An atomizing system and method are disclosed. A system can include a tundish configured to hold a molten material and a nozzle in fluid communication with the tundish. The nozzle and/or the tundish can be comprised of a material having a composition that is substantially similar to the composition of the molten material. An internal channel can be defined in at least one of the tundish or the nozzle. Additionally, a pump can be configured to pump a molten heat transfer medium through the internal channel. A method of atomizing the molten material can include affecting heat transfer between the molten material and the tundish and/or the nozzle with a molten heat transfer medium in at least one internal channel in the tundish and/or the nozzle. The tundish and/or the nozzle can comprise a material that is substantially similar to the molten material.
ACTIVATE TUNDISH PREHEATING ELEMENT

ACTIVATE PUMP TO INTRODUCE MOLTEN HEAT TRANSFER MEDIUM TO INTERNAL CHANNELS

HEAT TUNDISH AND/OR NOZZLE WITH MOLTEN HEAT TRANSFER MEDIUM

ATOMIZE MOLTEN MATERIAL

COOL TUNDISH AND/OR NOZZLE WITH MOLTEN HEAT TRANSFER MEDIUM

FIG. 3
ATOMIZING APPARATUSES, SYSTEMS, AND METHODS

BACKGROUND OF THE TECHNOLOGY

[0001] Field of Technology

The present disclosure is directed to metal and metal alloy atomizing systems and methods. More particularly, the present disclosure is directed to apparatuses, systems, and methods for producing clean atomized metal and metal alloy powders.

[0003] Description of the Background of the Technology

During an atomizing operation, a heat of a metal or metal alloy is heated to high temperature and subjected to high pressures. Typically, during atomization operations starting materials are heated to a molten state and subjected to high-pressure atomizing jets to produce a powder from the molten material. When subjected to such high-temperature, high-pressure conditions, the material being atomized may be subjected to contaminants that are within the system or which become entrained as a result of erosion from the molten material. For example, the molten material may react and/or combine with elements in the atmosphere or other materials present in the atomizing system.

[0005] To prevent contamination of a molten material with elements in the atmosphere, the atomizing operation may be conducted within a chamber containing a non-reactive atmosphere. For example, molten titanium and high temperature titanium alloys are often maintained in a vacuum or in an inert atmosphere during certain stages of the atomizing operation. In an electron beam cold hearth furnace, a high or substantial vacuum is maintained in the melting and casting chambers to allow the electron beam guns to operate. In a plasma as cold hearth furnace, plasma torches use an inert gas, such as helium or argon, for example, to produce plasma. The atomization jets in an atomizing system can also utilize an inert gas to generate the atomized powder. Atomizing of titanium in a nonreactive atmosphere, for example, is described in U.S. Pat. No. 5,084,091, entitled “Method for Producing Titanium Particles”, the entire disclosure of which is hereby incorporated herein by reference.

[0006] To prevent erosion and contamination of the molten material by other material(s) in the atomizing system, the molten material can be isolated or separated from the other materials present in the system. For example, a solidified skull of the material being processed can physically separate the molten material from the materials from which the hearth and/or tundish are constructed in a melting, refining, and/or atomizing system. Additionally or alternatively, the hearth and/or tundish can be lined with ceramic or another high melting point material, which can isolate or inhibit contact between the molten material and the other materials in the system. The atomizing nozzle or a lining in the nozzle may also be comprised of ceramic or other high melting point material. An atomizing system including a ceramic nozzle, for example, is described in U.S. Pat. No. 5,263,689, entitled “Apparatus for Making Alloy Powders”, the entire disclosure of which is hereby incorporated herein by reference. Despite efforts to isolate the molten material from other material(s) in the atomizing system, erosion and/or contamination can still occur. For example, ceramic material in the nozzle can contaminate the molten material, which can produce inclusions or other defects in products formed from the powdered material.

[0007] It would be advantageous to provide an atomizing system and method that are less susceptible to erosion and contamination of the molten and atomized material contained therein. It would also be advantageous to provide improved thermal transfer to and from a tundish and an atomization nozzle. More generally, it would be advantageous to provide an improved atomizing system and method adapted to process titanium, other reactive materials, and metals and metal alloys generally.

SUMMARY

[0008] According to certain non-limiting embodiments, apparatuses, systems, and methods for producing atomized powder of metals and metal alloys are described.

[0009] Various non-limiting embodiments according to the present disclosure are directed to a system for atomizing a molten material selected from a molten metal and a molten metal alloy, the molten material having a first material composition. The system comprises a tundish configured to hold the molten material and a nozzle in fluid communication with the tundish, wherein the nozzle is comprised of a second material having a second material composition, and wherein the second material composition is identical or substantially identical to the first material composition. The system for atomizing the molten material further comprises an internal channel defined in at least one of the tundish or the nozzle and a pump configured to pump a molten heat transfer medium through the internal channel.

[0010] In certain non-limiting embodiments of the system according to the present disclosure, the tundish is comprised of a third material having a third material composition, and the third material composition is identical or substantially identical to the first material composition.

[0011] In certain non-limiting embodiments of the system according to the present disclosure, the internal channel is defined in the tundish, and a second internal channel is defined in the nozzle.

[0012] In certain non-limiting embodiments of the system according to the present disclosure, the molten heat transfer medium comprises at least one material selected from a molten salt, a molten metal, and a molten metal alloy.

[0013] In at least one non-limiting embodiment of the system according to the present disclosure, the boiling point of the molten heat transfer medium is greater than the boiling point of water at atmospheric pressure.

[0014] In certain non-limiting embodiments, the system according to the present disclosure further comprises a melt chamber, and the tundish is positioned in the melt chamber. In certain non-limiting embodiments, the system according to the present disclosure further comprises a melting hearth and a refining hearth positioned in the melt chamber. In at least one non-limiting embodiment, the system according to the present disclosure further comprises an atomization chamber, and the nozzle protrudes into the atomization chamber.

[0015] In certain non-limiting embodiments of the system according to the present disclosure, the molten heat transfer medium comprises a molten salt.

[0016] Various non-limiting embodiments according to the present disclosure are directed to a method for atomizing a molten material selected from a molten metal and a molten metal alloy, the molten material having a first material composition. The method comprises passing the molten material through an atomization nozzle comprised of a second material having a second material composition, wherein the sec-
ond material composition is identical or substantially identical to the first material composition, and wherein an internal channel is defined in the nozzle. The method further comprises pumping a molten heat transfer medium through the internal channel, wherein the molten heat transfer medium affects heat transfer to and from the atomization nozzle.

[0017] In certain non-limiting embodiments, the method for atomizing a molten material according to the present disclosure comprises providing the molten material to a tundish in fluid communication with the atomization nozzle, the tundish is comprised of a third material having a third material composition, and the third material composition is identical or substantially identical to the first material composition.

[0018] In certain non-limiting embodiments of the method according to the present disclosure, a second internal channel is defined in the tundish, and the method further comprises pumping the molten heat transfer medium through the second internal channel.

[0019] In certain non-limiting embodiments of the method according to the present disclosure, the molten heat transfer medium is at least one of a molten salt, a molten metal, and a molten alloy.

[0020] In at least one non-limiting embodiment, the method according to the present disclosure further comprises melting materials to provide the molten material.

[0021] Various non-limiting embodiments according to the present disclosure are directed to a method for regulating temperature in an atomizing system, wherein the atomizing system comprises a nozzle, and wherein the method comprises pumping a molten heat transfer medium through an internal channel in the nozzle to modify a temperature of the nozzle. According to certain embodiments of the method, the method includes pumping the molten heat transfer medium through the internal channel in the nozzle to heat the nozzle. According to certain embodiments of the method, the method includes pumping the molten heat transfer medium through the internal channel in the nozzle to cool the nozzle.

[0022] In certain non-limiting embodiments of the method for regulating temperature in an atomizing system according to the present disclosure, the method further comprises obtaining a nozzle comprised of a first material having a first material composition, and the first material composition is identical or substantially identical to the material composition of the atomized powder produced by the atomizing system.

[0023] In certain non-limiting embodiments of the method for regulating temperature in an atomizing system according to the present disclosure, the atomizing system further comprises a tundish, and the method further comprises pumping the molten heat transfer medium through a second internal channel in the tundish to cool the tundish.

[0024] In certain non-limiting embodiments of the method for regulating temperature in an atomizing system according to the present disclosure, the atomizing system further comprises a tundish, the method further comprises pumping the molten heat transfer medium through a second internal channel in the tundish to cool the tundish, and the tundish is comprised of a second material having a second material composition that is identical or substantially identical to the material composition of the atomized powder produced by the atomizing system.

[0025] In at least one non-limiting embodiment of the method for regulating temperature in an atomizing system according to the present disclosure, the molten heat transfer medium is pumped through the internal channel in the nozzle to heat the nozzle during a pre-atomizing stage, and the molten heat transfer medium is pumped through the internal channel in the nozzle to cool the nozzle during an atomizing operation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The various non-limiting embodiments described herein may be better understood by considering the following description in conjunction with the accompanying drawings, in which:

[0027] FIG. 1 is a schematic showing aspects of an atomizing system according to various non-limiting embodiments of the present disclosure;

[0028] FIG. 2 is a schematic showing aspects of the tundish and nozzle of the atomizing system illustrated in FIG. 1, according to various non-limiting embodiments of the present disclosure; and

[0029] FIG. 3 is a flow chart of a process for using the atomizing system illustrated in FIG. 1, according to various non-limiting embodiments of the present disclosure.

DETAILED DESCRIPTION OF CERTAIN NON-LIMITING EMBODIMENTS

[0030] According to certain non-limiting embodiments of an atomizing system according to the present disclosure, the atomizing system can include a tundish and/or a nozzle having an internal channel defined therein. The tundish and/or the nozzle can be comprised of a material having a material composition that is identical or substantially identical to a material composition of the molten material positioned in and/or flowing through the tundish and/or the nozzle. A molten heat transfer medium can flow through the internal channel(s) to facilitate heat transfer to and/or from the tundish and/or the nozzle. For example, the molten heat transfer medium can heat the tundish and/or the nozzle to prevent solidification of the molten material within the nozzle. Also, in certain embodiments, the molten heat transfer medium can cool the tundish and/or the nozzle as the molten material flows through the tundish and/or the nozzle.

[0031] To prevent the erosion and contamination of molten material by other materials in an atomizing system, an atomization nozzle and/or tundish of non-limiting embodiments of an atomizing system according to the present disclosure can be comprised of a material having a material composition that is identical or substantially identical to a material composition of the molten material. As used herein, a first material composition is “substantially identical” to a second material composition if the materials are of the same base alloy composition or within 1 weight percent of the base alloy elemental composition. Contamination of a first material having a first material composition with a second material having a “substantially identical” second material composition will not significantly alter the properties of the first material. According to one non-limiting example, while a molten first material having a first material composition is atomized through an atomizing nozzle comprising a second material having a substantially identical second material composition passes through a nozzle, and the second material erodes and contaminates the first material, the properties of the first material will not be significantly altered by the contamination.
According to another non-limiting example, a first material and a second material can be the same CP grade of titanium or the same titanium alloy. However, the first material may have been produced at a different location and/or at a different time than the second material. Rather than having identical material compositions, the first material and the second material may have minor compositional differences, and contamination of the first material with the second material, or vice versa, will not significantly alter the properties of the contaminated material. In such case, as the phrase is used herein, the material composition of the first material is substantially identical to the material composition of the second material.

To prevent erosion and contamination of molten material passing through an atomization nozzle, the material composition of the molten material can be substantially identical to the material composition of a material from which the atomization nozzle is comprised. For example, the atomization nozzle can be ceramic-free, and can also be free of other potential contaminants that would significantly affect properties of powder produced from the molten material. In certain non-limiting embodiments, the molten material and the atomization nozzle can both be comprised of the same CP titanium grade or titanium alloy; however, the titanium grade or alloy may have been produced at different locations and/or different times and not be produced in the same heat. As the molten material and the atomization nozzle are comprised of materials having substantially identical material compositions, nozzle material that contaminates the molten material would not significantly affect properties of powder produced from the molten material.

The tundish can also be comprised of a material having a material composition that is substantially similar to the material composition of the molten material. For example, if the molten material is comprised of a particular CP titanium grade or titanium alloy, the tundish can also be comprised of the same CP titanium grade or titanium alloy. Because the material composition of the molten material is substantially identical to the material composition of the tundish material, the tundish material would not significantly affect the properties of the molten material if it were to erode or dissolve in the molten material.

If an atomization nozzle is insufficiently heated prior to and/or during the atomizing operation, the molten material flowing through the nozzle may solidify and obstruct the nozzle opening. Additionally, if the nozzle is overcooled during operation of the atomizing system, high thermal stresses between the nozzle and the molten material may result in fracturing of the nozzle.

To provide adequate thermal transfer between the nozzle and the molten material, a molten heat transfer medium can be used in non-limiting embodiments of systems and methods according to the present disclosure. For example, a molten heat transfer medium can be used instead of conventional coolant for an atomizing nozzle, which typically is or is comprised of water. The molten heat transfer medium according to the present invention can comprise at least one of a molten metal, a molten alloy, or a molten salt, for example. To facilitate heating and/or cooling of the atomization nozzle, the molten heat transfer medium can be circulated through one or a plurality of internal channels in the nozzle. Alternatively, the molten heat transfer medium can be pumped through one or a plurality of internal channels in the tundish of an atomizing system according to the present disclosure, for example, and the molten heat transfer medium can facilitate thermal transfer between the tundish and the molten material.

The molten heat transfer medium can have a boiling point that is greater than the boiling point of water at atmospheric pressure. As a result, the molten heat transfer medium can more effectively be maintained at higher temperatures than water. Water can maintain a temperature of approximately 140°F (60°C), for example, while in various non-limiting embodiments according to the present disclosure a molten heat transfer medium can maintain temperatures between 500°F (260°C) and 900°F (482°C), for example. In other instances, the molten heat transfer medium can maintain temperatures below 500°F (260°C) or above 900°F (482°C), for example. Accordingly, the molten heat transfer medium can be heated to and maintain higher temperatures within the internal channels than can be achieved with conventional water or predominantly water-based coolant. In various embodiments of the present system and method, the molten heat transfer medium can assume and maintain a temperature that is greater than the temperature achievable by conventional water or predominantly water-based coolant and less than the temperature of the molten material in the tundish.

The higher temperature of the molten heat transfer medium (relative to conventional coolant) can facilitate heating of the nozzle. For example, the nozzle can be heated by the molten heat transfer medium, circulating as coolant, to a temperature higher than that could be achieved with conventional water or a predominantly water-based coolant. Hecting the nozzle to higher temperatures can prevent or inhibit undesirable cooling and freezing of the molten material within the nozzle. For example, certain molten alloys atomized to powder can have solidus temperatures up to 3000°F (1649°C), and the molten heat transfer medium according to the present disclosure can heat the nozzle to temperatures closer to 3000°F (1649°C) than can be achieved using conventional water or predominantly water-based nozzle coolants. Because the molten heat transfer medium according to the present disclosure facilitates heating the nozzle to higher temperatures than can be achieved using conventional coolant, unintentional obstruction of the atomizing nozzle can be prevented or inhibited.

Additionally, because the molten heat transfer medium can achieve a higher temperature than water, the temperature difference between the molten heat transfer medium and the molten material processed in the atomizing system is reduced. Consequently, the temperature difference between the tundish and/or the nozzle in an atomizing system according to the present disclosure may be reduced relative to certain conventional atomizing systems. This reduced temperature differential can reduce thermal shock effects to and the incidence of cracking of the nozzle and/or the tundish. Moreover, because the molten heat transfer medium according to the present disclosure can be maintained at a temperature closer to the temperature of the molten material than can be achieved with water, the incidence of overcooling of the tundish and/or the nozzle by contact with the molten heat transfer medium can be avoided or reduced.

FIG. 1 schematically illustrates certain elements of an atomizing system 100 according to one non-limiting embodiment of the present invention configured to produce powders of metals and metal alloys. The atomizing system 100 includes a melting hearth 110 and a refining hearth 120.
In various non-limiting embodiments, feed materials 102 can enter the atomizing system 100 at an inlet or material feed 104. For example, solid material 102, which may include, for example, sponge, revert, master alloys, and other alloying input materials can enter the melting hearth 110 at the inlet 104. An energy source 116 can energize the solid material 102 to generate molten material 112. In various non-limiting embodiments, the energy source 116 may be, for example, an electron beam gun or other electron generating device or a plasma torch. In other non-limiting embodiments, the energy source 116 can include an electron beam gun, for example. The melting hearth 110 and the refining hearth 120 may be configured so that the molten material 112 flows along the melting hearth 110 and to the refining hearth 120 along a path 118. In various non-limiting embodiments, an energy source 126, such as, for example, a plasma torch, an electron beam gun, or another electron generating device can energize the molten material 112 in the refining hearth 120 to heat and refine the molten material 112.

[0041] In various non-limiting embodiments, the melting hearth 110 and/or the refining hearth 120 can be comprised of copper. For example, the melting hearth 110 and the refining hearth 120 can comprise copper hearths. Additionally, in certain non-limiting embodiments, the melting hearth 110 and/or the refining hearth 120 can include internal channels through which a coolant such as, for example, water or a predominantly water-based fluid can circulate to cool the hearths 110, 120. Accordingly, in certain non-limiting embodiments the hearths 110, 120 can comprise water-cooled copper hearths. In the depicted non-limiting embodiment shown in FIG. 1, a skull 114 of the molten material that has solidified (frozen) on the melting hearth 110 separates the molten material 112 from the melting hearth 110. Additionally, in the depicted, non-limiting embodiment, a skull 124 of material on the refining hearth 120 separates the molten material 112 from the refining hearth 120. In such non-limiting embodiments, the skulls 114, 124 of solid material can prevent erosion and/or contamination of the molten material 112 by the copper hearths 110, 120.

[0042] Referring still to FIG. 1, the atomizing system 100 can further include a tundish 140. The tundish 140 can receive the molten material 112 from the refining hearth 120. For example, the molten material 112 can flow along a path 128 and/or through a pool 130 between the refining hearth 120 and the tundish 140. As described in greater detail herein, the tundish 140 can include one or a plurality of internal channels through which the molten heat transfer medium circulates.

[0043] In various non-limiting embodiments of an atomizing system according to the present disclosure, the melting hearth 110, the refining hearth 120, and the tundish 140 can be disposed within a sealed melt chamber 150. In various embodiments, the melt chamber 150 can contain an environment that does not react with the molten material. For example, a vacuum or substantial vacuum can be maintained within the melt chamber 150 if electron beam devices or other electron generating devices are used to melt, heat, and/or refine material within the melt chamber 150. In embodiments in which a plasma torch device is used to melt, heat, and/or refine material within the melt chamber 150, the environment within the melt chamber may include an inert gas, such as helium or argon, for example.

[0044] Referring now to FIGS. 1 and 2, in the schematically illustrated non-limiting embodiment of system 100, the tundish 140 is in fluid communication with an atomizing nozzle 160. The depicted nozzle 160 extends between the tundish 140 positioned in the melt chamber 150 and an atomization chamber 152 in which atomized powder is formed. For example, in the system 100, the nozzle 160 depicted in FIGS. 1 and 2 provide the only connection between the melt chamber 150 and the atomization chamber 152. The nozzle 160 can direct and control the molten material 112 in the tundish 140 to enter the atomization chamber 152. For example, the nozzle 160 can act as a throttling mechanism to stabilize the stream 162 of molten metal 112 entering the atomization chamber 152. Additionally, the molten material 112 in the nozzle 160 can act as a seal between the environment in the atomization chamber 152 and the environment in the melting chamber 150. In certain non-limiting embodiments, the nozzle 160 can be separate and distinct from the tundish 140 and in other non-limiting embodiments; the nozzle 160 can be integrally formed with the tundish 140, for example.

[0045] In various non-limiting embodiments, the material composition of the molten material 112 can be identical or substantially identical to the material composition of material comprising the tundish 140 and/or the atomization nozzle 160. For example, the tundish 140 and/or the atomization nozzle 160 can be ceramic-free, as well as free of other potential harmful contaminants. In certain non-limiting embodiments, for example, the molten material 112, the tundish 140, and the atomization nozzle 160 can be comprised of a particular alloy, such as Ti-6Al-4V alloy, for example. However, the Ti-6Al-4V alloy of the molten material 112, the tundish 140 and/or the nozzle 160 may have been produced at different locations and/or different times and, therefore, may vary in composition to some degree, although remaining within the required compositional specification for Ti-6Al-4V alloy. Because the molten material 112, the tundish 140, and the atomization nozzle 160 are comprised of substantially identical materials, erosion and/or problematic contamination of the molten material 112 by contact with the tundish 140 and/or the nozzle 160 is avoided. For example, if material from the tundish 140 and/or the nozzle 160 contaminates the molten material 112, but the materials are substantially identical in composition, the contaminants do not significantly affect properties of the molten material 112 or the powder formed from the molten material 112.

[0046] In various non-limiting embodiments, one or a plurality of internal channels 142 can be defined within the tundish 140 and/or the nozzle 160. For example, referring primarily to FIG. 2, a channel 142 is defined within the tundish 140. The channel 142 can extend from an inlet 144 in the tundish 140 to an outlet 146 in the tundish 140. In certain instances, a plurality of channels 142 can be defined within the tundish 140. The plurality of channels 142 can be fluidly connected, for example, or can define multiple discrete fluid paths, for example. In various non-limiting embodiments, a channel 142 or a plurality of channels 142 can be defined in the nozzle 160. In certain non-limiting embodiments, at least one channel in the nozzle 160 can be fluidly connected to at least one channel in the tundish 140.

[0047] In various non-limiting embodiments, the internal channels 142 can be formed in the tundish 140 and/or the nozzle 160 by casting or by other conventional techniques. For example, the channels 142 can be produced using additive manufacturing techniques. In various non-limiting embodiments, the channels 142 are formed relatively close to surfaces of the tundish 140 and the nozzle 160 that are contacted by the molten material 112 positioned in the tundish
140 and passing through the nozzle 160. For example, in certain non-limiting embodiments the channels 142 can be positioned less than 0.12 inch (3 mm) from the surfaces of the tundish 140 and/or the nozzle 160 contacted by the molten material during the atomization process, e.g., the outer surfaces of the tundish 140. In certain non-limiting embodiments, the channels 142 can be positioned less than 0.5 inches (13 mm) from the outer surfaces of the tundish 140. In still other non-limiting embodiments, the channels 142 can be positioned between 0.12 inch (3 mm) and 1.0 inch (25 mm) from the outer surfaces of the tundish.

In certain conventional tundishes, the channels are positioned farther from the outer surface of the tundish. For example, in a conventional tundish of that type, the channels may be positioned between 0.5 inches (13 mm) and 1.0 inches (25 mm) from the outer surface of the tundish.

The channels 142 can be configured to allow a heat transfer material to flow through the tundish 140 and/or the nozzle 160. In certain non-limiting embodiments, the heat transfer material can comprise a molten heat transfer medium, such as a molten mineral substance, for example. In various non-limiting embodiments, the molten heat transfer medium can include at least one of a molten metal, a molten alloy, and a molten salt. For example, the molten heat transfer medium can be comprised of molten sodium. The boiling point of the molten heat transfer medium can exceed the boiling point of water. For example, the boiling point of molten sodium is 1659°F (899°C).

Referring primarily to FIG. 2, in certain non-limiting embodiments, a preheating device, such as, for example, a radiant preheating element 148, can be positioned adjacent or around the tundish 140. The preheating element 148 can comprise a plurality of coils 149 configured to heat the tundish 140 before the molten heat transfer medium is introduced through the channels 142. In such instances, preheating of the tundish 140 can prevent or inhibit the molten heat transfer medium from freezing within the channels 142 when the molten heat transfer medium is introduced into the channels 142.

In various non-limiting embodiments, the atomizing system 100 can include a pump 170, which can be configured to pump the molten heat transfer medium from a source 180 into and through the channels 142. The pump 170 can comprise an electromagnetic pump, for example, that can pump high-temperature molten material through the channels 142. For example, commercially available electromagnetic pumps having suitable performance characteristics are available from CMI Novacast, Inc., Des Plaines, Ill. Such pumps can pump molten aluminum, zinc, sodium, mercury, potassium, NaK, and magnesium, for example, and can pump these materials at high temperatures, such as temperatures up to 1472°C (800°C), for example.

Referring to FIGS. 1 and 2, at least one atomization jet 164 can be positioned within the atomization chamber 152, for example. The atomization jet(s) 164 emit a high-pressure stream of gas or another fluid. The atomization jet(s) 164 can be directed toward the stream 162 of the molten material 112 exiting the nozzle 160. For example, in certain instances, the atomization jet(s) 164 can form a gas ring. In other instances, the jet(s) 164 can be arranged in alternative configurations. In various non-limiting embodiments, the atomization jet(s) 164 can force an inert gas, such as helium or argon, for example, into the stream 162 of the molten material 112. In such instances, the pressure exerted by the atomization jet(s) 164 can freeze the molten material into a particulate form and produce a flume 166 of powered material within the atomization chamber 160.

In various non-limiting embodiments, the atomization chamber 152 can comprise a chamber that is sealed from the outside environment. Moreover, in certain instances, the atomization chamber 152 can comprise an environment that does not react with the molten material or the powder formed from the molten material. For example, the atomization chamber 152 can comprise an inert gas, such as helium or argon, for example. In various non-limiting embodiments, the atomization chamber 152 can comprise a first inert gas and the melt chamber 150 can comprise a second, different inert gas. For example, the atomization jet(s) 164 can expel argon into the atomization chamber 152 such that the atomization chamber 152 comprises argon, and the melt chamber 150 can comprise a different inert gas, such as, for example, helium.

In certain non-limiting embodiments of system 100, the atomization chamber 152 can be isolated from the melt chamber 150. For example, the molten material 112 flowing through the nozzle 160 can form a seal or barrier between the melt chamber 150 and the atomization chamber 152. In such instances, gases and/or contaminants from the melt chamber 150 can be prevented from entering the atomization chamber 152.

Referring now to FIG. 3, a process for using the atomizing system 100 illustrated schematically in FIGS. 1 and 2 is depicted. At step 190, a preheating device, such as the radiant preheating element 148 (see FIG. 2) can be activated. Activation of the preheating element 148 can heat a tundish, such as the tundish 140 (see FIGS. 1 and 2), for example. Referring still to FIG. 3, the preheating element 148 can be activated before the molten heat transfer medium is introduced into the channels 142 (FIG. 2) in the tundish 140 and/or the nozzle 160 (FIGS. 1 and 2). In such instances, preheating of the tundish 140 can prevent the molten heat transfer medium from freezing within the channels 142 when it is introduced into the channels (at step 192, for example).

Referring still to FIG. 3, at step 192, a pump, such as the pump 170 (FIGS. 1 and 2), for example, can be activated. Activation of the pump 170 can initiate pumping of the molten heat transfer medium into and through the internal channels 142 (FIG. 2) in the tundish 140 and/or the nozzle 160 (FIGS. 1 and 2). The molten heat transfer medium can flow through the internal channels 142 to heat the tundish 140 and/or the nozzle 160 at step 194. In such non-limiting embodiments of the system 100, the molten heat transfer medium can be at a temperature greater than the temperature achievable using water or a predominantly water-based heat transfer medium as a coolant, for example, but also can be at a temperature that is less than the temperature of the molten material 112 (FIGS. 1 and 2) in the system 100 (FIGS. 1 and 2), for example. The molten heat transfer medium can heat the tundish 140 to a suitable temperature to facilitate the flow of the molten material 112 through the tundish 140 and the nozzle 160, and into the atomization chamber 152 (FIGS. 1 and 2), where it is atomized to a powder.

At step 196 of the process shown in FIG. 3, the molten material 112 can be atomized. For example, the atomization jets 164 (FIGS. 1 and 2) can force a gas into the stream 162 (FIGS. 1 and 2) of the molten material 112 exiting the nozzle 160. The atomization jets 164 can create a powder flume 166 (FIGS. 1 and 2) from the molten material 112 in the stream 164. As the jets 164 atomize the molten material 112,
the molten heat transfer medium can flow through the internal channels 142 in the tundish 140 and/or the nozzle 160 at step 198. In such instances, the molten heat transfer medium can cool the tundish 140 and/or the nozzle 160 during continuous operation of the atomizing system 100. Although the present system and method is advantageously applied to processing very reactive metals and metal alloys, it may also be applied to other alloys. For example, the present system and method may be applied to nickel based alloys, cobalt based alloys, and iron based alloys, and especially where extremely clean alloy material is required.

[0058] It is to be understood that various descriptions of the disclosed non-limiting system and method embodiments have been simplified to illustrate only those features, aspects, characteristics, and the like that are relevant to a clear understanding of the disclosed embodiments, while eliminating, for purposes of clarity, other features, aspects, characteristics, and the like. Persons having ordinary skill in the art, upon considering the present description of the disclosed non-limiting embodiments, will recognize that other features, aspects, characteristics, and the like may be desirable in a particular implementation or application of the disclosed embodiments. However, because such other features, aspects, characteristics, and the like may be readily ascertainable and implemented by persons having ordinary skill in the art upon considering the present description of the disclosed embodiments, and are, therefore, not necessary for a complete understanding of the disclosed embodiments, a description of such features, aspects, characteristics, and the like is not provided herein. As such, it is to be understood that the description set forth herein is merely exemplary and illustrative of the disclosed non-limiting embodiments and is not intended to limit the scope of the invention as defined solely by the claims.

[0059] In the present disclosure, other than where otherwise indicated, all numbers expressing quantities or characteristics are to be understood as being prefaced and modified in all instances by the term “about.” Accordingly, unless indicated to the contrary, any numerical parameters set forth in the following description may vary depending on the desired performance and other properties one seeks to obtain in the embodiments according to the present disclosure. For example, the term “about” can refer to an acceptable degree of error for the quantity measured, given the nature or precision of the measurement. Typical exemplary degrees of error may be within 20%, within 10%, or within 5% of a given value or range of values. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter described in the present description should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques.

[0060] Also, any numerical range recited herein is intended to include all sub-ranges subsumed therein. For example, a range of “1 to 10” is intended to include all sub-ranges between (and including) the recited minimum value of 1 and the recited maximum value of 10, that is, having a minimum value equal to or greater than 1 and a maximum value equal to or less than 10. Any maximum numerical limitation recited herein is intended to include all lower numerical limitations subsumed therein, and any minimum numerical limitation recited herein is intended to include all higher numerical limitations subsumed therein. Accordingly, Applicants reserve the right to amend the present disclosure, including the claims, to expressly recite any sub-range subsumed within the ranges expressly recited herein. All such ranges are intended to be inherently disclosed herein such that amending to expressly recite any such sub-ranges would comply with the requirements of 35 U.S.C. §112, first paragraph, and 35 U.S.C. §132(a).

[0061] The grammatical articles “one”, “a”, “an”, and “the”, as used herein, are intended to include “at least one” or “one or more”, unless otherwise indicated. Thus, the articles are used herein to refer to one or more than one (i.e., to at least one) of the grammatical objects of the article. By way of example, “a component” means one or more components, and thus, possibly, more than one component is contemplated and may be employed or used in an implementation of the described embodiments.

[0062] Any patent, publication or, other disclosure material that is said to be incorporated by reference herein, is incorporated herein in its entirety unless otherwise indicated, but only to the extent that the incorporated material does not conflict with existing definitions, statements, or other disclosure material expressly set forth in this disclosure. As such, and to the extent necessary, the express disclosure as set forth herein supersedes any conflicting material incorporated by reference herein. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material set forth herein is only incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material. Applicant reserves the right to amend the present disclosure to expressly recite any subject matter, or portion thereof, incorporated by reference herein.

[0063] The present disclosure includes descriptions of various non-limiting embodiments. It is to be understood that all embodiments described herein are exemplary, illustrative, and non-limiting. Thus, the invention is not limited by the description of the various exemplary, illustrative, and non-limiting embodiments. Rather, the invention is defined solely by the claims, which may be amended to recite any features expressly or inherently described in or otherwise expressly or inherently supported by the present disclosure. Therefore, any such amendments would comply with the requirements of 35 U.S.C. §112, first paragraph, and 35 U.S.C. §132(a).

[0064] The various non-limiting embodiments disclosed and described herein can comprise, consist of, or consist essentially of, the features, aspects, characteristics, limitations, and the like, as variously described herein. The various non-limiting embodiments disclosed and described herein can also comprise additional or optional features, aspects, characteristics, limitations, and the like, that are known in the art or that may otherwise be included in various non-limiting embodiments as implemented in practice.

[0065] The present disclosure has been written with reference to various exemplary, illustrative, and non-limiting embodiments. However, it will be recognized by persons having ordinary skill in the art that various substitutions, modifications, or combinations of any of the disclosed embodiments (or portions thereof) may be made without departing from the scope of the invention as defined solely by the claims. Thus, it is contemplated and understood that the present disclosure embraces additional embodiments not expressly set forth herein. Such embodiments may be obtained, for example, by combining, modifying, or reorganizing any of the disclosed steps, ingredients, constituents, components, elements, features, aspects, characteristics, limitations, and the like, of the embodiments described.
herein. Thus, this disclosure is not limited by the description of the various exemplary, illustrative, and non-limiting embodiments, but rather solely by the claims. In this manner, Applicants reserve the right to amend the claims during prosecution to add features as variously described herein.

We claim:

1. A system for atomizing a molten material having a first material composition, wherein the system comprises:
   a) a tundish configured to hold the molten material;
   b) a nozzle in fluid communication with the tundish, wherein the nozzle is comprised of a second material having a second material composition, and wherein the second material composition is substantially similar to the first material composition;
   c) an internal channel defined in at least one of the tundish or the nozzle; and
   d) a pump configured to pump a molten heat transfer medium through the internal channel.

2. The system of claim 1, wherein the tundish is comprised of a third material having a third material composition, and wherein the third material composition is substantially similar to the first material composition.

3. The system of claim 1, wherein the internal channel is defined in the tundish, and wherein a second internal channel is defined in the nozzle.

4. The system of claim 1, wherein the molten heat transfer medium comprises a material selected from a group consisting of a salt, a metal, and an alloy.

5. The system of claim 1, wherein the boiling point of the molten heat transfer medium is greater than the boiling point of water at atmospheric pressure.

6. The system of claim 1, further comprising a melt chamber, wherein the tundish is positioned in the melt chamber.

7. The system of claim 6, further comprising a melting hearth and a refining hearth positioned in the melt chamber.

8. The system of claim 1, further comprising an atomization chamber, wherein the nozzle protrudes into the atomization chamber.

9. The system of claim 1, wherein the molten heat transfer medium comprises a molten salt.

10. A method for atomizing a molten material comprising a first material composition, wherein the method comprises:
   a) passing the molten material through an atomization nozzle comprised of a second material comprising a second material composition, wherein the second material composition is substantially similar to the first material composition, and wherein an internal channel is defined in the nozzle; and
   b) pumping a molten heat transfer medium through the internal channel, wherein the molten heat transfer medium is configured to affect heat transfer to and from the atomization nozzle.

11. The method of claim 10, further comprising providing the molten material to a tundish in fluid communication with the atomization nozzle, wherein the tundish is comprised of a third material comprising a third material composition, and wherein the third material composition is substantially similar to the first material composition.

12. The method of claim 11, wherein a second internal channel is defined in the tundish, and wherein the method further comprises pumping the molten heat transfer medium through the second internal channel.

13. The method of claim 10, wherein the molten heat transfer medium comprises a material selected from a group consisting of a salt, a metal, and an alloy.

14. The method of claim 10, further comprising melting the molten material.

15. The method of claim 14, further comprising refining the molten material.

16. A method for regulating temperature in an atomizing system, wherein the atomizing system comprises a nozzle, and wherein the method comprises:
   a) pumping a molten heat transfer medium through an internal channel in the nozzle to heat the nozzle; and
   b) pumping the molten heat transfer medium through the internal channel in the nozzle to cool the nozzle.

17. The method of claim 16, further comprising obtaining a nozzle comprised of a first material having a first material composition, and wherein the first material composition is substantially similar to the material composition of the atomized powder exiting the atomizing system.

18. The method of claim 16, wherein the atomizing system further comprises a tundish, and wherein the method further comprises pumping the molten heat transfer medium through a second internal channel in the tundish to cool the tundish.

19. The method of claim 18, wherein the tundish is comprised of a second material having a second material composition, wherein the second material composition is substantially similar to the material composition of the atomized powder exiting the atomizing system.

20. The method of claim 16, wherein heating of the nozzle occurs during a pre-atomizing stage, and wherein cooling of the nozzle occurs during an atomizing operation.