ABSTRACT OF THE DISCLOSURE

In general, this disclosure relates to the production of metal powders, in which molten metal is atomized in a tower by a tornado-like spiral stream of fluid produced by an atomizing nozzle device. The atomized metal powder is collected by a reciprocating conveyor disposed beneath the tower.

The methods and apparatus shown by the prior art for producing metal powders generally involve a batch-type process, in which a stream of molten metal is "dis-integrated" or partially atomized by an impinging jet of gas, or rotating discs or the like. The atomized metal droplets are directed into a tank of liquids such as water, where they freeze and settle to the bottom of the tank for collection. The metal powder must then be extracted and dried. The yield of fine mesh metal powder from such processes is generally low, and the powders are poring and irregular. Further, such processes have not been commercially satisfactory for comparatively "light" metal alloys, such as high percentage manganese alloys.

Examples of the prior art metal atomization devices and methods are as follows: 1,501,449; 1,938,876; 2,306,449; 2,968,062; 1,635,653; 2,006,891; 2,956,304; and 3,093,315.

The metal atomization nozzles shown by the prior art generally include a nozzle for the molten metal and a circumferential annular gas equalization chamber. The gas is discharged from the chamber through an annular nozzle, across the exit of the molten metal receiving nozzle, as shown in FIGURE 2 at 186 in U.S. Patent 2,006,891, to create a vacuum opposite the metal exit. This vacuum draws the metal into the gas cone, which partially atomizes the metal. To the best of our knowledge such nozzles have only been commercially utilized in batch-type fluid systems, such as described hereinabove.

A primary object of this invention is to provide an atomization apparatus and process which produces dry metal powders directly from molten metal, without requiring collection of the powder in a liquid settling tank.

Another object of this invention is to provide a metal atomizing nozzle which produces dry, spherical metal powder, which may be collected in the dry state.

Another object of this invention is to provide a metal atomizing nozzle which suspends the atomized particles in a spiral tornado-effect produced by a gas stream, to permit collection of the powder in a dry state, and subject the powder to a shearing action which produces a round cleaner denser powder.

Another object of this invention is to provide a method of producing dense dry metal powders from molten metal in a continuous process.

Basically, the molten metal atomizing nozzle of this invention comprises a downwardly discharging molten metal nozzle having a discharge orifice adjacent its lower end, and a circumferential annular gas chamber having a generally annular discharge port surrounding the lower end of the molten metal receiving nozzle. The annular gas chamber is provided with at least two tangential gas inlets adjacent its outer extent, and the gas chamber decreases in cross section toward the discharge port.

The tangential gas inlets are additive to generate a rapid swirling action in the gas chamber, and the decreasing cross section of the chamber toward its annular exit increases the velocity of the gas to create an inverted tornado, or "tornado-effect" adjacent the exit of the molten metal nozzle. The term "tornado-effect" is used herein to characterize the action of the gas, because the resulting conditions are analogous to an inverted natural tornado. For example, the velocity of the gas at the vortex is substantially zero, and the pressure decreases from a maximum at the vortex to a minimum at the slip stream or perimeter of the tornado. The molten metal is drawn from the discharge orifice of the nozzle into the low pressure slip stream of the tornado-effect, where it is atomized and suspended in the tornado. The greater pressure and relative zero velocity of the tornado at its vortex substantially eliminates metal flow through the vortex, causing substantially all of the metal to be suspended and atomized. Further, the spiral tornado action rolls and shears the atomized particles to produce dense round metal powders, which it is an object of this invention to produce. The suspension of the atomized particles permits freezing prior to contact with the sides or bottom of the atomization chamber, and prevents agglomeration of the particles at the bottom of the chamber. Previous atomization devices permitted the atomized particles to free fall from the atomizing device, requiring a liquid collection means or the like.

Other objects, advantages and meritorious features of this invention will more fully appear from the following specification, claims, and accompanying drawings, where-in:

FIGURE 1 is a top elevation of an atomization nozzle of this invention;
FIGURE 2 is a side cross sectional view of the atomization nozzle shown in FIGURE 1;
FIGURE 3 is a side cross sectional view of an atomization nozzle illustrating the tornado-effect developed by the nozzle of this invention;
FIGURE 4 is a side elevation of an atomization apparatus of this invention;
FIGURE 5 is a top elevation of the atomization apparatus shown in FIGURE 4; and
FIGURE 6 is a cross sectional view of the top portion of the atomization apparatus shown in FIGURE 4 including the atomization nozzle.

FIGURES 1 and 2 illustrate one embodiment of the atomization nozzle means of this invention. The molten metal receiving nozzle 20 may be formed from a single piece of ceramic or refractory material capable of withstanding the temperatures of molten metal. The nozzle 20, which is generally conical as shown in FIGURE 2, has a cup shaped opening 22 which receives the molten metal to be atomized, and a discharge orifice 24 adjacent its lower end. In this embodiment, the discharge orifice is provided with a conical insert 26 which directs the molten metal through an annular opening 30 at the perimeter of the orifice. The insert is supported within the orifice by a bridge 28. The purpose of the conical nozzle insert is to provide an increased mass transfer rate through the nozzle orifice, without increasing the distance between the molten metal discharged therefrom and the exit 32 of the gas chamber 34, as described hereinafter.

The gas chamber 34 is defined by a pair of nozzle body members 36 and 38, and by a spacer ring 40. The body members and spacer ring may be formed from any material capable of withstanding the gas pressure. The gas nozzle assembly is secured by a series of bolts 42 and nuts 44. The metal receiving nozzle, which is not subject to pressure, need not be secured in place. The
gas chamber has a pair of gas inlets 46, as shown in FIGURE 1, tangentially entering the chamber adjacent its outer extremity, and the chamber decreases in cross section toward the annular discharge port 32. It can be seen from FIGURE 1 that the gas inlets 46 are additive to generate a rapid swirling action in the chamber, and the decreasing cross section of the chamber, toward the annular exit 32, further increases to the velocity to create a tornado-effect about the axis of the metal nozzle 24.

The spacer ring 40 has been utilized for convenience of forming the chamber body members 36 and 38, and to provide a means of adjusting the width of the gas discharge port 32. The width of the port may be varied by utilizing various lengths of rings by adding or removing shims, not shown. The ring may also be integral with either body member, or the entire gas nozzle body may be formed from a single blank.

The mechanism of atomization, and the effect of the tornado on this mechanism, is best described in combination with Figure 3 which shows a modified form of the atomizing nozzle means shown in FIGURES 1 and 2. The embodiment of FIGURE 3 has a molten metal receiving nozzle 50, including an integral cup shaped ladle 52 which receives the molten metal, and a conical nozzle portion 54. The nozzle portion has a discharge orifice 56 adjacent its lower end. The gas chamber 58 is defined by a pair of body members 60 and 62, which may be secured in any conventional manner, as by bonding with adhesives or the like. The gas chamber has a pair of tangential inlets 64, as shown in FIGURE 1, and decreases in cross section toward the annular discharge port 66 defined around the lower outer end 68 of the metal receiving nozzle 50.

Fluid is introduced under pressure into the tangential inlets 64, which generates a rapid swirling action in the chamber 58. The fluid is preferably a nonoxidizing gas, such as nitrogen, or an inert gas such as argon to prevent oxidation of the molten metal, however certain applications may utilize air or even liquids. The decreasing cross section of the chamber increases the gas velocity to create a tornado-effect 70 about the axis of the metal nozzle 50. The characteristics of the tornado-effect are shown by the pressure-velocity curves, wherein "p" and "u" indicate pressure and velocity respectively, and "L" indicates the distance from the axis of the metal nozzle.

It can be seen from the pressure curve 72 that the pressure is greatest at the vortex of the tornado, which coincides with the axis of the metal receiving nozzle because of the symmetry of the system. And, the pressure decreases as a minimum at the slip stream or perimeter 74 of the tornado, which is a partial vacuum. Conversely, the velocity of the gas is maximum at the slip stream 74, and decreases substantially to zero at the tornado vortex, as shown by the velocity curve 76.

Molten metal at the nozzle orifice 56, which is subject to atmospheric pressure, is drawn into the vacuum defined at the slip stream of the tornado 74, as shown by arrows 78, and suspended in the spiral motion of the tornado. This mechanism is to be differentiated from an atomizing gas nozzle wherein the gas is merely blown across the exit of the metal receiving nozzle, creating a vacuum within the nozzle orifice similar to the action of air across an airplane wing creating the lift. In such a nozzle, the metal free falls from the nozzle orifice, and the particles produced are porous and irregular. The tornado-effect of the nozzle of our invention suspends the atomized particles sufficiently to permit collection in the dry state, and roll down to the metal to produce dense spherical particles. Substantially all of the metal is drawn into the spiral slip stream of the tornado, and therefore atomized because of the relatively greater pressure and zero velocity at the vortex of the tornado.

The fluid or gas must reach a critical velocity in the gas chamber to maintain a stable tornado-effect. This velocity will depend on the density of the fluid, and the atmosphere defined beneath the atomization device in which the tornado is to be sustained. This critical velocity has been attained in the gas chamber of this invention by the pair of additive gas inlets in combination with the decreasing cross section of the gas chamber. However, it should be understood that a greater number of tangential inlets may be utilized, and the configuration of the chamber may therefore be modified. It has been our experience, however, that the angle defined by the walls 80 and 82 in FIGURE 3 of the conical annular gas chamber is preferably less than 15°.

There are several design details and relationships which will affect the yield, the size, and the quality of metal powders produced by the embodiments of our invention disclosed. For example, the angle defined by the perimeter of the tornado-effect 74, or the cone angle of the tornado, is dependent on the velocity of the gas, and the cone angle of the annular gas chamber 58. Assuming a constant gas velocity, the smaller the cone angle of the gas chamber or the greater cone incline, the smaller the cone angle of the tornado. The cone angle of the tornado-effect may thus be varied, by varying the gas velocity and/or the cone angle of the tornado-effect, depending on the diameter and the height of the atomization enclosure.

The molten metal receiving nozzle and the gas chamber have been designed such that the metal flow is in close proximity to the exit of the gas nozzle, to assure that the metal will be drawn into the spiral stream of the tornado-effect, and atomized. Nozzle orifices smaller than approximately 1/8 inch in diameter may be circular in cross section, as shown in FIGURE 3, however larger nozzle orifices, as required by large mass transfer rates, are preferably annular as shown in FIGURES 1 and 2. Annular orifices are preferred for large mass transfer rates to insure interaction between the molten metal and the gas, and because the thinner the metal stream, the finer the metal particle size with a given gas pressure.

The lower end of the metal receiving nozzle extends below the annular discharge port of the gas chamber to prevent blow-back of gas through the nozzle, thereby reversing the metal flow and causing metal freezing at the nozzle orifice. Long extensions, however adversely affect the metal powder yield because the metal receiving nozzle exit is preferably in close proximity to the exit in the gas chamber, as described hereinabove. We have found that the metal receiving nozzle preferably protrudes between 1/16 and 1/8 of an inch below the exit of the gas chamber to provide the optimum yield of fine metal powders. The protruding lower outer edge of the nozzle 90, in FIGURE 3, is preferably sharp to provide metal buildup which might adversely affect the flow pattern of this embodiment, and thereby affect the efficiency of the system.

The width of the gas discharge port will also affect the size and yield of metal powders. An optimum range for producing fine metal powders in the embodiment disclosed in FIGURES 1 to 3 has been found to be 0.005 to 0.025 inch. Gas discharge ports in this range of widths provides a pinching and atomizing effect which has been found desirable. Larger gas chamber openings may be utilized, but the metal powder yield is not as great in the fine mesh ranges, and larger openings may not sustain the tornado-effect described. Smaller openings may not permit sufficient gas flow to sustain the tornado-effect.

The annular gas chamber may taper evenly from an inner diameter of one-fourth inch in width, however decreasing cross sectioned spiral chambers, or other configurations, may also be utilized. The lower surface of the gas chamber should be configured such that it does not interfere with the path of the atomized metal as it leaves the metal nozzle. In the embodiment shown, the lower surface is tapered toward the axis. The exit or discharge port of the gas chamber may also be contoured, as shown at 32 in FIGURE 2, to provide a
smooth transition from the chamber into the tornado-effect. The relationship of the inlet diameter of the gas chamber to the outlet diameter will also affect the gas velocity, and therefore the yield of metal powder. Friction, however decreases the beneficial effects of any large increase in this ratio.

Two other factors which affect the yield and particle size are the inlet gas pressure and the metal temperature. The gas pressure is inversely proportional to the average metal powder particle size. Pressures from 100 to 700 p.s.i. have been used successfully, however very fine particles are produced with pressures of 1000 p.s.i. and greater. The metal temperature must be sufficient to prevent precipitation of the metal oxide from the metal nozzle orifice, however if the metal is too hot the atomized particles will not freeze prior to collection.

For purposes of illustration only, the following is an example of the improved results obtained with the atomization means of this invention. A nickel base alloy, AMS 4777 was atomized at 2150 degrees Fahrenheit using nitrogen gas at a pressure of 600 p.s.i. The metal nozzle orifice was 0.25 inch in diameter and a gas discharge port of 0.010 inch was used. A dense round metal powder was collected dry having 52% of minus 100 mesh.

FIGURES 4 to 6 illustrate one embodiment of the atomization apparatus of our invention. The apparatus includes a metal atomization chamber 100 having an open lower end 102, an atomizing nozzle means 104 communicating with the upper end of the chamber, and a reciprocating collection means 106 for simultaneously spending and collecting metal powders from the open end of the chamber.

The atomizing nozzle means 104 may be similar to the embodiments disclosed in FIGURES 1 to 3, as shown in FIGURE 6, and has therefore been numbered similar to FIGURES 1 and 2.

The atomization chamber 100 provides the enclosure in which atomization occurs. In this embodiment, the chamber includes an upper divergent conical section 108 which receives the atomizing nozzle, as shown in FIGURE 6, a cylindrical section 110, and a lower convergent conical section 112. The upper divergent conical section 108 is utilized primarily to save space and materials, and is conical to permit the constriction, or convergent tornado-effect, created by the atomizing nozzle. The lower convergent conical section 112 aids in directing the atomized metal powder into the reciprocating collection means 106. A hinged door 114 is provided in the cylindrical section 110 for inspection and cleaning, and the chamber is supported by four legs 116.

The reciprocating collection means is adapted to suspend the atomized particles and collect them in a dry state. In this embodiment, the reciprocating collection means comprises an oscillatory conveyor, which is enclosed to prevent oxidation of the powder. The conveyor 118 is suspended by a series of leaf springs 120. Power is transmitted to the conveyor system by a positively driven eccentric shaft 122, which is rotated by a motor 124. Horizontal vibration of the conveyor by the eccentric shaft 122 simultaneously suspends and conveys the atomized particles along the conveyor 118. The particles are literally thrown along the conveyor, as the conveyor oscillates on the leaf springs 120. The suspension of the atomized metal particles prevents heat transfer between the particles, while moving the particles from contact with the recently atomized particles. The oscillatory conveyor in this embodiment is enclosed by a cover 126 which communicates with the open end of the chamber 102 through a bellows seal 128. A nonoxidizing gas, such as argon or inert gas such as argon may be introduced into the enclosure to prevent oxidation of the relatively hot atomized metal powder.

The atomizing nozzle means 104 is supported in the upper divergent conical section 108 of the chamber by a frame 130, as shown in FIGURE 6. A separate ladle or cup 32 communicates with the conical opening 22 of the molten metal receiving nozzle, and is supported by the frame means 130. The ladle 132 is secured in place by a cover plate 134 which is retained to the conical chamber section 108 by a spring lock 136.

Molten metal is introduced into the ladle 132, which may be formed from a ceramic or refractory material, similar to the metal nozzle 22. The molten metal is circulated through the metal nozzle orifice 24, where it is atomized by fluid discharged from the gas chamber 34. Where an atomizing nozzle means similar to the embodiments disclosed in FIGURES 1 to 3 is utilized, the atomized metal particles are suspended and formed into a dense spherical powder by the spiral slip stream of the tornado-effect. The atomized particles are carried by the spiral gas stream into the oscillatory conveyor 106. Some of the atomized particles will impinge against the convergent conical walls of the chamber and be carried into the conveyor. The particles are then simultaneously suspended and conveyed through the enclosed conveyor system 106 to a packaging station not shown.

The method of producing dry metal powders directly from molten metal of this invention has already been described in reference to the atomizing nozzle means of this invention, and the atomization apparatus. Briefly, the method includes introducing a gas under pressure tangentially into an annular chamber having a restricted annular discharge nozzle to produce a tornado-effect adjacent the nozzle opening. Molten metal is discharged into the spiral slip stream of the tornado-effect to atomize the molten metal and suspend the particles to permit collection thereof in a dry state. The particles are then simultaneously suspended and conveyed from beneath the discharge nozzle of the gas chamber with a reciprocating conveyor, or the like, to prevent agglomeration of the atomized powder. The method may include introducing a nonoxidizing gas into an enclosure defined around the reciprocating conveyor, to inhibit oxidation of the atomized powder, and aid in the heat transfer.

It will be understood by those skilled in the art that several modifications may be made to the embodiments of the atomizing nozzle means, apparatus, and method of producing dry metal powders, without departing from the purview of the appended claims. For example, any conventional form of metal nozzle may be utilized. The metal nozzle disclosed herein may be characterized as a convergent nozzle, however, a divergent, or convergent-divergent nozzle may also be utilized. Further, the molten metal in the nozzle is subject to atmospheric pressure, however the metal nozzle may also be subjected to pressure to increase the mass transfer rate. A pressure system may also be utilized when the molten metal is highly sensitive to oxidation, in which case a nonoxidizing gas could be utilized to pressurize the system. It is also understood that the atomization apparatus disclosed in FIGURES 4 to 6 was designed primarily for use with an atomizing nozzle means which creates a tornado-effect in the chamber, however, the principles taught in the Improved atomization apparatus may also be utilized with nozzle means taught by the prior art.

What is claimed is:

1. A molten metal atomization device, comprising: a downwardly discharging molten metal receiving nozzle having a discharge orifice adjacent its lower end, and a circumferential annular gas chamber having a generally annular discharge port surrounding the lower end of said molten metal receiving nozzle, said gas chamber decreasing in cross section toward said discharge port to increase the velocity of gas discharged therefrom and at least two spaced gas inlets entered said gas chamber tangential to the inner surface of the radial outer wall of the annular
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chamber, said gas inlets directing the gas in the same direction about the vertical axis of the annular chamber and additive to create a tornado-effect adjacent the exit of said molten metal nozzle to draw molten metal from said nozzle exit, into the spiral slip stream of the tornado-effect, atomize the metal and suspend the atomized particles for a sufficient time to permit collection thereof in the dry state.

2. The molten metal atomization device defined in claim 1, characterized in that said molten metal receiving nozzle discharge orifice is generally annular to improve the mass transfer of said molten metal into the stream of the tornado created adjacent the discharge orifice.

3. The molten metal atomization device defined in claim 1, characterized in that said annular gas chamber defines a downwardly extending annular cone in cross section to provide the vertical component of said tornado-effect.

4. The molten metal atomization device defined in claim 3, characterized in that the walls which define said conical annular gas chamber converge at an angle of less than 15°.

5. The molten metal atomization device defined in claim 1, characterized in that the lower end of said molten metal receiving nozzle protrudes beneath said gas chamber discharge port 1/16 to 1/8 of an inch.

6. The molten metal atomization device defined in claim 1, characterized in that said tangential gas inlets are evenly spaced about the perimeter of said gas chamber.

7. The molten metal atomization device defined in claim 1, characterized in that said gas chamber is provided with two tangential gas inlets spaced 180° apart.

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