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Bellows pump for liquid metals

Abstract

According to various aspects, the present disclosure provides pumps for pumping a liquid metal, systems for filling a container with a liquid metal, and methods for filling a container with a liquid metal. According to at least one aspect, a pump can include an actuator including a drive rod, a first plate, a second plate, guide rods extending between the first plate and the second plate, a traveling stage, and a bellows. The traveling stage can be operatively coupled to the drive rod and can be slidable along the guide rods intermediate the first plate and the second plate. The bellows can extend between the second plate and the traveling stage to define a bellows chamber. The actuator can be configured to slide the traveling stage to expand and contract the bellows to pump the liquid.

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Background/Summary

FIELD
(1) The present disclosure is generally related to pumps for pumping a liquid metal, systems for filling a container with a liquid metal, and methods for filling a container with a liquid metal. More particularly, in some aspects, present disclosure is related to pumps for pumping liquid alkali metals, systems for filling a heat pipe (e.g., a heat pipe used for heat transfer in a nuclear micro reactor) with a liquid alkali metal, and methods for filling a heat pipe with a liquid alkali metal.
SUMMARY
(2) According to various aspects, the present disclosure provides a pump for pumping liquid metal. The pump can include an actuator, a first plate, a second plate, guide rods, a traveling stage, and a bellows. The actuator can include a drive rod. The first plate can support the actuator. The second plate can define an intake port and a discharge port. The guide rods can extend between and be coupled to the first plate and the second plate. The traveling stage can be slidable along the guide rods intermediate the first plate and the second plate. The traveling stage can be operatively coupled to the drive rod. The bellows can extend between and be hermetically sealed to the second plate and the traveling stage to define a bellows chamber. The actuator can be configured to slide the traveling stage toward the first plate to a first position to expand the bellows chamber and cause the liquid metal to flow through the intake port and into the bellows chamber. The actuator can be further configured to slide the traveling stage toward the second plate to a second position to contract the bellows chamber and cause the liquid metal to flow out of the bellows chamber and through the discharge port.
(3) According to various aspects, the present disclosure provides a method for filling a container with a metal using a filling system. The filling system can include a supply tank at least partially filled with the metal, a pump, a filling chamber, a first line for fluid communication between the supply tank and the pump, and a second line for fluid communication between the pump and the filling chamber. The method can include loading the container into the filling chamber, applying a vacuum to the filling chamber, and heating the filling chamber to a liquid-phase temperature of the metal. The method can further include heating the supply tank to the liquid-phase temperature of the metal to liquefy the metal and heating the pump, the first line, and the second line to the liquid-phase temperature of the metal. The method can further include pressurizing the supply tank to cause the metal to flow from the supply tank and fill the pump, the first line, and the second line. The method can further include cycling the pump for a predetermined number of cycles to fill the container with the metal.
(4) According to various aspects, the present disclosure provides a system for filling a container

with a metal. The system can include a supply tank, a bellows pump, a filling chamber, a first line, a second line, and an oven. The supply tank can be at least partially fillable with the metal. The bellows pump can be configured to pump a predetermined volume of the metal from the supply tank to the container. The filling chamber can be configured to least partially enclose the container. The first line can be configured for fluid communication between the supply tank and the bellows pump. The second line can be configured for fluid communication between the bellows pump and the filling chamber. The oven can be configured to heat at least one of the supply tank, the bellows pump, the first line, the second line, or a combination thereof to a liquid-phase temperature of the metal.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The various aspects described herein, together with objects and advantages thereof, may best be understood by reference to the following description, taken in conjunction with the accompanying drawings as follows.

(2) FIG. **1** is a perspective view of bellows pump, according to at least one non-limiting aspect of this disclosure.

(3) FIG. **2** is a side view of the bellows pump of FIG. **1**, according to at least one non-limiting aspect of this disclosure.

(4) FIG. **3** is a cross sectional view of the bellows pump of FIG. **1**, taken along section **3-3** of FIG. **2**, with the bellows in an expanded configuration, according to at least one non-limiting aspect of this disclosure.

(5) FIG. **4** is another a cross sectional view of the bellows pump of FIG. **1** taken along section **3-3** of FIG. **2**, with the bellows in a compressed configuration, according to at least one non-limiting aspect of this disclosure.

(6) FIG. **5** is a schematic diagram of a system for filling a container with a metal, according to at least one non-limiting aspect of this disclosure.

(7) FIG. **6** illustrates a flow chart of a method for filling a container with a metal, according to at least one non-limiting aspect of this disclosure.

(8) Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate various aspects of the present disclosure, in one form, and such exemplifications are not to be construed as limiting the scope of any of the aspects disclosed herein.

DETAILED DESCRIPTION

(9) Numerous specific details are set forth to provide a thorough understanding of the overall structure, function, manufacture, and use of the aspects as described in the disclosure and illustrated in the accompanying drawings. Well-known operations, components, and elements have not been described in detail so as not to obscure the aspects described in the specification. The reader will understand that the aspects described and illustrated herein are non-limiting examples, and thus it can be appreciated that the specific structural and functional details disclosed herein may be representative and illustrative. Variations and changes thereto may be made without departing from the scope of the claims.

(10) In the following description, like reference characters designate like or corresponding parts throughout the several views of the drawings. Also in the following description, it is to be understood that such terms as “forward,” “rearward,” “left,” “right,” “above,” “below,” “upwardly,” “downwardly,” and the like are words of convenience and are not to be construed as limiting terms.

(11) Generally, heat pipes are devices that rely on latent heat transfer associated with liquid-to-gas

and gas-to-liquid phase transition to absorb heat from a first location and release heat at a second location. Heat pipes can be used to facilitate heat transfer in a wide variety of applications. For example, electronic devices and systems such as laptops, phones, satellites, enclosure cooling systems, and avionics systems may employ heat pipes to facilitate heat removal.

(12) Heat pipes may also be employed in nuclear reactors to facilitate heat transfer. For example, a nuclear micro reactor may include multiple high-temperature, high-performance alkali metal heat pipes to transfer heat from the reactor core to heat exchangers external to the core. In this context, each of the reactor heat pipes is filled with an alkali metal, such as sodium. Heat from the reactor is transferred to a first end of the heat pipe, causing the alkali metal to transition from a liquid to a vapor phase. The vapor-phase alkali metal travels to a second end of the heat pipe where it condenses back to a liquid phase, thereby releasing heat. The liquid-phase alkali metal then travels back to the first end of the heat pipe through capillary action where it can again be evaporated to remove heat from the reactor core. Examples of heat pipes can be found in U.S. Patent Application Publication No. 2021/0325122, title METHOD OF INSTALLING A HEAT PIPE WICK INTO A CONTAINER OF DIFFERING THERMAL EXPANSION COEFFICIENT, published Oct. 21, 2021, which is incorporated by reference herein in its entirety.

(13) It can be difficult to manufacture alkali metal heat pipes, for example, because it can be difficult to fill a heat pipe with the alkali metal. Alkali metals generally exist as solids under standard conditions. Accordingly, existing methods of filling heat pipes with alkali metal typically employ an oven or furnace to heat a filling system that includes a reservoir of solid alkali metal. Heating the filling system liquefies the alkali metal. Further, because conventional pumps are not suitable for pumping liquid alkali metal, inert gas is injected into the reservoir in an attempt to force a desired volume of the liquid alkali metal from the reservoir, through the filling system, to the heat pipe.

(14) There can be numerous challenges associated with existing methods of filling heat pipes with alkali metal. For example, extensive manipulation of manual valves inside the heated oven or furnace is typically required to transport the alkali metal from the reservoir to the heat pipe. Further, the inert gas used to force the alkali metal into the heat pipe may inadvertently enter the heat pipe along with the alkali metal and need to be removed. As another example, the volume of alkali metal injected into the heat pipe can be inaccurate. As yet another example, the filling system is typically constructed to inject a specific volume of alkali metal that cannot be adjusted. Thus, a new filling system typically needs to be constructed if a different sized heat pipe needs to be filled. Moreover, each filling system may not be reusable.

(15) Given these challenges, filling heat pipes with alkali metal using existing methods can be costly and time consuming. For example, because achieving a minimum volume of alkali metal inside the heat pipe can be critical for performance, a larger-than-required injection volume is typically applied to the heat pipe to account for the above-mentioned volume inaccuracies, which can increase material costs. Further, extensive labor and time can be required to construct each new filling system (e.g., 1-2 engineers and 1 laboratory technician working 2-4 hours to setup the filling system and fill 1 heat pipe). Accordingly, there exists an unsolved need for devices capable of pumping liquid alkali metals, systems for filling heat pipes with alkali metals, and methods for filling heat pipes with liquid alkali metals.

(16) The present disclosure provides bellows pumps for pumping liquid metals (e.g., liquid alkali metals), systems for filling containers (e.g., heat pipes) with liquid metals, and methods for filling containers with liquid metals. The bellows pumps, systems, and methods disclosed herein can provide numerous benefits, as explained further throughout the present disclosure. For example, the pumps, systems, and methods disclosed herein can enable the heat pipe filling process to be automated through the use of an actuated pump. Moreover, as a result of the automation, a furnace and/or oven used to heat the system may not need to be entered by operators for manual manipulation of valves, thereby enhancing safety, reducing the potential for human error, reducing

downtime, and saving costs. As yet another example, the pumps, systems, and methods can enable a more precise and accurate volume of alkali metal to be applied to the heat pipe compared to existing methods. As yet another example, the pumps and systems can be reused to fill multiple heat pipes and can be adjusted to supply different predetermined volumes of the alkali metal to accommodate heat pipes of different sizes. As yet another example, the pumps described herein can be constructed with removable and adjustable parts, allowing for easy maintenance, repair, and/or calibration.

(17) FIGS. **1-3** illustrate a bellows pump **100**, according to at least one non-limiting aspect of this disclosure. FIG. **1** is a perspective view of the bellows pump **100**, FIG. **2** is a side view of the bellows pump **100**, and FIG. **3** is a cross sectional view of the bellows taken along section **3-3** of FIG. **2**.

(18) Referring to FIGS. **1-3**, the bellows pump **100** can include a first plate **106**, a second plate **108**, and one or more guide rods **114** extending between the first plate **106** and the second plate **108**. In the non-limiting aspect of FIGS. **1-3**, the bellows pump **100** includes four guide rods **114**. In other aspects, the bellows pump **100** can include less than four guide rods **114** (e.g., 1, 2, or 3 guide rods) or more than four guide rods **114** (e.g., 5, 6, 7 or 8 guide rods).

(19) Each of the guide rods **114** can be coupled to the first plate **106** and the second plate **108**. In one aspect, each of the guide rods **114** is removably coupled to at least one of the first plate **106** or the second plate **108**. For example, as best shown in FIG. **1**, the ends of each of the guide rods **114** may include a threaded rod that is insertable through a corresponding hole in the first plate **106** or the second plate **108**. The threaded rod can be fastened to a corresponding threaded nut, thereby removably coupling the corresponding one of the guide rods **114** to the first plate **106** and/or the second plate **108**. Removably coupling each of the guide rods **114** to at least one of the first plate **106** or the second plate **108** can enable the bellows pump **100** to be easily assembled and disassembled for purposes such as maintenance, repair, and/or adjustment of the stops **128**, which are described further herein. In another aspect, one or both of the ends of each guide rod **114** can be welded to the first plate **106** and/or the second plate **108**. The first plate **106**, the second plate **108**, and the guide rods **114** can generally define a support structure of the bellows pump **100**.

(20) In some aspects, passages (e.g., holes) formed in the second plate **108** can define an intake port **110** (FIG. **1**) and a discharge port **112** (FIG. **2**) of the bellows pump **100**. The discharge port **112** can be disposed in the second plate **108** opposite the intake port **110**.

(21) Referring still to FIGS. **1-3**, the bellows pump **100** can include a traveling stage **116**. The traveling stage **116** is slidable along the guide rods **114** intermediate the first plate **106** and the second plate **108**. For example, the traveling stage **116** can include holes corresponding to each of the guide rods **114**, and through which the guide rods **114** are insertable, thereby enabling the traveling stage **116** to slide along the guide rods **114**. In some aspects, as best shown in FIG. **3**, the traveling stage **116** can include bushings **134** to enable the traveling stage **116** to slide smoothly along the guide rods **114**.

(22) The bellows pump can include an actuator **102**. The actuator **102** can be supported by or otherwise coupled to the first plate **106**. The actuator **102** can be configured to cause the traveling stage **116** to slide along the guide rods **114**. For example, as best shown in FIG. **3**, the actuator **102** can include a drive rod **104** that is coupled to the traveling stage **116**. Actuating the actuator **102** can translate the drive rod **104**, thereby causing the traveling stage **116** to slide along the guide rods **114**.

(23) The actuator **102** may be actuated in a first manner and a second manner. Actuating the actuator in the first manner can cause the traveling stage **116** to slide in a first direction toward the first plate **106**. Actuating the actuator in the second manner can cause the traveling stage **116** to slide in a second direction toward the second plate **108**. In some aspects, the actuator **102** can be a pneumatically actuated actuator, such as a tie rod air cylinder, as shown in FIG. **3**. In other aspects, the actuator **102** can be another type of actuator, such as a hydraulic actuator or an electric actuator.

In some aspects, the actuator **102** can be dual acting. In other aspects, the actuator **102** can be single acting with a spring return.

(24) The bellows pump **100** and the actuator **102** can be configured such that the traveling stage **116** is normally in (e.g., biased to, fails to) a first position proximate the first plate **106** (e.g., the configuration shown in FIG. **3**) and is slidable to a second position proximate the second plate **108** (e.g., the configuration shown in FIG. **4**) by actuating the actuator **102**. For example, as explained further herein, the bellows pump **100** can include a bellows **118**. The bellows **118** may exert a spring force on the traveling stage **116** that biases the traveling stage to the first position (FIG. **3**). As another example, as explained further herein, the pump can include a spring **130**. The spring **130** and/or the bellows **118** may exert a spring force on the traveling stage **116** that biases the traveling stage **116** to the first position (FIG. **3**). As yet another example, the actuator **102** can include a spring that biases the traveling stage **116** to the first position (FIG. **3**). In other aspects, the bellows pump **100** and the actuator **102** can be configured such that the traveling stage **116** is normally in the second position proximate the second plate **108**.

(25) Referring again to FIGS. **1-3**, the bellows pump **100** can include a bellows **118**. The bellows **118** extends between and is coupled to the second plate **108** and the traveling stage **116**. As best shown by FIG. **3**, the bellows **118** (e.g., the bellows **118**, the traveling stage **116**, and the second plate **108**) can define a bellows chamber **120**. In some aspects, the bellows **118** is hermetically sealed to the second plate **108** and the traveling stage **116**, for example, by welding the bellows **118** to the second plate **108** and the traveling stage **116**. In some aspects, a first flange **122** of the bellows **118** is welded to the traveling stage **116** to hermetically seal the bellows **118** to the traveling stage **116**. In some aspects, a second flange **124** of the bellows is welded to the second plate **108** to hermetically seal the bellows **118** to the second plate **108**. Welding the bellows **118** to the second plate **108** and the traveling stage **116** can create a hermetically sealed bellows chamber **120** without the use of o-rings, bushing, gaskets, and/or the like. Welding the bellows **118** to the second plate **108** and the traveling stage **116** to create a hermetically sealed bellows chamber **120** without the use of o-rings, bushing, gaskets, and/or the like can enable the bellows pump **100** to be suitable for pumping liquid metals, such as liquid alkali metals (e.g., liquid sodium).

(26) As noted above, FIG. **3** is a cross sectional view of the bellows pump **100** taken along section **3-3** of FIG. **2**. FIG. **3** shows the traveling stage **116** in a first position proximate the first plate **106**. FIG. **4** is another a cross sectional view of the bellows pump **100** showing the traveling stage **116** in a second position proximate the second plate **108**, according to at least one non-limiting aspect of the present disclosure. As also noted above, the actuator **102** can cause the traveling stage **116** to slide between the first position and the second position. Sliding the traveling stage **116** to the first position can cause the bellows chamber **120** to be in an expanded configuration (FIG. **3**) and sliding the traveling stage to the second position can cause the bellows chamber **120** to be in a contracted configuration (FIG. **4**).

(27) During an intake stroke of the bellows pump **100**, the bellows chamber **120** is expanded, thereby causing liquid to flow through the intake port **110** and into the bellows chamber **120**. During a discharge stroke of the bellows pump **100**, the bellows chamber is contracted, thereby causing liquid to flow out of the bellows chamber **120** and through the discharge port **112**. Each intake stroke and corresponding discharge stroke can define a single cycle of the bellows pump **100**.

(28) Referring primarily to FIGS. **3** and **4**, the bellows **118** can include convolutions **126**. Each of the convolutions **126** has a first inner diameter ID.sub.1 and a second inner diameter ID.sub.2. Further, the bellows **118** has a length L. The first inner diameter ID.sub.1, the second inner diameter ID.sub.2, and the length L can define a volume of the bellows chamber **120**. The first inner diameter ID.sub.1, the second inner diameter ID.sub.2, and the length L can be configured to precisely control the volume of liquid displaced by a single cycle of the bellows pump **100** (e.g., the stroke volume V.sub.s of the bellows pump **100**).

(29) For example, expanding and contracting the bellows **118** can cause the length L, the first inner diameter ID.sub.1, and/or the second inner diameter ID.sub.2 to change, thereby changing the volume of the bellows chamber **120**. When in the expanded configuration shown in FIG. **3**, the bellows **118** can have an expanded length L.sub.e. When in the contracted configuration shown in FIG. **4**, the bellows **118** can have a contracted length L.sub.c that is less than the expanded length L.sub.e. In some aspects, the first inner diameter ID.sub.1 may transition between an expanded first inner diameter ID.sub.1,e and a contracted first inner diameter ID.sub.1,c. In some aspects, the second inner diameter ID.sub.2 may transition between an expanded second inner diameter ID.sub.2,e and a contracted second inner diameter ID.sub.2,c. The expanded length L.sub.e, the expanded first inner diameter ID.sub.1,e, and/or the expanded second inner diameter ID.sub.1,e can define an expanded volume V.sub.e of the bellows chamber **120**. The contracted length L.sub.c, the contracted first inner diameter ID.sub.1,c, and/or the contracted second inner diameter ID.sub.1,c can define a contracted volume V.sub.c of the bellows chamber **120**. The contracted volume V.sub.c is less than the expanded volume V.sub.e. Thus, the stroke volume can be calculated by subtracting the contracted volume V.sub.c from the expanded volume V.sub.e (e.g., V.sub.s=V.sub.e−V.sub.c).
(30) The lengths L.sub.e, L.sub.c, the first inner diameters ID.sub.1,e, ID.sub.1,c, and/or the second inner diameters ID.sub.2,e, ID.sub.2,c can be configured to achieve a desired expanded volume V.sub.e and a desired contracted volume V.sub.c of the bellows chamber **120**, thereby achieving a desired or predetermined stroke volume V.sub.s of the bellows pump **100**. Moreover, by operating the bellows pump **100** for a predetermined number of cycles N.sub.cycle, with each cycle supplying the predetermined stroke volume V.sub.s, the bellows pump **100** can be used to supply a precise total volume V.sub.T (e.g., V.sub.T=V.sub.s×N.sub.cycle) of liquid (e.g., to fill a container). Thus, in some aspects, the bellows pump **100** can be used to deliver a precise total volume V.sub.T of liquid alkali metal (e.g., liquid sodium) to fill a heat pipe.
(31) In some aspects, the bellows **118** can be a welded bellows, with each leaf of the convolutions **126** being edge welded to an adjacent leaf, or in the case of the leafs of the endmost convolutions **126**, edge welded to one of the first flange **122** or the second flange **124**. In other aspects, the bellows **118** can be a formed bellows, with the convolutions **126** being formed from a forming die. However, a welded bellows can allow more, smaller convolutions to be constructed over a given length compared to a formed bellows, which can enable more precise control of the stroke volume V.sub.s. In addition to or in lieu of the above, a welded bellows can enable improved cyclic capability (e.g., durability) and/or an improved pressure rating compared to a formed bellows. Furthermore, in some aspects, the bellows **118** can be double walled, which can enable improved cyclic capability and an improved pressure rating compared to a single-walled bellows. Thus, the welded construction of the bellows **118** can enable the bellows pump **100** to be suitable for pumping liquid metals, such as liquid alkali metals (e.g., liquid sodium).
(32) Referring to FIGS. **1-4**, the bellows pump can include stops **128**. Each of the stops **128** can be removably disposed about a corresponding one of the guide rods **114** intermediate the second plate **108** and the traveling stage **116**. In some aspects, the stops **128** can be used to control the stroke volume V.sub.s by preventing the traveling stage **116** from sliding beyond the second position (FIG. **4**) toward the second plate. For example, as the bellows pump **100** is cycled from the first position (FIG. **3**) to the second position (FIG. **4**), the stops **128** can contact the traveling stage **116**, thereby setting the contracted length L.sub.c of the of the bellows **118** and defining the contracted volume V.sub.c of the bellows chamber **120**. As described above, the bellows pump **100** can be disassembled by, for example, decoupling the second plate **108** and the guide rods **114**. Different size stops **128** can be interchangeably installed to achieve a different contracted length L.sub.c of the of the bellows **118** and a different contracted volume V.sub.c. Thus, the stops **128** can be interchanged to achieve a desired stroke volume V.sub.s.
(33) In some aspects, the stops **128** can be constructed of a material that has a thermal expansion coefficient that is substantially the same as or greater than that of the material(s) of the other

components of the bellows pump **100** (e.g., the material of the first plate **106**, the material of the second plate **108**, the material of the traveling stage **116**, the material of the guide rods **114**). When being used to pump a liquid alkali metal, the bellows pump **100** may be heated to a liquid-phase temperature of the alkali metal. Constructing the stops **128** of a material that has a thermal expansion coefficient that is substantially the same as or greater than that of the material(s) of the other components of the bellows pump **100** can enable the dimensions of the stops **128** to change in proportion to the dimensions of the other components of the bellows pump **100** as the bellows pump **100** is heated. Thus, constructing the stops **128** of a material that has a thermal expansion coefficient that is substantially the same as or greater than that of the material(s) of the other components of the bellows pump **100** can cause a predictable change in the contracted length L.sub.c as the bellows pump **100** is heated, thereby enabling precise control of the stroke volume V.sub.s.

(34) In some aspects, the stops **128** can be constructed of a non-metal material, such as a thermoplastic material. For example, the stops **128** can be constructed of polyetheretherketone (PEEK). Constructing the stops **128** of a non-metal material, such as a thermoplastic material, can enable a soft landing of the traveling stage **116** as it contacts the stops **128** during cycling of the bellows pump **100**.

(35) Referring still to FIGS. **1-4**, in some aspects, the bellows pump **100** can include a spring **130** positioned intermediate the second plate **108** and the traveling stage **116**. In some aspects, as shown in FIGS. **1-4**, the spring **130** can be disposed about the bellows **118**. The spring **130** can exert a spring force on the traveling stage **116** that, in concert with the actuator **102**, causes the traveling stage **116** to transition to the first position and causes the bellows **118** to transition to the expanded configuration (FIG. **3**). As explained further herein, the spring **130** can bias the traveling stage **116** to the first position.

(36) Referring still to FIGS. **1-4**, in some aspects, the bellows pump **100** can include one or more springs **132** positioned intermediate the first plate **106** and the traveling stage **116**. In some aspects, as shown in FIGS. **1-4**, each of the one or more springs **132** can be disposed about a corresponding one of the guide rods **114**. The one or more springs **132** can exert a spring force on the traveling stage **116** that counteracts and/or balances the spring force applied by the spring **130**, the bellows **118**, and/or a spring of the actuator **102**. In some aspects, the one or more springs **132** can provide resistance to enable the traveling stage **116** to smoothly transition for the first position (FIG. **3**) (e.g., without the drive rod **104** slamming against the internals of the actuator **102**).

(37) The bellows pump **100** can be suited for pumping liquid metals and liquid metal alloys, such as liquid alkali metals (e.g., liquid sodium). For example, some metals and metal alloys (e.g., sodium-potassium alloy, sometimes referred to as NaK; mercury) can exist in liquid phase a standard temperature and pressure conditions. Thus, in some aspects, the bellows pump **100** can be suited for pumping liquid metals at standard conditions. High temperatures (e.g., greater than 100° C., such as 100° C. to 200° C., greater than 120° C., or 120° C. to 200° C.) and vacuum conditions (e.g., pressures less than 102 kPa, such as, for example, high-vacuum condition which can include pressures less than 0.000133 kPa) can be required to maintain alkali metals and other metals or metal alloys in a liquid phase. Thus, in some aspects, the bellows pump **100** can be configured to withstand the high temperatures (e.g., greater than 100° C., such as 100° C. to 200° C., greater than 120° C., or 120° C. to 200° C.) and vacuum conditions (e.g., pressures less than 102 kPa, such as, for example, high-vacuum condition which can include pressures less than 0.000133 kPa) that can be required to maintain alkali metals and other liquid metals or metal alloys in a liquid phase. Furthermore, in some aspects, the bellows pump **100** can be configured to be chemically compatible with (e.g., corrosion resistant to) liquid alkali metals.

(38) Accordingly, any of the components of the bellows pump **100**, such as the actuator **102**, the drive rod **104**, the first plate **106**, the second plate **108**, the traveling stage **116**, the bellows **118**, the spring **130**, and/or the spring **132** can be constructed of material configured to withstand a

temperature and pressure of a liquid phase of an alkali metal. Any of wetted components of the bellows pump **100** (e.g., the bellows **118**, the second plate **108**, the traveling stage **116**) can be constructed of a material that is configured to be chemically compatible with (e.g., corrosion resistant to) a liquid alkali metal. For example, any of the actuator **102**, the drive rod **104**, the first plate **106**, the second plate **108**, the traveling stage **116**, the bellows **118**, the spring **130**, and/or the spring **132** can be constructed of an austenitic stainless steel, such as, for example, 304, 316, 347 stainless steel or other species of 300 series stainless steel; martensitic steel, such as, for example, species of 400 series stainless steel; or other suitable metal or metal alloys such as, for example austenitic nickel-chromium-based alloys (e.g., alloys known under the trade name Inconel) or precipitation-hardened steels.
(39) FIG. **5** is a schematic diagram of a system **550** for filling a container **552** with a metal, according to at least one non-limiting aspect of this disclosure. The container **552** can be any type of tube, canister, tank, measuring device, sensor, medical device, pipe, and/or other type of container for holding a volume of material. For example, the container **552** can be a heat pipe, such as a heat pipe configured for use in a nuclear reactor (e.g., a modular reactor, a mini reactor, a micro reactor, a space reactor). The system **550** can be configured to fill the container **552** with various types of metal, such as, for example, alkali metals (e.g., sodium, potassium, cesium, rubidium, lithium, francium, sodium-potassium alloy (NaK)) or other types of metals and metal alloys (e.g., bismuth, tin, mercury, alloys of any combination thereof, eutectic alloys).
(40) The system **550** can include a bellows pump **500**, a supply tank **554**, a filling chamber **556**, a first line **558** for fluid communication between the supply tank **554** and the bellows pump **500**, a second line **560** for fluid communication between the bellows pump **500** and the filling chamber **556**, and an oven **562**.
(41) The bellows pump **500** can be configured to pump the metal (e.g., a metal in liquid phase, an alkali metal in liquid phase) from the supply tank **554** to the container **552**. In some aspects, the bellows pump **500** can be configured the same or similar to the bellows pump **100** described further herein. Thus, the bellows pump **500** can be configured to be chemically compatible with a liquid alkali metal. Further, the bellows pump **500** can be configured to withstand the high temperatures (e.g., greater than 100° C., such as 100° C. to 200° C., greater than 120° C., or 120° C. to 200° C.) and vacuum conditions (e.g., pressures less than 102 kPa, such as, for example, high-vacuum condition which can include pressures less than 0.000133 kPa) that can be required to maintain alkali metals and/or other metals or metal alloys in a liquid phase.
(42) The bellows pump **500** can include a bellows chamber that is actuatable between an expanded configuration and a contracted configuration. Actuating the bellows chamber between the expanded configuration and the contracted configuration can respectively correspond to an intake stroke and a discharge stoke of the bellows pump **500**. Each intake and corresponding discharge stroke of the bellows pump **500** can define a single cycle of the pump. With each cycle, the bellows pump **500** can pump a predetermined volume of the metal (e.g., a stroke volume V.sub.s) from the supply tank **554** to the container **552**. Further, based on the stroke volume V.sub.s and the volume of the container **552**, the bellows pump **500** can cycled for a predetermined number of cycles N.sub.cycle to fill the container **552** with the metal.
(43) The supply tank **554** can serve as a reservoir to supply the metal that is pumped by the bellows pump **500** to fill the container **552**. The supply tank **554** is at least partially fillable with the metal. In some aspects, the supply tank **554** can be provided to the system **550** at least partially filled with the metal in a sold phase.
(44) The oven **562** can be configured to heat the supply tank **554**, the first line **558**, the bellows pump **500**, and/or the second line **560** to a liquid-phase temperature of the metal (e.g., temperature greater than 100° C., such as 100° C. to 200° C., greater than 120° C., or 120° C. to 200° C., under vacuum or high vacuum conditions). Thus, in some aspects, the supply tank **554**, the first line **558**, the bellows pump **500**, and/or at least a portion of the second line **560** can be positioned within the

oven **562**. In the non-limiting aspect of FIG. **5**, a portion of the second line **560** is positioned in the oven **562**. Further, a portion of the second line **560** positioned outside of the oven **562** can include heat tracing and/or insulation **580** to heat the portion of the second line **560** to the liquid-phase temperature of the metal. Heating the supply tank **554** to the liquid-phase temperature of the metal can cause the metal that at least partially fills the supply tank **554** to transition from a solid phase to a liquid phase.

(45) In some aspects, the system **550** can include a gas supply **570** and a gas line **574** for fluid communication between the gas supply **570** and the supply tank **554**. The gas supply **570** can include, for example, a gas supply bottle (e.g., filled with an inert gas such as argon) and a gas header. The gas line **574** can include an actuated isolation valve **578**. Actuating the actuated isolation valve **578** can cause the supply tank **554** to be pressurized with gas from the gas supply **570**. Pressurizing the supply tank **554** can force the liquid metal in the supply tank **554** to flow to the first line **558**, the bellows pump **500**, and the second line **560**, thereby initially priming the system **550** with the liquid metal.

(46) In some aspects, the system **550** can include one or more than one vacuum system **568** for applying a vacuum to the second line **560**, the bellows pump **500**, the first line **558**, and/or the filling chamber **556**. The system **550** can further include one or more than one vacuum line **572** for fluid communication between the one or more than one vacuum system **568**, the second line **560**, and/or the filling chamber **556**. Each of the one or more than one vacuum line **572** may include an actuated isolation valve **576**. The one or more than one vacuum system **568** can be used to apply a vacuum to the second line **560**, the bellows pump **500**, and/or the first line **558** prior to priming the system with the liquid metal. In some aspects, the one or more than one vacuum system **568** can be used to apply a vacuum to the filling chamber **556** prior filling the container **552** with the liquid metal.

(47) The filling chamber **556** can include one or more than one chamber for enclosing, heating, pressurizing, and/or holding the container **552**. For example, the filling chamber **556** can include a chamber that encloses the container **552** and maintains a desired temperature (e.g., temperature greater than 100° C., such as 100° C. to 200° C., greater than 120° C., or 120° C. to 200° C.) and pressure (e.g., a vacuum condition, such as a pressures less than 102 kPa; a high-vacuum condition which can include pressures less than 0.000133 kPa) for filling the containing **552** with the metal (e.g., a liquid alkali metal). In some aspects, the filling chamber **556** can include heat tracing and/or insulation for achieving and maintaining temperature. As another example, the chamber **556** can include a chamber that holds more than one container **552** and is configured to sequentially position (e.g., rotate) each of the more than one container **552** in fluid communication with the second line **560**, thereby enabling each of the more than one container **552** to be rapidly filled without repriming, reheating, and/or repressurizing the system **550**.

(48) In some aspects, the first line **558** can include a first actuated valve **564** and the second line **560** can include a second actuated valve **566**. The first actuated valve **564** and the second actuated valve **566** can be configured to actuate in concert with the intake and discharge strokes of the bellows pump **500**. In some aspects, the first actuated valve **564** and the second actuated valve **566** can control a direction of the flow of the liquid metal. For example, the first actuated valve **564** can be configured to be open during the intake stroke and closed during the discharge stroke. This configuration of the first actuated valve **564** can ensure that liquid metal is able to flow from the supply tank **554** during the intake stroke and prevent flow of the liquid metal back to the supply tank **554** during the discharge stroke. Likewise, the second actuated valve **566** can be configured to be closed during the intake stroke and open during the discharge stroke. This configuration of the second actuated valve **566** can ensure that liquid metal is able to flow to the container **552** during the discharge stroke and prevent flow of the liquid metal from the container **552** back to the bellows pump **500** during the intake stroke. As another example, the configuration of the first actuated valve **564** and the second actuated valve **566** described above can be reversed to achieve

flow of the liquid metal in the opposite direction. In some aspects, in addition to or in lieu of the first actuated valve **564** and the second actuated valve **566**, the first line **558** and/or the second line **560** can include a check valve to control the directional flow of the liquid metal. Persons of ordinary skill in the art will appreciate that the system **550** can include isolation valves on the first line **558** and/or the second line **560** to isolate any of the components or valves thereon (e.g., for maintenance, startup, etc.).

(49) FIG. **6** illustrates a flow chart of a method **600** for filling the container **552** with a metal using the system **550** of FIG. **5**, according to at least one non-limiting aspect of this disclosure. As noted above, the system **550** can include a supply tank **554** at least partially filled with the metal, a bellows pump **500**, a filling chamber **556**, a first line **558** for fluid communication between the supply tank **554** and the bellows pump **500**, and a second line **560** for fluid communication between the bellows pump **500** and the filling chamber **556**. As also noted above, in some aspects, the container **552** can be heat pipe and the metal can be an alkali metal (e.g., sodium). Thus, in some aspects, the method **600** can be executed to fill a heat pipe with an alkali metal.

(50) Referring to FIGS. **5** and **6**, according to the method **600**, the container **552** is loaded **602** into the filling chamber **556**. A vacuum is applied **604** to the filling chamber **556**, for example, using the vacuum system **568**. The filling chamber **556** is heated **606** to a liquid-phase temperature of the metal (e.g., a liquid-phase temperature of the alkali metal under vacuum or high vacuum conditions). In some aspects, applying **604** the vacuum can comprise achieving a pressure in the filling chamber **556** that is no greater than 102 kPa. In some aspects, heating **606** the filling chamber **556** can comprise achieving a temperature in the filling chamber **556** that is no less than 100° C., such as 100° C. to 200° C., greater than 120° C., or 120° C. to 200° C.

(51) Still referring to FIGS. **5** and **6**, according to the method **600**, the supply tank **554** is heated **608** to the liquid-phase temperature of the metal to liquefy the metal. Further, the first line **558**, the second line **560**, and the bellows pump **500** are heated **610** to the liquid-phase temperature of the metal. In some aspects, the first line **558**, at least a portion of the second line **560**, and the bellows pump **500** are heated using the oven **562**. In some aspects, at least a portion of the second line **560** is heated using heat tracing and/or insulation **580**. In some aspects, heating **608** the supply tank **554** and/or heating **610** the first line **558**, the second line **560**, and the bellows pump **500** can comprise achieving a temperature in the supply tank **554**, the first line **558**, the second line **560**, and/or the bellows pump **500** that is no less than 120° C., such as 120° C. to 200° C.

(52) Still referring to FIGS. **5** and **6**, according to the method **600**, the supply tank **554** is pressurized **612** to cause the metal to flow from the supply tank **554** to fill the first line **558**, the bellows pump **500**, and the second line **560**. In some aspects, the supply tank **554** is pressurized **612** with inert gas using the gas supply **570**.

(53) Still referring to FIGS. **5** and **6**, according to the method **600**, the bellows pump **500** is cycled **614** for a predetermined number of cycles (N.sub.cycle) to fill the container with the metal. For example, each cycle of the bellows pump **500** can supply a predetermined stroke volume V.sub.s. Further, a total volume V.sub.T may be required to fill the container. Thus, by cycling **614** the bellows pump **500** for the predetermined number of cycles (N.sub.cycle), the bellows pump **500** can be used to supply the precise total volume V.sub.T of liquid (e.g., V.sub.T=V.sub.s×N.sub.cycle) to fill the container **552**.

(54) As noted above, the bellows pump **500** can include a bellows chamber that is expanded and contracted during a single cycle of the bellows pump **500**. Further, the first line **558** can include a first actuated valve **564** and the second line can include a second actuated valve **566**. According to some aspects of the method **600**, cycling **614** the bellows pump **500** for the predetermined number of cycles N.sub.cycle to fill the container **552** with the metal can include closing the second actuated valve **566**, expanding the bellows chamber to cause a predetermined volume of metal V.sub.s to enter the bellows chamber, closing the first actuated valve **564**, opening the second actuated valve **566**, and contracting the bellows chamber to cause the predetermined volume

V.sub.s of metal to exit the bellows chamber, thereby causing the predetermined volume of the metal V.sub.s to enter the container **552**.
(55) In some aspects, the bellows pump **500** can further include an actuator, a first plate supporting the actuator, a second plate, guide rods extending between the first plate and the second plate, a traveling stage operatively coupled to the actuator and slidable along the guide rods intermediate the first plate and the second plate, and a bellows extending between and hermetically sealed to the second plate and the traveling stage to define the bellows chamber. According to some aspects of the method **600**, expanding the bellows chamber can include applying a first action by the actuator to slide the traveling stage toward the first plate to a first position. Further, contracting the bellows chamber can include applying a second action by the actuator to slide the traveling stage toward the second plate to a second position.
(56) Various examples of the devices, systems, and methods described herein are set out in the following clauses.
(57) To be updated based on the approved claims.
(58) Clause 1: A pump for pumping liquid metal, the pump comprising: an actuator comprising a drive rod; a first plate supporting the actuator; a second plate defining an intake port and a discharge port; guide rods extending between and coupled to the first plate and the second plate; a traveling stage slidable along the guide rods intermediate the first plate and the second plate, the traveling stage operatively coupled to the drive rod; a bellows extending between and hermetically sealed to the second plate and the traveling stage to define a bellows chamber; wherein the actuator is configured to slide the traveling stage toward the first plate to a first position to expand the bellows chamber and cause the liquid metal to flow through the intake port and into the bellows chamber; and wherein the actuator is configured to slide the traveling stage toward the second plate to a second position to contract the bellows chamber and cause the liquid metal to flow out of the bellows chamber and through the discharge port.
(59) Clause 2: The pump of Clause 1, wherein the second plate comprises a second plate material, wherein the traveling stage comprises a traveling stage material, wherein the bellows comprises a bellows material, wherein each of the second plate material, the traveling stage material, and the bellows material are chemically compatible with a liquid alkali metal, and wherein each of the second plate material, the traveling stage material, and the bellows material are selected to withstand a temperature and pressure of a liquid phase of the liquid alkali metal.
(60) Clause 3: The pump of Clause 2, wherein the liquid alkali metal comprises sodium, potassium, cesium, rubidium, lithium, or francium, or an alloy of any combination thereof.
(61) Clause 4: The pump of Clause 3, wherein the second plate material, the traveling stage material, and the bellows material each comprise austenitic stainless steel.
(62) Clause 5: The pump of any one of Clauses 1-4, wherein the bellows comprises: a first flange welded to the traveling stage to hermetically seal the bellows to the traveling stage; a second flange welded to the second plate to hermetically seal the bellows to the second plate; and convolutions intermediate the first flange and the second flange.
(63) Clause 6: The pump of any one of Clauses 1-5, wherein the bellows chamber has a first volume when the traveling stage is in the first position and a second volume when the traveling stage is in the second position, and wherein a stroke volume of the pump is defined based on a difference between the first volume and the second volume, the pump further comprising: stops removably disposed about the guide rods intermediate the second plate and the traveling stage, wherein the stops control the stroke volume by preventing the traveling stage from sliding beyond the second position toward the second plate.
(64) Clause 7: The pump of Clause 6, further comprising a first spring disposed about the bellows intermediate the second plate and the traveling stage to bias the traveling stage to the first position.
(65) Clause 8: The pump Clause 7, further comprising second springs disposed about the guide rods intermediate the first plate and the traveling stage to counteract a force applied to the traveling

stage by the first spring.
(66) Clause 9: A method for filling a container with a metal using a filling system, the filling system comprising a supply tank at least partially filled with the metal, a pump, a filling chamber, a first line for fluid communication between the supply tank and the pump, and a second line for fluid communication between the pump and the filling chamber, the method comprising: loading the container into the filling chamber; applying a vacuum to the filling chamber; heating the filling chamber to a liquid-phase temperature of the metal; heating the supply tank to the liquid-phase temperature of the metal to liquefy the metal; heating the pump, the first line, and the second line to the liquid-phase temperature of the metal; pressurizing the supply tank to cause the metal to flow from the supply tank and fill the pump, the first line, and the second line; and cycling the pump for a predetermined number of cycles to fill the container with the metal.
(67) Clause 10: The method of Clause 9, wherein the pump comprises a bellows chamber, wherein the first line comprises an actuated intake valve, wherein the second line comprises an actuated discharge valve, and wherein cycling the pump for the predetermined number of cycles to fill the container with the metal comprises: closing the discharge valve; expanding the bellows chamber to cause a predetermined volume of metal to enter the bellows chamber; closing the intake valve; opening the discharge valve; contracting the bellows chamber to cause the predetermined volume of metal to exit the bellows chamber, thereby causing the predetermined volume of metal to enter the container.
(68) Clause 11: The method of Clause 10, wherein the pump further comprises an actuator, a first plate supporting the actuator, a second plate, guide rods extending between the first plate and the second plate, a traveling stage operatively coupled to the actuator and slidable along the guide rods intermediate the first plate and the second plate, and a bellows extending between and hermetically sealed to the second plate and the traveling stage to define the bellows chamber; wherein expanding the bellows chamber comprises applying a first action by the actuator to slide the traveling stage toward the first plate to a first position; and wherein contracting the bellows chamber comprises applying a second action by the actuator to slide the traveling stage toward the second plate to a second position.
(69) Clause 12: The method of Claim 11, wherein the container is a heat pipe.
(70) Clause 13: The method of Claim 12, wherein the metal is an alkali metal.
(71) Clause 14: The method of Claim 13, wherein heating the supply tank to the liquid-phase temperature of the metal to liquefy the metal comprises heating the supply tank to a temperature in a range of 100° C. to 200° C.
(72) Clause 15: A system for filling a container with a metal, the system comprising: a supply tank at least partially fillable with the metal; a bellows pump configured to pump a predetermined volume of the metal from the supply tank to the container; a filling chamber to at least partially enclose the container; a first line for fluid communication between the supply tank and the bellows pump; a second line for fluid communication between the bellows pump and the filling chamber; and an oven to heat at least one of the supply tank, the bellows pump, the first line, the second line, or a combination thereof to a liquid-phase temperature of the metal.
(73) Clause 16: The system of Clause 15, wherein the bellows pump comprises a bellows chamber, wherein the bellows chamber is actuatable between an expanded configuration and a contracted configuration to cause an intake stroke and a discharge stroke, and wherein the intake stroke and the discharge stoke act to pump the predetermined volume of the metal from the supply tank to the container.
(74) Clause 17: The system of Clause 16, further comprising: a first actuated valve in the first line, wherein the first actuated valve is configured to be open during the intake stroke and to be closed during the discharge stroke; and a second actuated valve in the second line, wherein the second actuated valve is configured to be closed during the intake stroke and to be closed during the discharge stroke.

(75) Clause 18: The system of Clause 17, wherein the bellows pump further comprises: an actuator comprising a drive rod; a first plate supporting the actuator; a second plate defining an intake port and a discharge port; guide rods extending between and coupled to the first plate and the second plate; a traveling stage slidable along the guide rods intermediate the first plate and the second plate, the traveling stage operatively coupled to the drive rod; a bellows extending between and hermetically sealed to the second plate and the traveling stage to define the bellows chamber; wherein the actuator is configured to slide the traveling stage along the guide rods to actuate the bellows chamber between the expanded configuration and the contracted configuration.

(76) Clause 19: The system of any one of Clauses 15-18, further comprising: a vacuum header to apply a vacuum to at least one of the first line, the second line, the bellows pump, the filling chamber, or a combination thereof; and an inert gas header to apply a pressure to the supply tank and cause the metal to flow from the supply tank to fill the first line, the bellows pump, and at least a portion of the second line.

(77) Clause 20: The system of any one of Clauses 15-19, wherein the container is a heat pipe and wherein the metal is an alkali metal.

(78) Those skilled in the art will recognize that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as “open” terms (e.g., the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases “at least one” and “one or more” to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles “a” or “an” limits any particular claim containing such introduced claim recitation to claims containing only one such recitation, even when the same claim includes the introductory phrases “one or more” or “at least one” and indefinite articles such as “a” or “an” (e.g., “a” and/or “an” should typically be interpreted to mean “at least one” or “one or more”); the same holds true for the use of definite articles used to introduce claim recitations.

(79) In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of “two recitations,” without other modifiers, typically means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to “at least one of A, B, and C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, and C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to “at least one of A, B, or C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, or C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that typically a disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms unless context dictates otherwise. For example, the phrase “A or B” will be typically understood to include the possibilities of “A” or “B” or “A and B.”

(80) It is worthy to note that any reference to “one aspect,” “an aspect,” “an exemplification,” “one exemplification,” and the like means that a particular feature, structure, or characteristic described

in connection with the aspect is included in at least one aspect. Thus, appearances of the phrases “in one aspect,” “in an aspect,” “in an exemplification,” and “in one exemplification” in various places throughout the specification are not necessarily all referring to the same aspect. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner in one or more aspects.
(81) Any patent application, patent, non-patent publication, or other disclosure material referred to in this specification and/or listed in any Application Data Sheet is incorporated by reference herein, to the extent that the incorporated materials is not inconsistent herewith. As such, and to the extent necessary, the disclosure as explicitly set forth herein supersedes any conflicting material incorporated herein by reference. 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 will only be incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.
(82) The terms “comprise” (and any form of comprise, such as “comprises” and “comprising”), “have” (and any form of have, such as “has” and “having”), “include” (and any form of include, such as “includes” and “including”) and “contain” (and any form of contain, such as “contains” and “containing”) are open-ended linking verbs. As a result, a system that “comprises,” “has,” “includes” or “contains” one or more elements possesses those one or more elements, but is not limited to possessing only those one or more elements. Likewise, an element of a system, device, or apparatus that “comprises,” “has,” “includes” or “contains” one or more features possesses those one or more features, but is not limited to possessing only those one or more features.
(83) The term “substantially”, “about”, or “approximately” as used in the present disclosure, unless otherwise specified, means an acceptable error for a particular value as determined by one of ordinary skill in the art, which depends in part on how the value is measured or determined. In certain embodiments, the term “substantially”, “about”, or “approximately” means within 1, 2, 3, or 4 standard deviations. In certain embodiments, the term “substantially”, “about”, or “approximately” means within 50%, 20%, 15%, 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.5%, or 0.05% of a given value or range.
(84) In summary, numerous benefits have been described which result from employing the concepts described herein. The foregoing description of the one or more forms has been presented for purposes of illustration and description. It is not intended to be exhaustive or limiting to the precise form disclosed. Modifications or variations are possible in light of the above teachings. The one or more forms were chosen and described in order to illustrate principles and practical application to thereby enable one of ordinary skill in the art to utilize the various forms and with various modifications as are suited to the particular use contemplated. It is intended that the claims submitted herewith define the overall scope.

Claims

1. A pump capable of pumping liquid metal, the pump comprising: an actuator comprising a drive rod; a first plate supporting the actuator; a second plate defining an intake port and a discharge port; guide rods extending between and coupled to the first plate and the second plate; a traveling stage slidable along the guide rods intermediate the first plate and the second plate, the traveling stage operatively coupled to the drive rod; a bellows extending between and hermetically sealed to the second plate and the traveling stage to define a bellows chamber, wherein the actuator is configured to slide the traveling stage toward the first plate to a first position to expand the bellows chamber and cause a liquid to flow through the intake port and into the bellows chamber, and wherein the actuator is configured to slide the traveling stage toward the second plate to a second position to contract the bellows chamber and cause the liquid to flow out of the bellows chamber and through the discharge port; a first spring disposed about the bellows intermediate the second

plate and the traveling stage to bias the traveling stage to the first position; second springs disposed about the guide rods intermediate the first plate and the traveling stage to counteract a force applied to the traveling stage by the first spring, and stops removably disposed about the guide rods intermediate the second plate and the traveling stage, wherein the bellows chamber has a first volume when the traveling stage is in the first position and a second volume when the traveling stage is in the second position, wherein a stroke volume of the pump is defined based on a difference between the first volume and the second volume, and wherein the stops control the stroke volume by preventing the traveling stage from sliding beyond the second position toward the second plate.

2. The pump of claim 1, wherein the second plate comprises a second plate material, wherein the traveling stage comprises a traveling stage material, wherein the bellows comprises a bellows material, wherein each of the second plate material, the traveling stage material, and the bellows material are chemically compatible with a liquid alkali metal, and wherein each of the second plate material, the traveling stage material, and the bellows material are selected to withstand a temperature and pressure of a liquid phase of the liquid alkali metal.

3. The pump of claim 2, wherein the liquid alkali metal comprises sodium, potassium, cesium, rubidium, lithium, or francium, or an alloy of any combination thereof.

4. The pump of claim 3, wherein the second plate material, the traveling stage material, and the bellows material each comprise austenitic stainless steel.

5. The pump of claim 4, wherein the bellows comprises: a first flange welded to the traveling stage to hermetically seal the bellows to the traveling stage; a second flange welded to the second plate to hermetically seal the bellows to the second plate; and convolutions intermediate the first flange and the second flange.

6. A method for filling a container with a metal using a filling system comprising the pump of claim 1, the filling system further comprising a supply tank at least partially filled with the metal, a filling chamber, a first line for fluid communication between the supply tank and the pump, and a second line for fluid communication between the pump and the filling chamber, the method comprising: loading the container into the filling chamber; applying a vacuum to the filling chamber; heating the filling chamber to a liquid-phase temperature of the metal; heating the supply tank to the liquid-phase temperature of the metal to liquefy the metal; heating the pump, the first line, and the second line to the liquid-phase temperature of the metal; pressurizing the supply tank to cause the metal to flow from the supply tank and fill the pump, the first line, and the second line; and cycling the pump for a predetermined number of cycles to fill the container with the metal.

7. The method of claim 6, wherein the first line comprises an actuated intake valve, wherein the second line comprises an actuated discharge valve, and wherein cycling the pump for the predetermined number of cycles to fill the container with the metal comprises: closing the discharge valve; expanding the bellows chamber to cause a predetermined volume of metal to enter the bellows chamber; closing the intake valve; opening the discharge valve; contracting the bellows chamber to cause the predetermined volume of metal to exit the bellows chamber, thereby causing the predetermined volume of metal to enter the container.

8. The method of claim 6, wherein the container is a heat pipe.

9. The method of claim 8, wherein the metal is an alkali metal.

10. The method of claim 9, wherein heating the supply tank to the liquid-phase temperature of the metal to liquefy the metal comprises heating the supply tank to a temperature in a range of 100° C. to 200° C.

11. A system configured to fill a container with a metal using the pump of claim 1, the system comprising: a supply tank at least partially fillable with the metal; the pump, wherein the pump is configured to pump a predetermined fill volume of the metal from the supply tank to the container; a filling chamber to at least partially enclose the container; a first line for fluid communication between the supply tank and the pump; a second line for fluid communication between the pump

and the filling chamber; and an oven to heat at least one of the supply tank, the pump, the first line, the second line, or a combination thereof to a liquid-phase temperature of the metal.

12. The system of claim 11, further comprising: a vacuum header to apply a vacuum to at least one of the first line, the second line, the pump, the filling chamber, or a combination thereof; and an inert gas header to apply a pressure to the supply tank and cause the metal to flow from the supply tank to fill the first line, the pump, and at least a portion of the second line.

13. The system of claim 11, wherein the container is a heat pipe and wherein the metal is an alkali metal.

14. They system of claim 11, wherein cycling the pump a predetermined number of cycles at the stroke volume causes the pump to pump the predetermined fill volume of metal from the supply tank to the container.