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Reed et al.

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[54] METHOD FOR VAPORIZING MOLTEN METAL

[72] Inventors: William A. Reed, West Richfield; Frank J. Cole, Parma, both of Ohio

[73] Assignee: Republic Steel Corporation, Cleveland, Ohio

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[58] Field of Search 117/106 R, 107, 107.1, 107.2; 118/48, 49, 49.1

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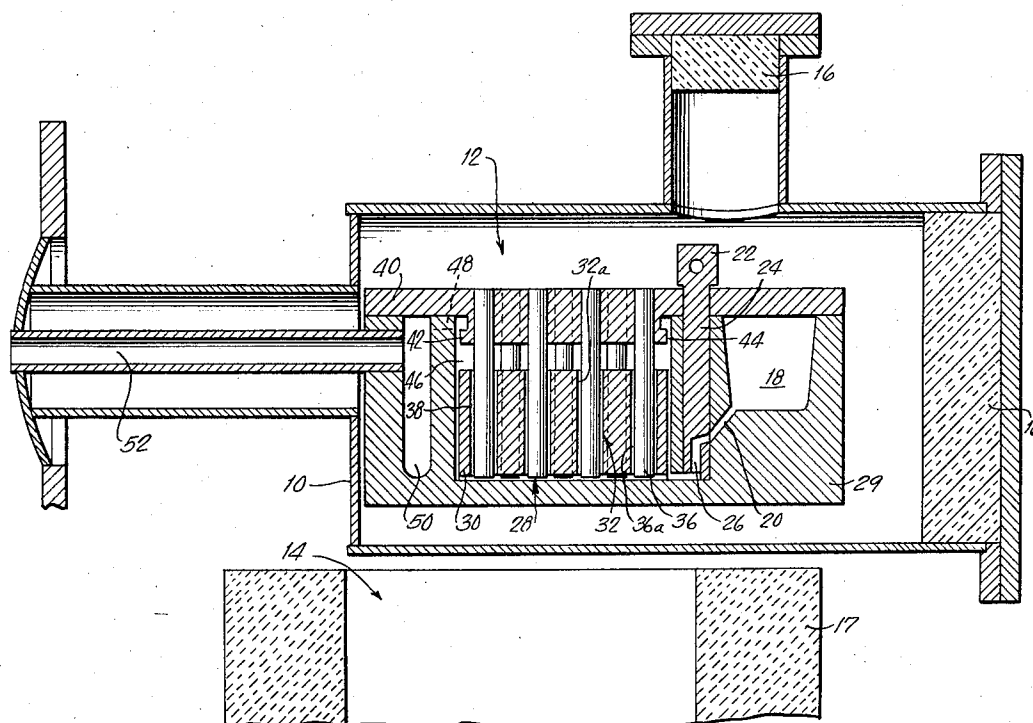
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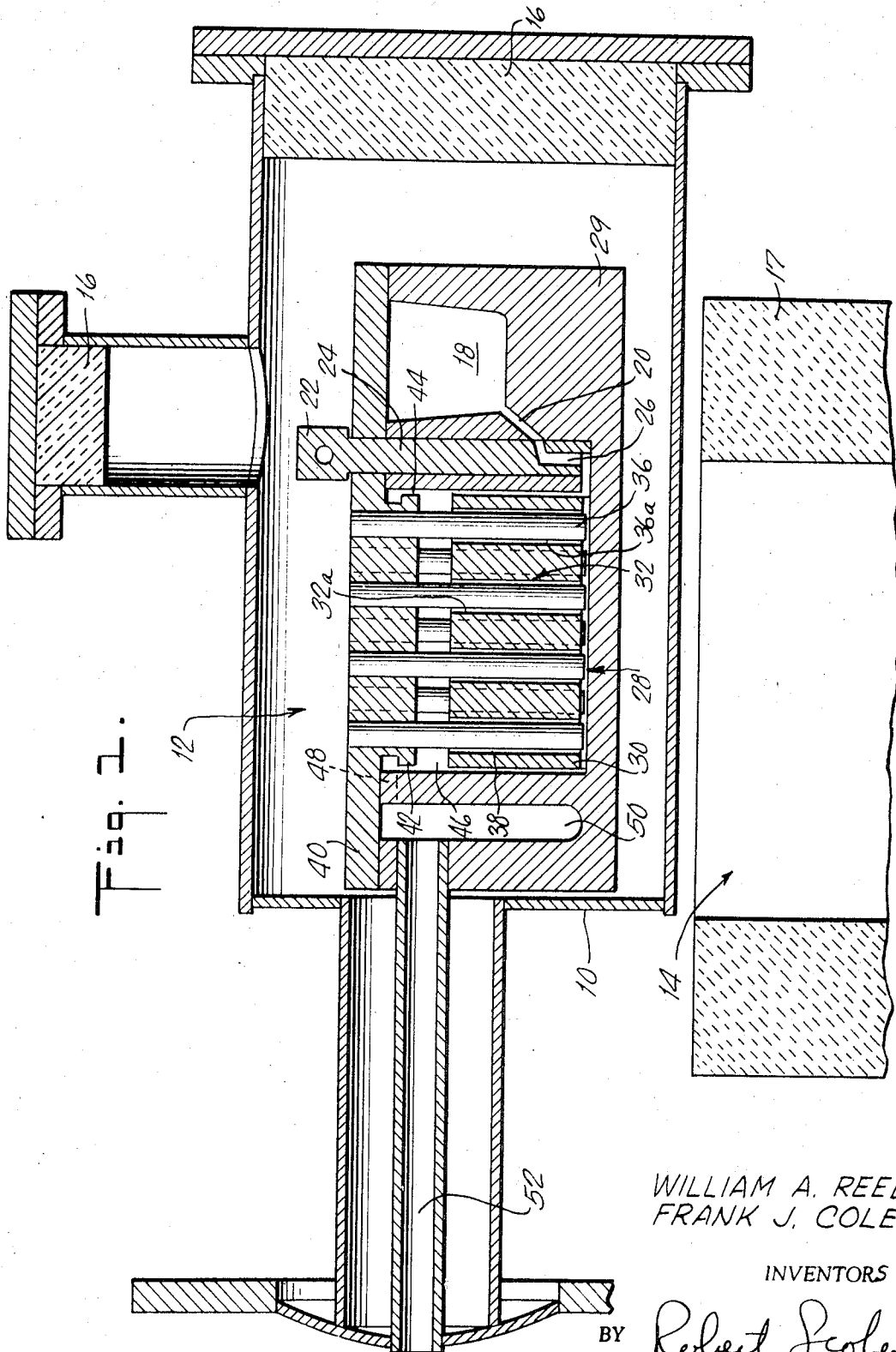
Primary Examiner—Alfred L. Leavitt
Assistant Examiner—Kenneth P. Glynn
Attorney—Robert P. Wright and Joseph W. Malleck

[57] ABSTRACT

Apparatus and method for vaporizing molten metal without entrainment of liquid droplets includes charging a pool of molten metal into a chamber in which there is a block having a plurality of passages. A finger is disposed in each passage of the block, a space being left between the inner surface of the passage and the outer surface of the finger to create a shell of fluid metal within the passage. Heating the shells of fluid metal generates metal vapor. The metal vapor is passed through a tortuous path and then directed by a nozzle toward a moving substrate to be coated.

10 Claims, 2 Drawing Figures





WILLIAM A. REED
FRANK J. COLE

INVENTORS

BY

Robert Scoley
ATTORNEY

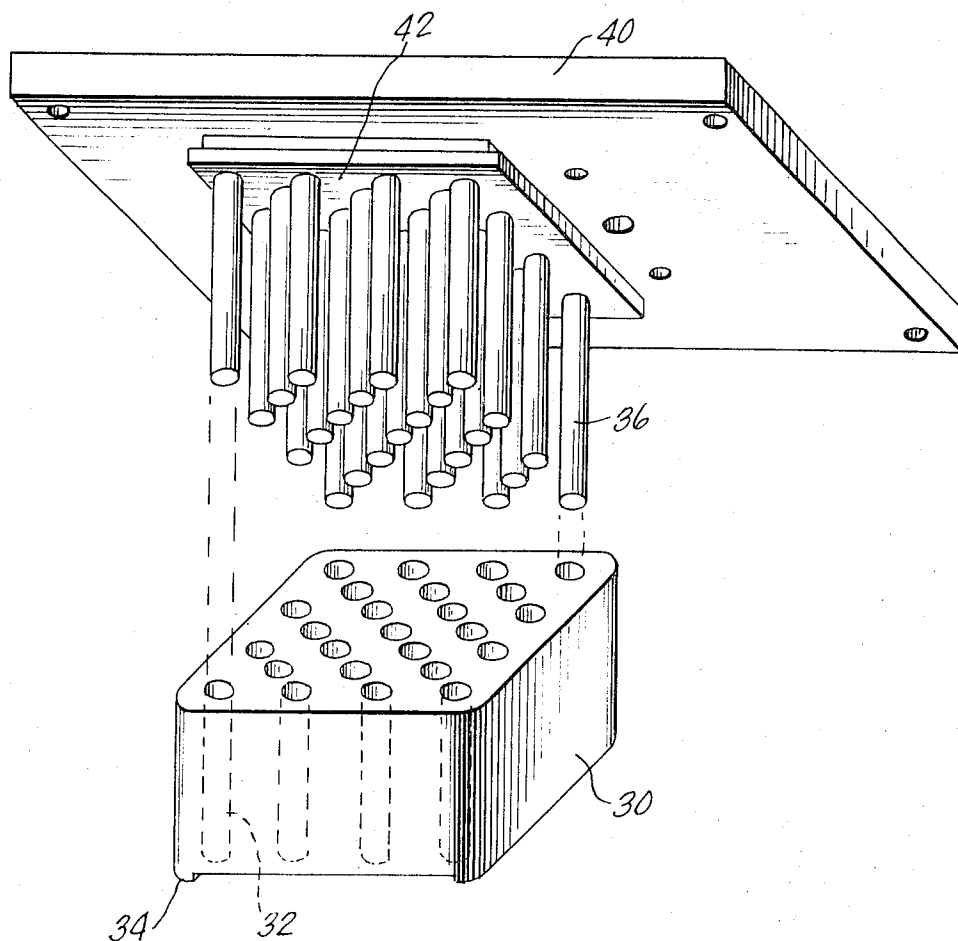


Fig. 2.

WILLIAM A. REED
FRANK J. COLE

INVENTORS

BY *Robert Scoley*
ATTORNEY

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 vapor.

Vaporized zinc coatings on steel offer many advantages over conventional electroplated zinc coatings and hot dip galvanized coatings. A smooth, nonsplattered 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. 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 or chambers simply by heating the metal to a temperature above its vaporization point and then removing the vapor from the crucible or chamber, 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 tried. One involves locating a baffle plate or other baffle arrangement between the surface of the pool of molten metal to be evaporated and the area where the vapor is to be collected. Providing a tortuous path is somewhat effective in removing large inclusions from the vapor, but it has not been found effective in completely preventing splatter on the substrate to be coated.

Another attempt to provide particle-free metal vapor involves locating within the crucible or chamber a means whereby the vapor bubbles generated by heating might be obviated or at the least permitted to escape without bursting at the surface of the liquid. Elimination of the bubbles in the metal vapor substantially reduces the opportunity for particles to be retained by the generated vapor.

Abbott U.S. Pat. No. 1,265,863 discloses forming thin shells of liquid within a chamber. The thin shells of liquid are heated by steam contained within the central core of each shell to vaporize the liquid. The generated vapor is permitted to escape from each shell through a small annular space formed at the top of each shell. When an evaporator is constructed of steel or the like, it makes little difference how heat is transmitted to the thin shells of molten material. However, when the evaporator is fabricated of a material such as graphite or silicon carbide in order to negate reaction with molten metal, it is necessary that heat be transmitted to the molten metal from as great a contact surface as possible. In constructing a useful evaporator it must be kept in mind that the vapor must be completely free of liquid, be generated at a controllable rate, and be generated at a high rate. Prior art devices such as shown in Abbott do not provide particle-free metal vapor at a controllable and high production rate as is necessary for commercial operation. Thus, to be commercially successful it is necessary that an evaporator be constructed which provides liquid-free vapor at a rapid and controllable rate.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide apparatus and method for vaporizing molten metal without entrainment of particles in the metal vapor.

It is a further object of the invention to provide apparatus for coating a substrate with metal vapor at a high rate of production without liquid inclusions or splatter in the coating. Still another object of the invention is to provide for the vaporization of molten metal at a controllable rate.

To these and other ends, the present invention contemplates the use of metal vaporizing apparatus in which molten metal is continuously charged into a vacuum chamber. A block having plural passages is disposed in the chamber and plural fingers are disposed in the respective passages of the block. As spaces are left between the inner surfaces of the respective passages and the outer surfaces of the respective fingers, plural thin shells of fluid metal are created within the passages. Heating the thin shells of fluid metal generates metal vapor.

In accordance with the invention a reservoir contains a supply of molten metal and has an outlet extending from its bottom portion. A valve is disposed in the outlet and has an aperture extending therethrough such that upon alignment of the aperture with the outlet of the reservoir molten metal is permitted to flow through the aperture to the chamber. This allows continuous charging of the chamber with molten metal in order that metal vapor may be generated at a controllable rate. The metal can also be charged continuously from the outside of the vacuum system, if desired. The chamber has a substantially rectangular area of vaporization and is under vacuum so that metal vapor may be produced under vacuum. The base which forms the chamber is preferably fabricated of a material such as graphite or the like that is not attacked by the molten metal.

The block having a plurality of passages therethrough is located within the chamber in a manner whereby molten metal may flow into the passages. The block is also spaced from the bottom of the chamber so that a thin layer of molten metal is located at the bottom of the chamber during the vaporization process; thus, there is always a constant supply of molten metal in the chamber for vaporization. Disposing a plurality of fingers in respective passages in the block establishes a plurality of shells of fluid metal within the respective passages. The shells of fluid metal form in the spaces between the inner surfaces of the respective passages and the outer surfaces of the respective fingers. Both the block and the fingers are fabricated of a material such as graphite that is not attacked by the molten metal.

The shells of fluid metal are heated (by means either external or internal of the chamber) in order to generate metal vapor. Preferably, heat is transmitted to the shells through both the block and the fingers to rapidly vaporize the molten metal. The metal vapor is then passed through a tortuous path to remove any particles entrained in the vapor and is then directed horizontally by a nozzle from the chamber. The nozzle directs the metal vapor against a vertically moving substrate to form a coating thereon. As the metal vapor is generated at a rapid and constant rate, a coating of constant thickness is deposited on the continuously moving substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. 2 is an exploded perspective view of the block and fingers of the present invention.

DETAILED DESCRIPTION

Referring to FIG. 1 of the drawings, there is shown a shell 10 in which metal-vaporizing apparatus 12 is disposed. The shell 10 is fabricated of stainless steel or the like and is maintained under vacuum so that metal vapor may be produced under vacuum. The shell 10 is placed 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 an atmospheric pressure difference at 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 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 includes a reservoir 18 which is adapted to contain a supply of molten metal. The entire metal vaporizing apparatus 12 including the reservoir 18 is fabricated of a material that is not attacked (corroded or reactive with) by the molten metal, e.g., graphite or the like when the molten metal is zinc. Although it is possible to transfer molten metal directly into the reservoir 18, especially in a commercial installation, it is presently preferred to locate an ingot of the metal or metal granules within the reservoir so that upon heating the shell 10 the ingot or granules will melt to form fluid metal. Continuous or batch type feeding of molten metal from outside the shell 10 also may be employed.

At the base of the reservoir 18 is an outlet 20 through which molten metal flows naturally. The outlet, however, is blocked by a valve 22 which allows or prevents molten metal from leaving the reservoir 18. Normally, the valve 22 is in closed position until the metal ingot or granules within the reservoir 18 has melted and until the temperature of the metal vaporizing apparatus 12 has reached the desired level. The valve 22 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 22 comprises a valve body 24, an operator structure (not shown) which may be either manual or automatic, and an aperture 26 in the valve body alignable with the outlet 20 upon movement of the valve body 24 by the operator structure. In FIG. 1, the valve 22 is shown in open position. As the valve 22 is also fabricated of a nonattacked material, e.g., graphite when the molten metal is zinc, a liquid-to-liquid seal may be achieved about the valve body 24 so that there will be no liquid leakage through the various clearances about the valve components.

When the aperture 26 is aligned with the outlet 20, molten metal may flow from the reservoir 18 through the outlet 20 and the aperture 26 into a chamber 28 adapted to contain a pool of molten metal. The chamber 28 may be continuously charged with molten metal from the reservoir 18 so that a continuous supply of metal vapor may subsequently be generated. For convenience, both the reservoir 18 and the chamber 28 may be formed in a crucible 29. This prevents vapor and liquid leakage. The crucible 29 which forms the chamber 28 is fabricated of material not attacked by the molten metal, e.g., graphite or the like when the molten metal is zinc. Graphite has been found to be a suitable material for fabricating the crucible 29 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 chamber 28 is substantially rectangular in cross section. It is believed that a chamber 28 having a rectangular cross section is more efficient than one having a circular cross section. A more consistent and controllable evaporation rate can be more readily achieved in a horizontal rectangular cross section evaporator than in a horizontal cylindrical evaporator where the evaporator-molten metal interface area and the liquid-vapor interface area vary significantly with the amount of zinc in the evaporator. The evaporation rate is to a considerable degree dependent on these two interface areas.

Disposable within and substantially filling the chamber 28 is a block 30, as best seen in FIG. 2. The block 30 is cubic in shape and has a number of cylindrical passages 32 therethrough between the top and bottom thereof into which molten metal may flow when the block 30 is located within the chamber 28. Of course, the block 30 may be cylindrical or any other suitable shape where necessary to fit within the chamber 28. Preferably, the passages 32 are equally spaced about the

block 30 in a geometric pattern. Again, the block 30 is fabricated of a material not attacked by the molten metal, such as graphite when the molten metal is zinc. Legs 34 are formed at the bottom of the block 30 so that the block may rest within the chamber 28 with the major portion of the bottom of the block 30 being slightly spaced from the bottom of the chamber 28. This allows a thin layer of molten metal to be present on the bottom of the chamber 28 so that a continuous local supply of molten metal is available to enter into the passages 32 in the block 30. It should be understood that the block 30 may be integral with the crucible 29, but in order to practically fabricate the apparatus, it is desirable that the chamber 28 first be formed in the crucible 29 and then a separately formed block 30 be disposed therein.

Within each of the passages 32 in the block 30 is disposed a cylindrical finger 36. Each finger is slightly smaller in cross section than the respective passage 32. Thus, when a finger 36 is located in a passage 32, a concentric space 38 (FIG. 1) is formed between the inner surface 32a of the passage 32 and the outer surface 36a of the finger 36. Fluid metal enters the concentric space 38 from the bottom of the chamber 28 to form a shell of fluid metal within the passage. Preferably, the ends of the fingers 36 do not reach to the bottom of the chamber 28 so that the thin layer of molten metal thereat will be undisturbed. The plurality of fingers 36 suspended in the molten metal in the respective passages 32 increase the surface area in contact with the molten metal, which is necessary for efficient vaporization when the apparatus is fabricated of graphite. When the shell 10 is heated to a temperature of about 1,700° F., the temperature of the block 30 and the fingers 36 will be only about 1,500° F.

The fingers 36 are equally spaced on and extend from a plate 40 in a geometric pattern corresponding to the pattern of the passages 32 in the block 30 (see FIG. 2). The plate 40 also serves as a cover for the crucible 29 in which the chamber 28 and the reservoir 18 are formed. A protruding section 42 at the bottom of the plate 40 fits within the chamber 28 such that an annular passage 44 (FIG. 1) is left between the perimeter of the protruding section 42 and the inner wall of the chamber 28. Through this passage 44 generated metal vapor may pass, as explained below. The protruding section 42 at the bottom of the plate 40 does not contact the upper surface of the block 30 so that a gap 46 is left between the protruding section 42 and the block 30. Generated metal vapor may pass through the gap 46, as explained in more detail below. As noted above, both the fingers 36 and the plate 40 from which the fingers extend are fabricated of graphite or the like which is not attacked by molten zinc.

Forming a plurality of relatively thin shells of fluid metal in the concentric spaces 38 has definite advantages in vaporizing the molten metal. First, the thinness of the shells either reduces the size of vapor bubbles which form in the molten metal upon heating or obviates them altogether. Eliminating bubbles from the vapor consequently reduces the liquid inclusions or particles in the vapor. Second, by forming relatively thin shells of fluid, a relatively large surface area is provided for the application of heat to those volumes of fluid, which increases the efficiency of the transfer of heat for vaporization. The efficiency of heat transfer is also increased by the high velocity of bubble or fluid movement through the thin shells of fluid. 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.

But it is also within the scope of this invention to make block 30 integral and continuous with crucible 29 so that liquid zinc is forced to percolate to the upper edges of block 30 from one passage 38 (which now becomes a hole) to communicate to another passage 38. In this manner it is possible to have substantially total vapor in the region of the most remote passage 38, free of liquid zinc due to this progressive screening effect.

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 fluid metal has been heated to generate metal vapor, the metal vapor accumulates in the gap 46 between the protruding section 42 of the plate 40 and the top of the block 30. The metal vapor passes from the gap 46 through an aperture 48 in the crucible 29 into a trap 50, which also may be formed in the crucible. The gap 46, the aperture 48 and the trap 50 form a tortuous path wherein any splatter entrained in the metal vapor is removed therefrom. The entrained splatter removed from the metal vapor collects at the base of the trap 50 from which it may later be removed.

A nozzle 52 transfers the metal vapor from the tortuous path in a direction horizontally from the chamber 28. The nozzle 52 may be fabricated of the same material as the other elements of the metal-vaporizing apparatus 12, e.g., graphite or the like, and must be sufficient in size to permit ready transport of the vapor from the chamber 28. The nozzle 52 directs the metal vapor against a substrate (not shown) continuously moving transversely thereto so that the vapor condenses to form a coating thereon. The shell 10 preferably encases the entire metal-vaporizing apparatus 12 including the nozzle 52 so that no pressure leakage will occur in the system. As the metal vapor is generated at a rapid and constant rate, a coating of substantially equal thickness may be deposited about the surface area of the continuously moving substrate.

In operation of the apparatus of the present invention, a supply of molten metal, e.g., zinc, is disposed in the reservoir 18. At the same time the block 30 is inserted in the chamber 28 of the crucible 29 and plate 40 containing the fingers 36 is secured in place to the crucible. The entire vaporizing apparatus 12 including the nozzle 52 is located inside the stainless steel shell 10. The valve 22 is placed in the closed position, i.e., where aperture 26 is not in alignment with the outlet 20 from the reservoir 18. The shell 10 is then evacuated to a low pressure and heated by the furnace 14. A pressure of less than 30 microns is necessary to produce a bright coating on the substrate. Heating results in the metal in the reservoir 18 reaching a temperature of approximately 1,150° to 1,200° F. This temperature is sufficient to melt zinc ingot or granules in the reservoir. The valve 22 is then fully opened so that molten zinc will be permitted to flow into the chamber 28, the molten metal rising within the concentric spaces 38 surrounding the respective fingers 36 to form thin shells of fluid metal. The thin shells of fluid metal are heated by means of the furnace 14, which may be of the natural gas or electrical resistance type, to form metal vapor. Internal heating may also be employed. In such a case the walls of the vacuum shell 10 would be "cold," and the crucible 29 would be heated by gas-fired tubes or electric resistance elements, e.g., Passing through the tortuous path defined by the gap 46, the aperture 48 and the trap 50, the metal vapor is directed by the nozzle 52 away from the chamber 28. The vapor condenses upon a substrate, e.g., copper-plated steel strip, which moves transversely to the end of the nozzle 52. It is also possible to divert some of the metal vapor into a collecting box (not shown) rather than all of the vapor onto the moving strip when a thinner coating is desired.

EXAMPLES

In one particularly successful operation of representative apparatus used in the present invention, the shell 10 was placed horizontally in a furnace 14. The shell was evacuated to a pressure of about one micron and heated to a temperature of 1,750° F. A zinc ingot weighing about 13 lbs. was disposed in the reservoir 18 to be melted. The zinc in the reservoir 18 reached a temperature of 1,100° F. which was sufficient to liquefy the zinc. Before the liquid zinc was introduced into the chamber 28 through the valve 22, the temperature of the chamber was 1,710° F. The steady-state temperature of the chamber 28 after the liquid zinc entered the chamber was 1,680° F. Each of the passages 32 was 1.0 inch in diameter while each of the fingers 36 was 0.75 inch in diameter so that the thickness of each thin shell of fluid metal was 0.125 inch. The molten zinc was vaporized and the metal vapor produced upon continued heating of the molten zinc in the chamber 28 was passed through the tortuous path and directed through a 1-inch nozzle onto a moving steel strip. The strip had previously been prepared by cleaning in an alkali cleaner and pickling in a 5 percent hydrochloric acid solution; the strip, which was 0.015 inch thick, was then electroplated with a copper coating about 5 to 7 microinches thick to promote adherence of the zinc vapor. As the strip prior to coating was maintained at a temperature of only about 70° to 110° F., the zinc vapor condensed on the cool substrate rather than being dissipated into the warmer environment. During vapor condensation, the temperature of the strip reached 450°-600° F. About 500 feet of 6-inch wide strip were coated to a thickness of about 0.5 to 1.0 mils at a rate of up to 75 ft. per minute. The average condensation rate for the run was 0.55 lbs. zinc per minute while the maximum condensation rate was found to be 0.74 lbs. per minute or 2.24 lbs. per minute per square foot of evaporating area. Upon visual examination for coating appearance it was determined that little or no splatter occurred upon the substrate while the coating appearance was excellent.

The shell temperature should be maintained at no more than about 1,750° F. to avoid design problems in the shell 10 and furnace 14. Thus, in another operation using representative apparatus, the shell 10 was evacuated to a pressure of about one micron and maintained at a temperature of about 1,700° F. The temperature of the chamber 28 before introduction of 13 lb. of molten zinc was 1,620° F. and the temperature of the chamber after introduction of the zinc was 1,520° F. The average condensation rate upon a steel strip of the type used in the first example at these temperatures was 0.45 lbs. zinc per minute while the maximum condensation rate was 0.62 lbs. per minute. The shell 10 was maintained within the maximum operating temperature. Little or no splatter was present in the substrate coating and the coating appearance was excellent.

Thus, the present invention provides for vaporization of molten metal, particularly zinc, without entrainment of particles in the metal vapor. The invention further provides for coating of a substrate, particularly copper-plated steel strip, with a metal vapor at a high rate of production without the entrainment of liquid particles or the inclusion of splatter in the coating. Furthermore, the invention allows for vaporization of molten metal at a controllable rate so that a coating of equal thickness may be deposited on a continuously moving substrate.

We claim:

1. A method of vaporizing molten metal, comprising the steps of:

- disposing a pool of molten metal within a chamber;
- allowing said molten metal to flow into a plurality of passages in a block disposed within said chamber;
- forming a plurality of shells of fluid metal within said passages in said block by disposing a plurality of fingers in the respective passages such that spaces are left between the inner surfaces of the respective passages and the outer surfaces of the respective fingers; and

d. heating said shells of fluid metal to generate metal vapor.

2. A method according to claim 1, further comprising the step of continuously charging said chamber with said molten metal.

3. A method according to claim 1, wherein said chamber is maintained under vacuum to provide for the production of metal vapor under vacuum.

4. A method according to claim 1, wherein said chamber, said block and said fingers are not attacked by said molten metal.

5. A method according to claim 1, wherein said chamber, said block and said fingers are fabricated from graphite when said molten metal is zinc.

6. A method according to claim 1, further comprising the

step of directing the metal vapor from said chamber by nozzle means.

7. A method according to claim 6, further comprising the step of passing said metal vapor through a tortuous path between said chamber and said nozzle means.

8. A method according to claim 6, wherein said metal vapor passes horizontally from said chamber.

9. A method according to claim 1, further comprising the step of directing said generated metal vapor against a continuously moving substrate to be coated.

10. A method according to claim 1, wherein a thin layer of said molten metal is maintained at the bottom of said chamber.

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