average condensation rate upon the steel strip was 0.30 lbs. per minute while the maximum condensation rate was 0.56 lbs. per minute. In both runs very little splatter occurred in the coating on the substrate and the coating appearance was considered to be excellent.

FIGS. 3 and 4

A modification of the embodiment of FIG. **1** is shown in FIGS. **3** and **4**. A similar inner cylinder member **34'** is disposed in a similar outer evaporator cylinder **18'** such that a thin shell of fluid metal **40'** may form between the cylinders from the pool of molten metal **39'** through the passages **38'**. However, the apparatus of FIGS. **3** and **4** differs from the apparatus of FIGS. **1** and **2** in that baffles **44** are located at the top portions of the semi-cylindrical inner cylinder **34'** and in that no outlet tube **41** is provided for removing generated metal vapor from the vaporizing apparatus **12'**. The baffles **44** extend throughout the interior of the inner cylinder **34'** so that generated metal vapor rising from the pool of molten metal **39'** will first strike the baffles. As apertures **45** are formed between the baffles and the top of the inner cylinder **34'**, vapor rising from the thin shell of fluid metal **40'** will pass through the apertures **45** and beneath the baffles **44** before exiting from the vaporizing apparatus **12'**. The baffles **44** may also be fabricated of graphite when the metal vapor is zinc vapor.

To remove the generated vapor from the vaporizing apparatus **12'** an aperture **46** is provided in plate **24'** which defines an end wall of the cylinders **18'**, **34'**. As the apparatus may not entirely remove splatter from the generated vapor, it is preferred that an additional disengagement section **48** be provided adjacent the plate **24'** at the end of the metal vaporizing apparatus **12'**. The disengagement section **48** comprises a cylindrical section **50** fixed to the plate **24'** into which metal vapor is charged through the aperture **46**. Within the cylindrical section **50** are disposed a plurality of semicircular baffle plates **52** spaced apart along the length of the section **50** and alternately affixed to the top and bottom portions of the cylindrical section **50**. The semicircular baffle plates **52** are each slightly greater than 180° in circumference so that vapor may not pass through the disengagement section **48** in a direct path. Instead, the metal vapor must follow a tortuous path over each baffle plate **52** affixed to the bottom of the cylindrical section **50** and under each baffle plate **52** affixed to the top of the cylindrical section **50**. It is also possible for the baffle plates **52** to be affixed to the cylindrical section **50** at alternate sides thereof, such that the metal vapor must follow a tortuous path around each baffle. The baffle plates **52** may be fabricated of graphite or the like when the metal vapor is zinc vapor. The entrained droplets removed from the metal vapor collects at the base of the cylindrical section **50** from which it may later be removed.

A nozzle **54** transfers the metal vapor horizontally from the disengagement section **48**. The nozzle **54** may be fabricated of the same material as the other elements of the apparatus, e.g., graphite, or could be made of low carbon steel or stainless steel and may be of the type which forms a stream of metal vapor as wide as the substrate to be coated. Thus, the nozzle **54** may direct a wide stream of metal vapor against a continuously moving substrate so that the vapor condenses to form a coating thereon. Of course, any other type nozzle **54** may be employed which is sufficient in size to permit ready transport of the metal vapor from the disengagement section **48**.

EXAMPLE 2

Representative apparatus of the type shown in FIGS. **3** and **4** was employed to vaporize molten zinc. About 118 lbs. of 99.99 percent pure zinc were melted in an electric furnace and delivered through a heated tube (not shown) into the metal vaporizing apparatus **12'**. A stainless steel-clad tantalum tube heated to about 900° to 1,000° F. was utilized to deliver the molten zinc. A chromium carbide coated carbon steel tube might also be used. The metal vaporizing apparatus **12'** was located in the stainless steel shell **10** which in turn was disposed within the furnace **14**. The shell **10** was evacuated to a pressure of about 6 microns and heated to a temperature of about 1,220° F. The internal temperature of the graphite evaporator cylinder was 1,265° F. The temperature of the disengagement section **48** was about 1,020° F.

Steel strip about 10 in. wide and 0.015 in. thick was coated with generated metal vapor. The steel strip had previously been cleaned in an alkali cleaner maintained at a temperature of about 165° F., pickled in a 5 percent hydrochloric acid solution at ambient temperature and plated to a thickness of from 2 to 8 micro-inches (preferably to a minimum of 3 micro-inches) in a sodium cyanide-copper cyanide bath kept at a temperature of 130° F. to promote adherence of the coating. The strip was vapor zinc coated at a speed of about 30 ft. per minute and the temperature of the strip was raised by condensation to about 410° F. The condensation rate of the vapor on the substrate averaged 0.930 lbs. per minute to a coating thickness of 0.580 oz. per sq. ft.

In another run of the same apparatus the same type of substrate was coated. The temperature of the stainless steel shell **10** was raised to 1,320° F., while the internal temperature of the graphite vaporizing apparatus **12'** was 1,150° F. One hundred lbs. of molten zinc were delivered to the vaporizing apparatus which was maintained under a vacuum of about 25 microns pressure. The steel strip reached a temperature of about 300° F. and continuously moved at a speed of about 26 ft. per minute. The zinc vapor condensed at an average rate of about 1.21 lbs. per minute to a thickness of about 1.53 oz. per sq. ft. of substrate.

FIGS. 5 and 6

The device of FIGS. **5** and **6** includes an outer evaporator cylinder **18''** enclosing a semi-cylindrical inner cylinder **34''**. A pool of molten metal **39''** may be contained within the inner cylinder **34''** to supply through passages **38''** a thin shell of molten metal **40''** formed between the corresponding walls of the two cylinders **18''**, **34''**. The modification of FIGS. **5** and **6** differs from the apparatus of FIGS. **1** and **2** substantially only in the form of outlet tube employed to remove the metal vapor from the apparatus. Thus, an outlet tube **56** is disposed in the upper portion of the outer evaporator cylinder **18''**, which is the cut-away portion of the inner cylinder **34''**. The outlet tube **56** is substantially larger than the outlet tube **41** of FIGS. **1** and **2**. However, the outlet tube **56** contains a series of perforations **58** only at one end **56*a*** thereof and contains no perforations along the extent of the tube. Although in the figures the perforations **58** are shown in a radial pattern, any spacing is satisfactory so long as adequate vapor transport from the vaporizing apparatus **12''** is provided. The end **56*a*** of the outlet tube **56** terminates adjacent the end of the inner cylinder **34''**. Thus, the tortuous path of this modification is provided when the metal vapor generated is caused to flow over the top portions of the semi-cylindrical inner cylinder **34''** and then toward the end **56*a*** of the outlet tube **56** which contains the perforations **58**. If the perforations **58** are sufficiently small in diameter, droplets will substantially be removed from the metal vapor as the vapor passes through the perforations and will return to the pool of molten metal **39''** contained within the inner cylinder **34''**. Again, the outlet tube **56** is preferably fabricated of graphite or the like when the molten metal is zinc.

A nozzle **54'** similar to that shown in FIG. **3** may be coupled to the end of the outlet tube **56** opposite the end **56*a*** containing the perforations **58**. The nozzle **54'** will direct the metal vapor horizontally from the vaporizing apparatus **12''** toward a continuously moving substrate where the vapor may condense to form a coating thereon.

EXAMPLE 3

Apparatus of the type shown in FIGS. **5** and **6** was also employed in vaporizing molten zinc to provide a coating for copper-plated steel strip. About 200 lbs. of 99.99 percent pure molten zinc were delivered similarly to the procedure of Example 2 to the inner cylinder **34''**, which was maintained under a vacuum of about 27 to 40 microns pressure. The temperature of the stainless steel shell **10** was about 1,800° F. while the internal temperature of the graphite evaporator cylinders **18''**, **34''** was about 1,620° to 1,640° F. The zinc vapor condensed upon the substrate at an average rate of about 1.00 to 1.38 lbs. per minute to create a coating about 0.966 to 1.322 oz. per sq. ft. in thickness. Copper-plated steel strip of the type described in Example 2 reached a temperature in excess of 400° F. and was transported past the end of the nozzle **54** at a speed of about 20 ft. per minute. Adhesion of the coating to the substrate was found to be excellent and no splatter was present in the coating.

FIGS. 7 and 8

Another embodiment of the present invention is shown in FIGS. **7** and **8**. Vaporizing apparatus **59** comprises generally an evaporator cylinder **60** having its central axis disposed horizontally. Molten metal is disposed in the lower portion of the evaporator cylinder **60** while means for removing splatter from the generated metal vapor is located in the upper portion of the evaporator cylinder **60**. Thus, the vaporization area **60*a*** is separated from the splatter removal area in this embodiment as well. Molten metal may be charged into the lower portion of the evaporator cylinder **60** to form a pool of molten metal **61** either in the same manner as explained in connection with the vaporizing apparatus **12** of FIG. **1** or from an external source as described in Example 2. Furthermore, the evaporator cylinder **60** is preferably fabricated of graphite or the like when the molten metal is zinc, as is the entire vaporizing apparatus **59**. Again the entire system is maintained under vacuum to provide for the production of metal vapor under vacuum. The vaporizing apparatus **59** is heated within a shell **10** in a furnace **14** of the same type described above in connection with FIG. **1**. The molten metal contained in the lower portion of the evaporator cylinder **60** is therefore also heated in order to generate metal vapor. In this embodiment of the invention a thin shell of molten metal is not heated to generate metal vapor. It should be noted, however, that it is feasible to form the molten metal into a thin semi-cylindrical shell by placing an inner cylinder (not shown) within the evaporator cylinder **60**.

In accordance with this embodiment of the invention a shelf **62** extends horizontally across and divides the evaporator cylinder **60** substantially in half. Beneath the shelf **62** is contained the pool of molten metal **61** to be vaporized in the vaporization area **60*a*** while above the shelf **62** is located structure defining a tortuous path for removing droplets from the generated metal vapor. The shelf **62** has the important function of preventing droplets from leaving the vaporization area **60*a*** of the evaporator cylinder **60**. As shown in FIG. **7**, the shelf **62** does not extend entirely across the evaporator cylinder **60**. This allows the generated metal vapor to flow about the end of the shelf **62** through a passage **63** to reach the tortuous path where droplets are removed therefrom. Preferably, the shelf **62** is tilted downwardly toward one end thereof so that droplets removed by the tortuous path may flow back toward the pool of molten metal **61** contained in the lower portion of the evaporator cylinder **60**. A number of apertures **64** are located in the shelf **62** so that the droplets removed from the generated metal vapor will pass through the shelf **62**. In this regard recesses **62*a***

are formed in the shelf **62** surrounding each of the apertures **64** to collect the liquid flowing on the shelf **62** and direct it through the apertures **64** toward the pool of molten metal **61** where the liquid may be revaporized. Preferably, the shelf **62** is fabricated of graphite or the like when the metal vapor is zinc.

The structure defining the tortuous path contained in the upper portion of the evaporator cylinder **60** for removing splatter from the metal vapor consists of a plurality of baffles **66** disposed transversely to the length of the cylinder. The baffles **66** are spaced along the length of the evaporator cylinder **60** and may either alternate or be formed into pairs. The baffles **66**, which may be fabricated of graphite or the like when the metal is zinc vapor, are located in the upper portion of the evaporator cylinder **60**, between the passages **64** in the shelf **62** and the outlet from the cylinder **60**, each extending vertically from the shelf **62** to the interior wall of the cylinder **60**. Each of the baffles **66** is a segment of a circle and may be either slightly smaller or larger than a quarter circle. In the instance where each baffle **66** is slightly smaller than a quarter circle, the path followed by the vapor is defined by the gap left between adjacent baffles **66** extending down the center of the upper portion of the evaporator cylinder **60**, as shown in FIG. **8**. If the baffles **66** are each larger than a quarter circle in size, adjacent baffles **66** will slightly overlap so that generated metal vapor will be caused to follow a tortuous path about the ends of the baffles before leaving the cylinder **60**.

A nozzle (not shown) is located adjacent end plate **70** of the evaporator cylinder **60** in communication with an aperture **68** in the end plate. The nozzle must be sufficient in size to permit ready transport of the vapor from the cylinder **60** and serves to direct the metal vapor from the tortuous path horizontally of the evaporator cylinder **60**. A nozzle of the type shown in FIG. **3** is preferably employed. The nozzle directs the metal vapor against a continuously moving substrate so that the vapor condenses to form a coating thereon.

EXAMPLE 4

Copper-coated steel strip was coated with zinc vapor by use of apparatus of the type shown in FIGS. **7** and **8**. The substrate was of the same type and was prepared in the same manner as described in Example 2. In one run using this apparatus, 134 lbs. of 99.99 percent pure molten zinc were delivered in the manner explained in Example 2 to the evaporator cylinder **60** which was maintained under a vacuum of **65** microns pressure. The temperature of the stainless steel shell **10** enclosing the vaporizing apparatus **59** was 1,600° F., whereas the temperature within the evaporator cylinder **60** was 1,250° F. Zinc vapor condensed on a moving strip at an average rate of about 1.71 lbs. per minute to a thickness of about 0.820 oz. per sq. ft. The strip, which reached a temperature of 500° F., moved at a speed of about 40 ft. per minute. There was perfect adhesion of the zinc coating to the strip and no splatter was present in the coating. The splatter problem was minimized by minimizing the temperature difference between the evaporator cylinder **60** and the molten metal delivered to the cylinder.

In another run employing apparatus of the type shown in FIGS. **7** and **8** similar steel strip was vapor coated with zinc metal vapor produced from 215 lbs. of molten zinc. During this run the temperature of the stainless steel shell **10** was about 1,700° F. The pressure within the evaporator cylinder **60** was about 30 to 35 microns while the internal temperature of the evaporator cylinder **60** was about 1,270° F. About 3.24 lbs. per minute of zinc vapor condensed on a moving substrate (strip) to a thickness of about 0.890 oz. per sq. ft. The strip moved at about 70 ft. per minute and reached a temperature of about 450° F.

FIG. 9

A modification of the embodiment of FIGS. **7** and **8** is shown in FIG. **9**. Vaporizing apparatus **59'** includes an evaporator cylinder **60'** in which a pool of molten metal **61'** is disposed for vaporization in a vaporization area **60a'**. A shelf **62'** extends horizontally across and divides the evaporator cylinder **60'** into upper and lower portions. In the upper portion of the cylinder **60'** is located structure defining a tortuous path for removing droplets from the generated metal vapor. Thus, vaporization and droplet removal occur in separate locations. The difference between the embodiment of FIGS. **7** and **8** on one hand and the form shown in FIG. **9** on the other hand is that, in the vaporizing apparatus **59'** of FIG. **9**, the tortuous path extends longitudinally of the evaporator cylinder **60'** rather than transversely thereto. The shelf **62'** again does not extend along the entire length of the evaporator cylinder **60'** so that the generated metal vapor emanating from the pool of molten metal **61'** may pass around the end of the shelf to enter the tortuous path. Also, the shelf **62'** may be tilted downwardly toward one end of the evaporator cylinder **60'** and may include plural apertures **72** therein whereby droplets removed from the metal vapor by the tortuous path structure will flow down the shelf **62'** and be directed back to the pool of molten metal **61'**. Again the entire vaporizing apparatus **59'** may be fabricated of graphite when the metal is zinc.

In the upper portion of the evaporator cylinder **60'** of FIG. **9** there is an outlet tube **74**. The outlet tube **74**, which may be fabricated of graphite or the like when the metal vapor is zinc, extends along the length of the evaporator cylinder **60'** on the shelf **62'**. A plurality of uniform perforations **76** preferably are spaced along the length of the outlet tube **74** and preferably also are directed toward the upper portion of the evaporator cylinder **60'**. Although the outlet tube **74** and the shelf **62'** form a tortuous path about which the metal vapor must pass to leave the vaporizing apparatus **59'**, baffles **78** may be affixed additionally to the side of the outlet tube **74**. These baffles **78**, which may be graphite when the metal vapor is zinc vapor, extend along the entire length of the outlet tube **74** and are directed toward the upper portion of the evaporator cylinder **60'**. The tortuous path is thus completely defined as following the end of the shelf **62'** around which the generated metal vapor must pass, the ends or tops of the baffles **78**, and the perforations **76** in the outlet tube **74**. The entrained droplets removed from the metal vapor by the tortuous path structure will flow back along the shelf **62'** and be directed through the apertures **72** into the pool of molten metal **61'**.

Generated metal vapor is removed from the evaporator cylinder **60'** by passing through the perforations **76**

in the outlet tube **74**. A nozzle or the like (not shown), which may be either an extension of the outlet tube **74** (as in FIG. **1**) or a separate nozzle (as in FIGS. **3** and **5**), transfers the metal vapor from the tortuous path in a direction horizontally of the evaporator cylinder **60'**. The nozzle, which must be sufficient in size to transport the produced vapor from the evaporator cylinder **60'**, directs the metal vapor against a continuously moving substrate so that the vapor condenses to form a coating thereon.

EXAMPLE 5

Using representative apparatus of the type shown in FIG. **9**, about 35 lbs. of extremely pure zinc were fed into the evaporator cylinder **60'** by means described in Example 1. The metal vaporizing apparatus **59'** was placed in a stainless steel shell **10** which was heated to a temperature of about 1,700° F. in a furnace **14**. The shell **10** was evacuated to a pressure of about 1 micron. The temperature of the evaporator cylinder **60'** before introduction of the molten zinc was about 1,700° F. while the temperature of the cylinder after introduction of the molten zinc was about 1,500° F. A 2-inch outlet tube **74** was employed to remove the generated vapor from the evaporator cylinder **60'**. Copper-plated steel strip of the type used in Example 1 was plated (about 0.5 to 1.0 mils in thickness) at an average condensation rate of about 0.49 lbs. per minute, the maximum condensation rate being about 0.74 lbs. per minute.

Thus, the present invention provides for vaporization of molten metal, particularly zinc, without entrainment of a substantial amount of droplets in the metal vapor. The invention further provides for the coating of a substrate, particularly copper-plated steel strip with a metal vapor at a high rate of production and at a controllable rate so that a coating of uniform thickness may be deposited on the continuously moving substrate.

We claim:

1. Apparatus for vaporizing molten metal, comprising:

a. a first cylinder member with its central axis disposed horizontally for receiving and displacing a pool of molten metal and having at least one passage extending therethrough;

b. a second cylinder member with its central axis disposed horizontally enclosing said first cylinder member and adapted to receive molten metal through said passage from said first cylinder member to form a thin semi-cylindrical shell of molten metal between said cylinder members; and

c. means for heating said thin shell of molten metal to generate metal vapor.

2. Apparatus according to claim **1**, including means for continuously charging said first cylinder member with molten metal.

3. Apparatus according to claim **2**, wherein said charging means comprises:

a. a reservoir for containing a supply of molten metal and having an outlet therefrom in communication with said first cylinder member; and

b. valve means for controlling the flow of molten metal through said outlet from said reservoir to said first cylinder member.

4. Apparatus according to claim **1**, including means for maintaining said cylinder members under vacuum to provide for the production of metal vapor under vacuum.

5. Apparatus according to claim **1**, wherein said cylinder members are fabricated of graphite when said molten metal is zinc.

6. Apparatus according to claim **1**, further comprising means disposed in said cylinder members and defining a tortuous path for removing liquid droplets from said generated vapor.

7. Apparatus according to claim **1**, wherein said first cylinder member is open at the top portion thereof so that it is semi-cylindrical in shape.

8. Apparatus according to claim **7**, further comprising outlet means extending horizontally in said first cylinder member in the open portion thereof for removing said generated vapor therefrom.

9. Apparatus according to claim **8**, wherein said outlet means comprises a tube having a plurality of perforations therein through which said vapor may pass to be removed from said cylinder members.

10. Apparatus according to claim **1**, further comprising a nozzle extending horizontally from said cylinder members.

11. Apparatus according to claim **1**, including means for directing said generated metal vapor against a continuously moving substrate to be coated.

12. Apparatus for vaporizing molten metal, comprising:

a. an evaporator member for containing a pool of molten metal in the lower portion thereof which is heated to generate metal vapor;

b. a shelf extending horizontally across and dividing said evaporator member into distinct compartments communicating with each other only by a passage extending through said shelf through which metal vapor may pass;

c. means in the upper portion of said evaporator member above said shelf and defining a tortuous path to remove liquid droplets from said metal vapor which may pass through said passage;

d. outlet nozzle means extending from said upper portion of said evaporator member for removing said generated vapor therefrom and applying said vapor to a substrate to be coated; and

e. means for heating said evaporator member portions to generate metal vapor for deposition upon said substrate.

13. Apparatus for vaporizing molten metal, comprising:

a. an evaporator member for containing a pool of molten metal in the lower portion thereof which is heated to generate metal vapor;

b. a shelf extending horizontally across and dividing said evaporator member and having a passage extending therethrough through which metal vapor may pass, said shelf being tilted downwardly toward one end of said evaporator member;

c. means in the upper portion of said evaporator member above said shelf and defining a tortuous path to remove liquid droplets from said metal vapor which may pass through said passage;

d. outlet nozzle means extending from said upper portion of said evaporator member for removing

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said generated vapor therefrom and applying said vapor to a substrate to be coated; and

e. means for heating said evaporator member portions to generate metal vapor for deposition upon said substrate.

14. Apparatus for vaporizing molten metal, comprising:

a. an evaporator member for containing a pool of molten metal in the lower portion thereof which is heated to generate metal vapor;

b. a shelf extending horizontally across and dividing said evaporator member and having a passage extending therethrough through which metal vapor may pass, a portion of said shelf being recessed to collect droplets removed from said metal vapor and direct them to said pool of molten metal;

c. means in the upper portion of said evaporator member above said shelf and defining a tortuous path to remove liquid droplets from said metal vapor which may pass through said passage;

d. outlet nozzle means extending from said upper portion of said evaporator member for removing said generated vapor therefrom and applying said vapor to a substrate to be coated; and

e. means for heating said evaporator member portions to generate metal vapor for deposition upon said substrate.

15. Apparatus for vaporizing molten metal, comprising:

a. an evaporator member for containing a pool of molten metal in the lower portion thereof which is heated to generate metal vapor;

b. a shelf extending horizontally across and dividing said evaporator member and having a passage extending therethrough through which metal vapor may pass;

c. means in the upper portion of said evaporator member above said shelf and defining a tortuous path to remove liquid droplets from said metal vapor which may pass through said passage, said tortuous path means including plural baffles between said passage in said shelf and the outlet means of (d) below;

d. outlet nozzle means extending from said upper portion of said evaporator member for removing said generated vapor therefrom and applying said vapor to a substrate to be coated; and

e. means for heating said evaporator member portions to generate metal vapor for deposition upon said substrate.

16. Apparatus according to claim **15**, wherein said baffles are disposed longitudinally of said evaporator member within said upper portion thereof.

17. Apparatus according to claim **15**, wherein said baffles are disposed transversely in said upper portion of said evaporator member.

18. Apparatus according to claim **12**, wherein said outlet means extends throughout the length of said evaporator member.

19. Apparatus for vaporizing molten metal, comprising:

a. an evaporator member for containing a pool of molten metal in the lower portion thereof which is heated to generate metal vapor;

b. a shelf extending horizontally across and dividing said evaporator member and having a passage extending therethrough through which metal vapor may pass;

c. means in the upper portion of said evaporator member above said shelf and defining a tortuous path to remove liquid droplets from said metal vapor which may pass through said passage;

d. outlet nozzle means extending from said upper portion of said evaporator member for removing said generated vapor therefrom and applying said vapor to a substrate to be coated, said outlet means extending throughout the length of said evaporator member and comprising a tube having a plurality of perforations therein through which said generated vapor may pass to be removed from said evaporator member; and

e. means for heating said evaporator member portions to generate metal vapor for deposition upon said substrate.

20. Apparatus according to claim **12**, including means for maintaining said evaporator member under vacuum to provide for the production of metal vapor under vacuum.

21. Apparatus according to claim **12**, wherein said evaporator member, said shelf and said tortuous path means are fabricated of graphite when said molten metal is zinc.

22. Apparatus for vaporizing molten metal, comprising:

a. first and second concentric cylinder members with their central axes horizontally disposed, said cylinder members being spaced apart to define a space therebetween;

b. means for supplying molten metal to said space, said molten metal constituting a semi-cylindrical thin shell of metal in said space;

c. means for heating said thin shell of molten metal to vaporize it;

d. means for maintaining said thin shell under vacuum to provide for the production of metal vapor under vacuum; and

e. means for directing the metal vapor against a substrate to be coated.

* * * * *