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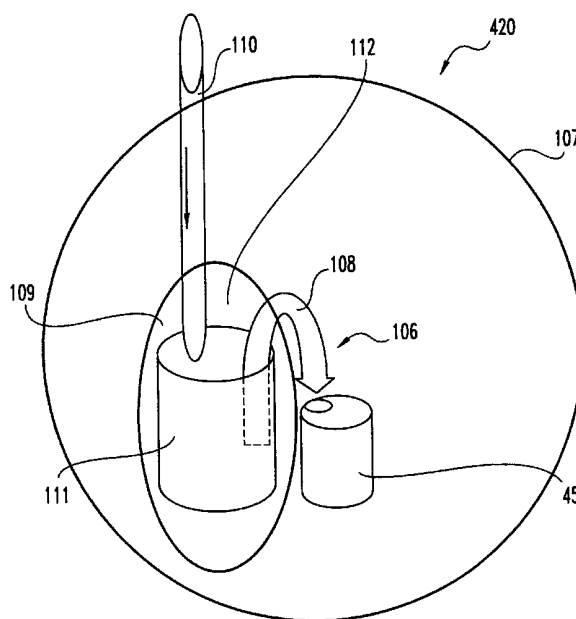
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(54) Title: METHOD AND APPARATUS FOR PRODUCTION OF A CAST COMPONENT



(57) Abstract: A system (420) for producing cast components from molten metal. One form of the present invention includes a system (420) for the precision pouring of molten metal within a casting mold (45). The precision pouring system (420) is driven by a pressure differential.

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METHOD AND APPARATUS FOR PRODUCTION OF A CAST COMPONENT

BACKGROUND OF THE INVENTION

The present invention relates generally to a method and apparatus for the production of a cast component. More particularly, in one embodiment of the present invention, a cast structure is formed by the solidification of a molten metal within a casting mold. Although the invention was developed for casting gas turbine engine components, certain applications may be outside of this field.

The performance of a gas turbine engine generally increases with an increase in the operating temperature of a high temperature working fluid flowing from a combustion chamber. One factor recognized by gas turbine engine designers as limiting the allowable temperature of the working fluid is the capability of the engine components to not degrade when exposed to the high temperature working fluid. The airfoils, such as blades and vanes, within the engine are among the components exposed to significant thermal and kinetic loading during engine operation.

One cooling technique often utilized in a gas turbine engine component is an internal network of apertures and passageways. A flow of cooling media is passed through the internal passageways of the component, and exhausted onto the exterior surface of the component. The passage of the cooling media through the internal passageways provides for heat transfer from the component to the cooling media.

A process and apparatus are disclosed in U.S. Patent No. 5,295,530, which is incorporated herein by reference, by which the production of a high temperature thin wall cast structure is described. The '530 patent describes a process of pouring a molten metal into a ceramic casting mold which is carried on a water-cooled chill plate within a vacuum furnace. The injection pressure of the molten metal can be varied over time so that the walls of the casting mold do not substantially distort during the process. Thereafter, the molten metal within the casting mold is solidified.

Although the prior techniques can produce thin walled cast components with internal passageways and apertures, there remains a need for an improved method and apparatus for casting a component. The present invention satisfies this and other needs in a novel and unobvious way.

SUMMARY OF THE INVENTION

One form of the present invention contemplates an apparatus for pouring a molten metal. The apparatus, comprising: a crucible having a bottom wall member with an aperture formed therethrough; an upstanding first tube positioned within
5 the crucible and having a first end located around the aperture and coupled to the bottom wall member and another second end that is closed, the first tube having at least one entrance for allowing the passage of molten metal from the crucible to the first tube; an upstanding second tube located within the first tube and having one
10 end coupled to the bottom wall member and in fluid communication with the aperture and another end defining an inlet from the tube, the second tube has a first cavity adapted for receiving a volume of molten metal therein; and a passageway extending along the second tube for the passage of the molten metal from the at least one entrance to the inlet.

Another form of the present invention contemplates, a method for pouring
15 molten metal into a casting mold within a furnace. The method, comprising: providing a crucible with a discharge aperture and a pour assembly located within the crucible, the pour assembly including an upstanding outer tube positioned around an upstanding inner tube, the inner tube is in fluid communication with the discharge aperture; melting a metal material within the crucible to a liquid state;
20 flowing the liquid state metal from the crucible into a cavity defined between the outer tube and the inner tube; overfilling the cavity so that liquid state metal flows into and fills the inner tube; stopping the filling of the inner tube; and discharging the liquid state metal from the inner tube.

Yet another form of the present invention contemplates an apparatus for
25 pouring a molten metal. The apparatus, comprising: a mechanical housing with a bottom wall member and an interior volume adapted to hold a molten metal; and a molten metal delivery member having a first molten metal inlet end adapted to receive molten metal from below the surface of the molten metal within the interior volume and a second molten metal outlet end with a passageway therebetween, at
30 least a portion of the delivery member positioned within the mechanical housing, the passageway has a first passageway portion and a second passageway portion

and a inflection portion wherein the direction of molten metal flow changes, in a first discharge mode a first direction of molten metal flow within the first passageway portion is from the molten metal inlet to the inflection portion and from the inflection portion through the second passageway portion in a second direction to said outlet.

Yet another form of the present invention contemplates a method, comprising: providing a casting mold having a plurality of layers of a material bonded together to define a cavity for receiving a molten metal material therein and an exit in communication with the cavity; orienting the casting mold at an inclination; rotating the casting mold to free any material located within the cavity and not bonded to one of the plurality of layers of material; and passing the material located within the cavity out of the cavity and through the exit.

One object of the present invention is to provide a unique system for production of a cast component.

Related objects and advantages of the present invention will be apparent from the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an illustrative view of a gas turbine engine.

5 FIG. 2 is a perspective view of a gas turbine engine blade within the FIG. 1 gas turbine engine.

FIG. 3 is a plan view of one embodiment of an internal cooling passageway comprising a portion of the FIG. 2 gas turbine engine blade.

10 FIG. 4 is a cross section of one embodiment of a cast airfoil having a thin outer wall.

FIG. 5 is an illustration of one embodiment of a cast multi-wall structure.

FIG. 6 is an illustration of one embodiment of an atmospheric air/spacecraft having a leading edge made with a process according to one aspect of the present invention.

FIG. 7 is an illustration of one embodiment of a cast valve body.

15 FIG. 8 is an illustrative partial sectional view of of a system for removing unbonded material from a casting mold.

FIG. 9 is an illustrative view of one embodiment of the system of FIG. 8 for removing the unbonded material from the casting mold.

20 FIG. 10 is an illustrative view of one embodiment of a casting system of the present invention.

FIG. 11 is an illustrative sectional view of one embodiment of the casting apparatus for casting a component of the present invention.

FIG. 12 is an illustrative plan view of the FIG. 11 casting apparatus.

25 FIG. 13 is an illustrative sectional view of an alternate embodiment of the casting apparatus for casting a component of the present invention.

FIG. 14 is an illustrative sectional view of an alternate embodiment of the casting apparatus for casting a component of the present invention.

FIG. 15 is an illustrative sectional view of an alternate embodiment of the casting apparatus for casting a component of the present invention.

30 FIG. 16 is an illustrative sectional view of an alternative embodiment of the molten metal delivery system located within a casting apparatus.

FIG. 17 is an illustrative sectional view of an alternate embodiment of the molten metal delivery system located within a casting apparatus.

FIG. 18 is an enlarged view of the molten metal delivery system of FIG. 13.

5 FIG. 19 is an illustrative view of an alternate embodiment of a molten metal delivery system.

FIG. 20A is an illustration of the molten metal delivery system of FIG. 18 in a first stage.

FIG. 20B is an illustration of the molten metal delivery system of FIG. 18 in a second stage.

10 FIG. 20C is an illustration of the molten metal delivery system of FIG. 18 in a third stage.

FIG. 20D is an illustration of the molten metal delivery system of FIG. 18 in a fourth stage.

15 FIG. 20E is an illustration of the molten metal delivery system of FIG. 18 in a fifth stage.

FIG. 21 is a graphic illustration of the process of varying charge pressure with time.

FIG. 22 is an illustrative view of the gas turbine engine blade of FIG. 2 within a pressure and temperature environment.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiment illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, such alterations and further modifications in the illustrated device, and such further applications of the principles of the invention as illustrated therein being contemplated as would normally occur to one skilled in the art to which the invention relates.

Referring to FIG. 1, there is illustrated a gas turbine engine 20 which includes a fan section 21, a compressor section 22, a combustor section 23, and a turbine section 24 that are integrated together to produce an aircraft flight propulsion engine. This type of gas turbine engine is generally referred to as a turbo-fan. One alternate form of a gas turbine engine includes a compressor, a combustor, and a turbine that have been integrated together to produce an aircraft flight propulsion engine without the fan section. The term aircraft is generic and includes helicopters, airplanes, missiles, unmanned space devices and any other substantially similar devices. It is important to realize that there are a multitude of ways in which the gas turbine engine components can be linked together. Additional compressors and turbines could be added with intercoolers connecting between the compressors and reheat combustion chambers could be added between the turbines.

A gas turbine engine is equally suited to be used for an industrial application. Historically, there has been widespread application of industrial gas turbine engines, such as pumping sets for gas and oil transmission lines, electricity generation, and naval propulsion.

The compressor section 22 includes a rotor 25 having a plurality of compressor blades 26 coupled thereto. The rotor 25 is affixed to a shaft 27 that is rotatable within the gas turbine engine 20. A plurality of compressor vanes 28 are positioned within the compressor section 22 to direct the fluid flow relative to blades 26. Turbine section 24 includes a plurality of turbine blades 30 that are

coupled to a rotor disk 31. The rotor disk 31 is affixed to the shaft 27, which is rotatable within the gas turbine engine 20. Energy extracted in the turbine section 24 from the hot gas exiting the combustor section 23 is transmitted through shaft 27 to drive the compressor section 22. Further, a plurality of turbine vanes 32 are positioned within the turbine section 24 to direct the hot gaseous flow stream exiting the combustor section 23.

The turbine section 24 provides power to a fan shaft 33, which drives the fan section 21. The fan section 21 includes a fan 34 having a plurality of fan blades 35. Air enters the gas turbine engine 20 in the direction of arrows A and passes through the fan section 21 into the compressor section 22 and a bypass duct 36. The term airfoil will be utilized herein to refer to fan blades, fan vanes, compressor blades, turbine blades, compressor vanes, and turbine vanes unless specifically stated otherwise in the text. Further details related to the principles and components of a conventional gas turbine engine will not be described herein as they are believed known to one of ordinary skill in the art.

With reference to FIGS. 2-7, there are illustrated examples of cast components that could be produced from a casting mold system of the present system. The present disclosure is not intended to be limited to the examples set forth in FIGS. 2-7, unless specifically set forth herein. More specifically, with reference to FIG. 2, there is illustrated a gas turbine engine blade 30. In one embodiment, the gas turbine engine blade 30 defines a cast article having an internal flow path for the passage of cooling media. The internal cooling path includes a passageway with a plurality of heat transfer pedestals 37. In one embodiment, the plurality of pedestals 37 are integrally formed between a pair of spaced walls. The pedestals are representative of the types of details that can be produced with the casting mold systems of the present invention. It is understood herein that the shape, size, and distribution of the cooling pedestals are a function of heat transfer parameters and design specific parameters. The FIG. 3 illustration is utilized herein merely to represent that pedestals having the following dimensions are more particularly contemplated, and the dimensional sizes of one embodiment of the channels and pedestals are set forth in Table 1. However, it is

understood that other pedestal and channel sizes and geometry's are contemplated herein.

PEDESTAL

5	<u>Length</u>	<u>Width</u>	<u>Height</u>
	0.020-.050"	0.020-.050"	0.012-.020"

CHANNEL

	<u>Length</u>	<u>Width</u>	<u>Height</u>
	N/A	0.012-.020"	0.012-.020"

10

TABLE 1

Referring to FIGS. 4 and 5, there is illustrated a sectional view of one embodiment of a single piece multi-wall gas turbine engine component producible by the present system. Further, FIG. 6 illustrates the leading edge 43 of a spacecraft 42, which is producible with the system of the present invention. While in FIG. 7 there is illustrated a hydraulic valve body 44 with internal fluid flow circuitry that depicts another example of the types of cast products that could be produced with the present system. The products illustrated herein are not intended to be limiting and other cast products are contemplated for production by the present system including, but not limited to art, jewelry, dental prosthesis, general prosthesis, custom hardware, golf club heads, propellers, electronic packaging, tubes, valves and other items that have been traditionally investment cast for precision tolerance and/or detail.

The methods and apparatuses of the present invention may be utilized to produce single piece single cast components or multi piece cast components having microstructures that are commonly categorized as equiaxed, directionally solidified or single crystal. The preferred casting mold system of the present invention is suitable for producing virtually any type of cast metallic product, however in a more preferred embodiment it is particularly useful for producing thin walled cast structures. The cast structures may have many different shapes, sizes, configurations, and can be formed of a variety of metallic materials. For example,

the system of the present invention allows the casting of multi-wall structures with at least one wall having a thickness less than about 0.03 inches. Further, in a preferred embodiment there can be formed very thin passageways within the cast structure/component and in a more preferred embodiment the very thin
5 passageways having a width of about 0.005 inches to about 0.015 inches. However, casting having passageways and wall thickness of other widths and/or sizes and/or thickness are contemplated herein.

Gas turbine engine components are preferably formed of a superalloy composition material. There are various types of superalloy compositions, such as
10 but not limited to nickel based or cobalt based compositions, and the manufacture of such compositions are generally known to those skilled in the art. Most superalloy compositions of interest are complicated mixtures of nickel, chromium, aluminum and other select elements. However, the present invention is applicable with any type of alloy, superalloy or metallic material.

15 With reference to FIGS. 8 and 9, there is illustrated a method and apparatus for removing unbonded material 400 from within the internal cavity of a casting mold 45. In one embodiment the casting mold 45 is a free form fabricated mold having a plurality of layers of a material bonded together, it is also contemplated as being useful for other mold structures having unbonded particles located within a
20 metal receiving cavity. Hereinafter, the term casting mold will be refer to casting molds generically and is intended to include all types of casting molds, unless specifically stated to the contrary. For example, a mold produced with conventional techniques of cores and patterns which are shelled by dipping in a ceramic slurry, resin shell molds, or sand molds are also contemplated herein.

25 The unbonded material within the casting mold relates to powders, particulate, and other material that is not bonded to the walls of the integral mold 45 within the cavity 48. In one form, the process for removing unbonded material from within a casting metal receiving cavity relates to a mold produced by the printing and binding of layers of powder to form a direct ceramic casting mold.
30 This technique is generally known as three dimensional printing. Information related to three dimensional printing is disclosed in U.S. Patent Nos 5,340,650,

5,387,380 and 5,204,055 which are incorporated herein by reference. A commercially available system for three dimensional printing is available from Soligen technologies of North Ridge California. However, the present invention is applicable with all molds. In another embodiment the mold 45 has been heated to
5 dry the unbonded materials within the cavity.

The mold 45 is positioned at an inclination angle θ and rotated about an axis Z. In the preferred embodiment, the angle θ is an acute angle within the range of about 5 to about 90 degrees, and more preferably, the angle θ is about 15 degrees. However, in the alternate embodiment the angle θ is variable. Rotation
10 and movement of the integral mold 45 causes the unbonded material 400 to be dislodged from the walls defining the internal cavity and passed through an exit aperture 101 that is in communication with the internal cavity, and into a bin 104. In an alternate embodiment the integral mold has a plug (not illustrated) put into the exit aperture 101 after the unbonded material 400 has been removed from the
15 internal cavity.

In one form a sprocket 77 of the mold 45 is engaged with a drive 102. The drive 102 is driven such that the container is revolved at speeds in the range of about 0.1 to 2 revolutions per minute, and more preferably rotates at a speed of about 1/3 revolutions per minute, however, other speeds are contemplated herein.
20 The dwell time for which the integral mold is subjected to rotation is in the range of about 15 minutes to about 2 days and more preferably is about 2 hours. However, other dwell times are contemplated herein. The molds 45 pass along a support 103 in the direction of arrow P as they are rotated about axis Z. A spacer 105 is positioned between pairs of molds 45 so as to prevent contact between the
25 containers. Further, the molds 45 may be inverted as necessary to facilitate removal of the material 400 from the internal cavity, and a fluid scrubbing can be introduced into the internal cavity to facilitate material removal. The introduction of fluids within the internal cavity can occur in the normal or inverted state.

The mold 45 is subjected to a thermal processing operation prior to the receipt of molten metal within its internal cavity. In one embodiment mold 45 is
30 formed by the three-dimensional printing has a green state strength that is not

sufficient for the casting process and therefore to increase its strength it has been fired. In some mold constructions it is necessary to burn out binders and other materials present in the green state mold. The mold produced by the three-dimensional printing techniques generally do not require the burn out process as there are not significant materials to be removed from the green state mold 45. Lastly, the mold must be preheated to the appropriate temperature, which is chosen to facilitate the growth of the microstructure desired. In the case of a columnar grain structure the temperature desired to preheat the mold is about 2700 degrees Fahrenheit and in the case of a single crystal casting the temperature desired for the mold preheat is about 2800 degrees Fahrenheit.

In one form of the present invention, it is preferred to have an integrated thermal processing operation for the mold 45. The integrated thermal processing will include firing the green state mold 45, burning out the unwanted materials in the green state mold, and preheating the mold to the desired temperature necessary for casting the desired microstructure. The molds after the firing and sintering operation are then cooled, inspected, repaired as necessary and prepared for casting. Thereafter, the mold is elevated to the temperature desired for preheating the mold. In a more preferred form, each of these steps occur in the same furnace in a substantially continuous fashion. Elimination of thermal cycling of the mold will enhance the ability to cast hollow structures with intricate/delicate passages.

With reference to FIG. 10, there is depicted a functional representation of a casting apparatus 420 for delivering a charge of molten metal 108 to a casting mold, such as the mold 45. The present invention contemplates a casting apparatus that can function in a substantially continuous or a batch processing fashion. The casting mold utilized with the casting apparatus is not intended to be limited herein to a specific mold style or construction. The casting apparatus includes a precision molten metal delivery system 106 that is located within a furnace 107. In a preferred form of the present invention, the furnace 107 is defined by a dual chambered vacuum furnace. However, it is understood that other types of furnaces such as air melt or pressurized casting furnaces are contemplated herein. In one form of the present invention the precision molten metal delivery

system for discharging a quantity of molten metal to the mold 45 is located within an environmentally controlled chamber 109. The molten metal delivery system 106 is fed molten metal from beneath the surface of the molten metal within a crucible 111. A supply of metal material 110 passes into the chamber 109 and is melted within the crucible 111. The supply of metal material within the crucible is heated to a super heated state, and for the alloys associated with casting turbine engine components the super heat is in the range of 350-400° Fahrenheit. However, it is understood that other super heat temperatures for these alloys and other types of metals is contemplated herein.

In one embodiment, the control chamber 109 is supplied with an inert gas 112 that forms a shield and/or membrane to slow surface vaporization of the molten metal within the crucible 111. Dispensing of the molten metal is controlled by a pressure differential between the molten metal delivery system 106 and the mold 45. In one embodiment, the discharge of molten metal is controlled by the application of a positive pressure to the surface of the molten metal, which in turn drives a quantity of molten metal from the crucible 111 into the mold 45. The mold 45 is positioned within a second chamber of the vacuum furnace and is at a lower pressure than the molten metal delivery system 106.

With reference to FIGS. 33 and 34, there is illustrated one embodiment of the casting apparatus of the present invention. The casting apparatus includes a dual chambered vacuum furnace 116 with an upper chamber 117 and a lower chamber 118 separated by a wall 114. The creation of a pressure difference between the chambers is utilized to deliver the charge of molten metal to the mold. A mold entry port 119 allows for the introduction and removal of casting molds 45, from the lower chamber 118. In one form of the present invention, the mold entry port 119 defines a fluid tight interlock that enables the maintenance of a vacuum environment within the lower chamber 118 as the mold container 45 is removed or inserted into the lower chamber. Positioned within the lower chamber is a rotatable fixture 121 for holding the molds 45 during the pouring and solidification of the molten metal.

A metal material feeder 120 allows for the introduction of unmelted metal material 137 into the melting crucible 122 located within upper chamber 117. In one form of the present invention, the unmelted metal material 137 is in bar form and is passed into the crucible without interrupting the operation of the casting apparatus 115. In the preferred embodiment, the melting crucible 122 defines a refractory crucible in which the metal material is inductively heated by an induction heater 123. It is understood that other forms of heaters, such as but not limited to levitation and resistant, are contemplated herein for melting and elevating the temperature of the metal material within the crucible 122. The crucible 122 is designed and constructed to hold a quantity of molten metal from, which is removed smaller charges of molten metal to fill the individual molds. The quantity of molten metal that the crucible can hold is preferably in the range of about 5-200 pounds, and more preferably is about 50 pounds. However, as discussed previously the crucible can have sufficient capacity for a continuous process or be sized for an individual single pour. In one embodiment, the crucible holding a reservoir of molten metal reduces temperature fluctuations related to the delivery of charges of molten metal and the introduction of unmelted metal material into the crucible for melting. The molten metal 124 within the melting crucible 122 passes into a molten metal dispensing system. In one embodiment, the molten metal dispensing system defines an apparatus for the precision pouring of molten metal through a nozzle 253 to a precision located input 78 of the fill tube 52. A more detailed description of the molten metal dispensing system 125 and alternate embodiments for dispensing molten metal from the crucible 122 will be discussed below.

In one embodiment of the present invention, the rotatable fixture 121 is located within the lower chamber 118 of the vacuum furnace and includes a plurality of mold container holders 129. In the embodiment of FIG. 12, the mold container holders 129 are spoke members, however, other structures are contemplated for holding the molds as they are filled with molten metal and solidified. The mold 45 is rotated to a position 131 wherein the filler tubes inlet 78 is in alignment with the pouring nozzle 253.

With reference to FIG. 13, there is illustrated an alternate embodiment 135 of the casting apparatus. The casting apparatus 135 is substantially similar to casting apparatus 115 and like features will be indicated by like feature numbers. The major distinction between the casting apparatus 135 and the casting apparatus 115 is the inclusion of a seal 136 for forming a fluid tight seal with the unmelted metal stock 137 as it moves into the upper chamber 117. In a preferred form, the seal 136 abuts an outer surface 137a of the unmelted metal stock 137. The advancement of the metal stock 137 into the upper chamber 117 in the direction of arrow S will cause an increased pressure acting on the molten alloy 124 in the crucible 122. The increasing of pressure and/or force on the molten metal 124 can be attributed to the advancement of the metal stock 137 into the molten metal 124 and/or by increasing the pressure of an inert gas 127 supplied through the valve 126. In a preferred form the inert gas is argon or helium and the pressure difference associated with the inert gas is 60 milli-torr.

Referring to FIG. 14, there is illustrated another embodiment 140 of the casting apparatus of the present invention. The casting apparatus 140 is substantially identical to the casting apparatus 135 with like feature numbers indicating like features. The casting apparatus 140 provides for the positioning of nozzle 253 into the inlet 78 of the metal fill tube 52. The coupling of the nozzle to the fill tube enables increased head pressure to improve fill. Further, in one form the system is applicable to control molten metal pressure over time. Therefore, upon discharge of the molten metal from the nozzle there is a confined passageway that the molten alloy passes through to the fill tube 52. In order to effectuate the mating of the nozzle 253 with the inlet 78 of the mold 45, the rotatable fixture 121 is moveable vertically. The fixture 121 is lowered to receive the mold container 45 the mold changer 130 and then raised to position the mold container in a seating relationship when it is desired to pour the charge of molten metal into the mold.

Referring to FIG. 15, there is illustrated a casting apparatus 145 that is substantially similar to the prior casting apparatuses of FIGS. 11-14, with the notable difference being the capability of casting apparatus 145 to handle larger casting molds. Casting apparatus 145 allows for the introduction of a larger

casting mold 525 through a doorway 146 adjoining the lower chamber 528. In one embodiment, the molten metal 124 is delivered from a molten metal dispensing system into the inlet 523 of the mold cavity 525. Thereafter, the mold 522 is withdrawn from the pour position with chamber 528 by an elevator 548.

5 With reference to FIG. 16, there is illustrated another embodiment 230 of the apparatus for dispensing molten metal from a casting apparatus, such as casting apparatus 115. The melting crucible 231 is substantially identical to the melting crucible 122 except that the molten metal does not pass through an aperture in the bottom wall member. A molten metal delivery passageway 232 has an input end
10 233 and a discharge end 234. Input end 233 is fed molten metal from beneath the surface of the molten metal and the passageway 232 is filled to the height of the column of molten metal within the crucible 231. The discharge of the molten metal from the delivery passageway 232 into the mold container 4580 is controlled by the difference in pressure between the chamber 117 and chamber 118.

15 The molten metal delivery passageway 232 includes a positive molten metal flow control feature. In one embodiment the portion 232a of the passageway 232 functions as a flow control means. Upon the application of sufficient pressure to the molten metal within the crucible the passageway 232 is filled with molten metal. Upon releasing the applied pressure molten metal will return to the crucible
20 and be maintained at a height within the passageway substantially equal to the height of the molten metal within the crucible. In one form, the delivery of molten metal from portion 232a and out nozzle 600 will have a predetermined pressure and velocity controlled by the height "C" plus the pressure difference between chamber 117 and chamber 118. The activation energy necessary to fill the
25 passageway 232 is indicated by "D".

 In a preferred form of the apparatus the discharge of molten metal is controlled by the application of pressure to the molten metal within the crucible 231. As discussed previously, the pressure applied to the molten metal can be created by advancing the metal stock 137 into the molten metal and/or by applying
30 pressure to the surface of the molten metal with an inert gas. Upon the increase in pressure on the surface of the molten metal, additional molten metal is forced

through the input end 233 and up through the delivery passageway 232 to the output end 234. At the output end 234 the molten metal passes through a nozzle 600 to the mold container inlet. Upon release of the pressure on the molten metal, the molten metal beyond point 235 is delivered, and the remaining molten metal

5 within the passageway remains there and/or is returned to the crucible 231. Therefore, the delivery of molten metal to the mold container 80 is controlled by the difference in pressure between chamber 117 and 118. In an alternate embodiment, the passage of molten metal to the mold container 80 could be effectuated by lowering the pressure around the container instead of raising the

10 pressure on the molten metal.

With reference to FIG. 17, there is illustrated an alternate embodiment 240 of the molten metal dispensing system for dispensing molten metal from a casting apparatus, such as casting apparatus 115. More particularly, the molten metal dispensing system 240 is located within the upper chamber 117 and the mold 45 is

15 located within the lower chamber 118. Crucible 241 is substantially similar to the crucible 122 and is heated by the heater 123 to melt the metal material stock. A crucible discharge aperture 242 is formed in the crucible and aligned with a passageway 243 through the wall member 114. A stopper rod 244 is disposed within the upper chamber 117 and moveable between a position wherein a sealing

20 surface 245 engages the wall of the crucible around aperture 242 to prevent the passage of molten metal therethrough, and another position wherein the sealing surface 245 is removed from the abutting relationship with the walls around the aperture 242. Gravitational forces will allow the passage of the molten metal into the mold 80 upon the removal of the stopper rod sealing surface 245 from it's

25 sealing position.

With reference to FIG. 18, there is illustrated an enlarged view of the crucible 122 with the molten metal dispensing system 125 located therein. The crucible 122 having an aperture 700. The molten metal dispensing system 125 includes an outer passageway 250 and an inner passageway 251 that are in fluid

30 communication with each other and the crucible 122. A plurality of filling apertures 252 allow the molten metal within the crucible 122 to flow into the outer

passageway 250 of the system 125. Upon the outer passageway 250 being filled with molten metal, the molten metal can overflow into an inlet end 251a of the inner passageway 251. The inner passageway 251 has an outlet end 251b through which the molten metal flows to a nozzle 253. A portion 255 of the inner
5 passageway 251 around the nozzle 253 allows the accumulation of molten metal which is used to maintain the temperature of the nozzle 253 close to that of the crucible of molten metal.

In one embodiment, a heat shield and/or heater 254 is spaced from and positioned around the nozzle 253 to mechanically guard the nozzle and reduce heat
10 loss therefrom. The nozzle 253 passes through the aperture 700 in the crucible and has a discharge aperture designed to provide a concentrated stream of molten metal. In one form the stream of molten metal is discharged substantially vertical, however in alternate embodiments the stream is discharged in other relative directions. In one embodiment the discharge aperture has a diameter of about
15 0.125 inches, however, other sizes are contemplated herein. Further, the nozzle is self cleaning in that it purges itself every time the discharge of molten metal is completed. More specifically, in one embodiment the nozzle 253 has a pointed end 253a.

The structure of the molten metal dispensing system 125 preferably
20 includes an outer member 257 having the plurality of inlet fill holes 252 formed therethrough with an inner member 256 spaced therefrom. The inner member 256 and the outer member 257 are preferably formed of alumina or other suitable ceramics, and the outer member includes four equally spaced inlet fill holes 252, however other numbers and spacing of inlet holes is contemplated herein. The
25 inner and outer members being coupled to the base of the crucible 122. More preferably, the dispensing system 125 defines a first upstanding outer tube 257 that is closed at one end and a second upstanding inner tube 256 spaced inwardly therefrom. The inner tube 256 and outer tube 257 are coupled to the bottom wall member 701 of the crucible 122 and positioned around the aperture 700. In a
30 preferred embodiment the inner tube 256 defines a metering cavity for holding a predetermined volume of molten metal therein.

With reference to FIG. 19, there is illustrated an alternate embodiment of the molten metal dispensing system. The molten metal dispensing system 650 is positioned within a mechanical housing/crucible 651. The mechanical housing has an interior volume 652 adapted to receive molten metal therein. The molten metal dispensing system includes a member 653 having a passageway 654 formed therein. At one end of the passageway 654 is a molten metal inlet 655 and at the other end is a molten metal outlet. In an alternate embodiment only a portion of the molten metal dispensing system is located within the interior volume where molten metal is located. An inflection portion 655 is defined within the passageway 654. The molten metal enters the passageway 654 and flows through the passageway to the height of the molten metal within the housing 651. Upon the application of a pressure to the molten metal within the mechanical housing the molten metal is driven to the inflection portion 655, and continues through the passageway 654 to the molten metal outlet and is discharged. In one form the molten metal flows in a first direction indicated by arrow A to the inflection portion 655 and from the inflection portion 655 in a second direction as indicated by arrow B. The molten metal inlet 655 is located beneath the surface 670 of the molten metal within the interior volume. In one embodiment the molten metal dispensing system is integrally formed.

In a preferred form of the molten metal dispensing system 650 the passageways have substantially upstanding portions that meet with the inflection portion to form a substantially U shape passageway. Further, it is preferred that the inflection portion is above the molten metal height within the mechanical housing/crucible 651. In one form a portion of the passageway varies in cross-sectional area between the molten metal inlet and the molten metal outlet. In a more preferred form at least a portion of the passageway tapers prior to the inflection portion, and more preferably defines a passageway having a frustum-conical shape. In one embodiment the passageway 654 has a vent 700 disposed in fluid communication therewith. However in an alternate embodiment the passageway does not have the vent 700 connected therewith. The vent has utilization for venting the passageway and allowing the purging of the passageway

with a pressurized fluid. The present invention contemplates other geometric shapes and sizes for the components of the molten metal dispensing system.

With reference to FIGS. 20A-20E, there is illustrated the process of dispensing molten metal from one embodiment of the molten metal dispensing system 125. As the unmelted metal material 137 is advanced into the crucible 122 the material is melted and forms a quantity of molten metal 124. The molten metal 124 flows through the plurality of filling apertures 252 into the outer passageway 250 of the system 125. The continued advancement of the unmelted metal stock 137 into the crucible and the subsequent melting thereof raises the height H of the molten metal within the crucible 122 to the height of the inlet end 251a of the inner passageway 251. In order to fill the inner passageway/metering chamber 251 with molten metal it is necessary to apply an additional force to the molten metal 124 within the chamber.

The additional force can be applied by the continued advancement of the unmelted metal material 137 into the quantity of melted metal within the crucible. A second method for increasing the pressure on the molten metal 124 within the crucible is to introduce a pressurized inert gas against the surface of the molten alloy. The additional pressure on the molten metal will cause the continued flow of molten metal through the filling apertures 252. Subsequent overflowing of the molten metal from the outer passageway 250 to the inlet end 251a of the inner passageway. The filling of the inner passageway is a relatively quick process as the filling apertures 252 have been sized to allow an inflow of material that is significantly greater than the nozzle 253 can discharge from the inner passageway. Upon the inner passageway 251 being substantially filled with molten metal, the pressure applied to the surface 124a is removed such that the inner passageway 251 no longer receives molten metal from the outer passageway 250 and the inner passageway discharges its charge of molten metal through the nozzle 253 in a concentrated stream.

In one embodiment of the molten metal dispensing system, a sensor 800 (FIG. 53D) is positioned proximate the nozzle 253 to detect the initial flow of molten metal from the nozzle. Upon the detection of the initial flow of molten

metal from the nozzle 253, the sensor will send a signal to have the additional pressure removed from the surface 124a of the molten metal. In one embodiment the signal is sent to a controller that controls the application of pressure to the molten metal. The early indication of a slight molten metal discharge from the nozzle 253 is substantially contemporaneous with the completion of filling of the inner passageway 251 due to the difference in the total size of the filling apertures 252 and the nozzle aperture. In one embodiment, the material inflow through filing apertures 252 is significantly greater than the material outflow through the nozzle aperture.

With reference to FIG. 21, there is an illustration of the pressure of the molten metal as a function of time. In one embodiment illustrated in FIG. 36 the nozzle 253 is coupled in fluid communication to the inlet 78 of the fill tube 52. Flow of molten metal can then be initiated by either increasing the pressure in chamber 117 or reducing the pressure in chamber 118. The reduction in pressure in 118 can function to: vacuum the internal mold cavity and thereby remove loose material like residual powder. Further, the increase in pressure in chamber 117 would aid in the fill of details in the mold cavity.

With reference to FIG. 22, there is illustrated a gas turbine engine blade 30 positioned within furnace 801 for having post casting operations performed thereon. The post casting processing operations for a single crystal and/or columnar grain casting include: a hot isostatic pressing operation; a homogenizing operation; and, a quench operation. The hot isostatic pressing operation involves placing the component 30 within the furnace 801 and subjecting the component to high temperature and pressure so as to remove porosity from the cast structure. In one embodiment, the hot isostatic processing taking place at a temperature of about 2375 to 2400 degrees Fahrenheit and at a pressure of about 30,000 lbs. per square inch. The pressure is preferably supplied by an inert gas, such as argon. With reference to FIG. 55, the pressure is indicated by arrows 802 and the temperature is indicated by arrows 803.

Subsequent to the hot isostatic pressing operation, the component is subjected to a homogenizing operation that causes diffusion between the elements

that may have separated during the solidification process and is designed to raise the incipient melting point of the cast structure. The homogenizing cycle is concluded by subjecting the component to a quenching step and subsequent tempering operations.

5 In one embodiment of the present invention, the three post casting operations are combined into a sequential process within the furnace 801. The hot isostatic pressing operation is performed within the furnace 801 by raising the temperature and pressure within the furnace 801 for a period of time so as to reduce the porosity in the casting. Thereafter, the temperature within the furnace
10 801 is raised to a value within about 25 degrees Fahrenheit of the incipient melting point of the material forming the component 30. Preferably the temperature within the furnace 801 is raised to within 5° Fahrenheit of the melting point of the material for a period of time. After the completion of the homogenizing operation, the quenching operation is undertaken by the high pressure transfer of a cold inert
15 gas into the furnace 801. The aging of the cast component can continue under vacuum or pressure as desired.

 While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiment
20 has been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected.

WHAT IS CLAIMED IS:

1. An apparatus for pouring a molten metal, comprising:
a crucible having a bottom wall member with an aperture formed therein;
5 an upstanding first tube positioned within said crucible and having a first end located around said aperture and coupled to said bottom wall member and another second end that is closed, said first tube having at least one entrance for allowing the passage of molten metal from said crucible to said first tube;
an upstanding second tube located within said first tube and having one end
10 coupled to said bottom wall member and in fluid communication with said aperture and another end defining an inlet from said first tube, said second tube has a first cavity adapted for receiving a volume of molten metal therein; and
a passageway extending along said second tube for the passage of the molten metal from said at least one entrance to said inlet.
15
2. The apparatus of claim 1, which further includes a nozzle in fluid communication with said aperture, said nozzle adapted to deliver a substantially vertical stream of molten metal.
- 20 3. The apparatus of claim 1, which further includes a nozzle coupled with said aperture and in fluid communication with said first cavity of the second tube, said nozzle has an inlet adapted to receive molten metal and an outlet adapted to discharge molten metal; and which further includes a mechanical housing having a first chamber at a first pressure and a second chamber at a second pressure, and
25 wherein said crucible is located within said first chamber and said outlet of the nozzle is located within said second chamber.
4. The apparatus of claim 3, which further includes pressure differential means for creating a pressure differential between said first chamber and said
30 second chamber, wherein upon said pressure differential means causing said first pressure to be greater than said second pressure the molten metal within said

crucible flows through said at least one entrance and into said passageway along said second tube.

5 5. The apparatus of claim 4, wherein said pressure differential means includes a supply of pressurized gas in fluid communication with said first chamber, and wherein said supply of pressurized gas is controlled to increase said first pressure in said first chamber.

10 6. The apparatus of claim 4, wherein said pressure differential means includes a quantity of unmelted metal stock extending into said first chamber, and wherein said unmelted metal stock is advanced into the molten metal within said crucible to increase said first pressure.

15 7. The apparatus of claim 4, wherein said pressure differential means includes a vacuum in fluid communication with said second chamber, said vacuum being operable to reduce said second pressure.

20 8. The apparatus of claim 3, wherein a difference in size between said outlet and said at least one entrance allows the volumetric flow rate of molten metal through said at least one entrance to be substantially greater than the volumetric flow rate of molten metal through said outlet.

25 9. The apparatus of claim 8, wherein said at least one entrance defines a plurality of entrances.

30 10. The apparatus of claim 3, wherein said nozzle has an upstanding portion that extends into said second tube, and wherein a second cavity is defined between said second tube and said upstanding portion of said nozzle, wherein said second cavity is adapted to receive molten metal and heat said upstanding portion of said nozzle.

11. The apparatus of claim 1, wherein said first cavity defines a metering cavity holding a predetermined volume of molten metal.

12. The apparatus of claim 4, which further includes a sensor positioned proximate said outlet, said sensor detects an initial flow of molten metal from said outlet and communicates with said pressure differential means to stop creating a pressure differential between said first chamber and said second chamber.

13. The apparatus of claim of claim 3, wherein said nozzle and said first tube and said second tube are parallel to one another, and wherein said at least one entrance is located adjacent said first end of the first tube.

14. A method for pouring molten metal into a casting mold within a vacuum furnace, comprising:
providing a crucible with a discharge aperture and a pour assembly located within the crucible, the pour assembly including an upstanding outer tube positioned around an upstanding inner tube, the inner tube is in fluid communication with the discharge aperture;
melting a metal material within the crucible to a liquid state;
flowing the liquid state metal from the crucible into a cavity defined between the outer tube and the inner tube;
overfilling the cavity so that liquid state metal flows into and fills the inner tube;
stopping the filling of the inner tube; and
discharging the liquid state metal from the inner tube.

25

15. The method of claim 14:
wherein in said providing the outer tube has a plurality of inlet apertures;
wherein said flowing involves passing the molten metal through the plurality of inlet apertures; and
which further includes increasing the pressure differential between the discharge aperture and the molten metal within the crucible.

30

16. The method of claim 15, wherein said increasing includes applying a positive pressure to the molten metal within the crucible.

5 17. The method of claim 16, wherein said applying a positive pressure includes advancing the unmelted metal material stock into the molten metal within the crucible.

10 18. The method of claim 14, wherein said flowing includes creating a pressure differential between the molten metal within the crucible and the cavity between the outer tube and the inner tube, and wherein the pressure on the molten metal in the crucible is greater than the pressure within the cavity between the outer and inner tube.

15 19. The method of claim 18, wherein said overflowing of the cavity includes maintaining a pressure differential between the molten metal in the crucible and the cavity between the outer tube and the inner tube, and wherein the pressure on the molten metal in the crucible is greater than the pressure within the cavity between the outer and inner tube.

20 20. The method of claim 19, wherein said stopping occurs when the pressure in the cavity between the inner and outer tube is greater than the pressure of the molten metal within the crucible.

25 21. The method of claim 14, which further includes providing a nozzle in flow communication with the discharge aperture, and which further includes flowing a quantity of molten metal into the cavity to heat at least a portion of the nozzle.

30 22. The method of claim 14, which further includes sensing the discharge of molten metal from the discharge aperture, and upon said sensing said stopping occurring.

23. The method of claim 14, which further includes providing a casting mold adapted to receive the molten metal, and which further includes connecting the discharging of the molten metal with the casting mold in a confined passageway.

5 24. The method of claim 23:
which further included providing a nozzle in flow communication with the discharge aperture and extending therefrom; and
which further includes positioning the nozzle adjacent an inlet to the casting mold prior to said discharging.

10

25. The method of claim 24, wherein said discharging delivers a substantially vertical stream of molten metal.

15

26. The method of claim 24, which further includes moving the casting mold to align the casting mold inlet with the nozzle.

20

27. An apparatus, comprising:
a mechanical housing;
a crucible adapted to receive a metal material therein, said crucible positioned within said housing;
a heater positioned adjacent said crucible for heating the crucible and melting the metal received within said crucible; and
a pressure controlled precision pour assembly positioned within said crucible, said pour assembly has an outer cavity with at least one entrance for the passage of melted metal material from said crucible to said outer cavity and an exit for the passage of melted metal material to an inner metering cavity, and wherein said pour assembly has a first state wherein said inner metering cavity receives melted metal material from said outer cavity until said inner metering cavity is full and a second state wherein the flow of melted metal material to said inner cavity is stopped and the melted metal material within said inner metering cavity is discharged.

25

30

28. The apparatus of claim 27, wherein said crucible includes a discharge opening, and wherein in said second state the melted metal material within said inner metering cavity flows through said discharge opening.

5

29. The apparatus of claim 28, which further includes a nozzle coupled to said crucible and in fluid communication with said discharge opening.

30. The apparatus of claim 29:

10 wherein said mechanical housing has a first chamber and a second chamber, and wherein said crucible is located within said first chamber; and said second state discharges molten metal when the pressure in said second chamber is greater than the pressure within said first chamber.

15 31. The apparatus of claim 29:

wherein said crucible has a bottom wall member, and wherein said discharge opening is formed in said bottom wall member;

wherein said pressure controlled precision pour assembly includes an outer upstanding tube coupled to said bottom wall member and positioned around said
20 discharge opening;

wherein said pressure controlled precision pour assembly includes an inner upstanding tube coupled to said bottom wall member and positioned around said discharge opening, wherein said inner upstanding tube is positioned within said outer upstanding tube, and said outer cavity is located between said tubes, and
25 wherein said inner metering cavity is positioned within said inner tube.

32. The apparatus of 31, wherein a difference in area between said nozzle outlet and said at least one entrance allows the volumetric flow rate of molten metal through said at least one entrance to be substantially greater than the
30 volumetric flow rate of molten metal through said outlet.

33. An apparatus for dispensing a molten metal, comprising:
a mechanical housing having a first chamber with a first pressure and a second chamber with a second pressure;
a crucible positioned within said first chamber of the mechanical housing and
5 adapted to receive a stock of unmelted metal material therein;
a heater positioned adjacent said crucible and adapted for heating the crucible and at least a portion of the unmelted metal material therein to a molten metal state, wherein said crucible holds the volume of molten metal melted by the heater therein;
10 a tube having a first end and a second end with a flow communication passageway therebetween, said first end positioned beneath a surface of the volume of molten metal within said crucible and a second end positioned in fluid communication with said second chamber and defining a discharge aperture; and
a pressure differential device within said first chamber and acting on the volume of
15 molten metal to increase the pressure thereof and cause molten metal to flow through said passageway and out of said second end, said pressure differential device is defined by at least a portion of the unmelted metal material.

34. The apparatus of claim 33, wherein said pressure differential device defines
20 a consumable member that is replenished by additional unmelted metal material.

35. The apparatus of claim 34, wherein said first chamber has an aperture therein adapted for the passage of the stock of unmelted metal material, and a substantially fluid tight seal is formed around the stock.

25

36. An apparatus for pouring a molten metal, comprising:
a mechanical housing with a bottom wall member and an interior volume adapted to hold a molten metal; and
a molten metal delivery member having a first molten metal inlet end adapted to
30 receive molten metal from below the surface of the molten metal within the interior volume and a second molten metal outlet end with a passageway therebetween, at

least a portion of said delivery member positioned within said mechanical housing, said passageway has a first passageway portion and a second passageway portion and a inflection portion wherein the direction of molten metal flow changes, in a first discharge mode a first direction of molten metal flow within said first
5 passageway portion is from said molten metal inlet to said inflection portion and from said inflection portion through said second passageway portion in a second direction to said outlet.

37. The apparatus of claim 36, wherein said first passageway portion and said
10 second passageway portion and said inflection portion define a substantially U shape.

38. The apparatus of claim 36, wherein said inflection portion is above the
15 surface of the molten metal within said interior volume.

39. The apparatus of claim 38, wherein the pressure of the molten metal within the inflection portion is greater than the pressure at either of said molten metal inlet or said molten metal outlet.

40. The apparatus of claim 39, wherein said molten metal delivery member is
20 integrally formed.

41. The apparatus of claim 36, wherein said second passageway portion defines a metering cavity.
25

42. The apparatus of claim 36 wherein the cross-sectional area of said passageway varies between said first inlet end and said second outlet end.

43. The apparatus of claim 42, wherein said first passageway portion tapers
30 prior to said inflection portion.

44. The apparatus of claim 42, wherein said first passageway has a substantially frustum-conical shape part prior to said inflection portion.

45. A method, comprising:

5 providing a casting mold having a plurality of layers of a material bonded together to define a cavity for receiving a molten metal material therein and an exit in communication with the cavity;

orienting the casting mold at an inclination;

10 rotating the casting mold to free any material located within the cavity and not bonded to one of the plurality of layers of material; and

passing the material located within the cavity out of the cavity and through the exit.

15 46. The method of claim 45, which further includes moving the casting mold along a pathway.

47. The method of claim 46, wherein said moving is occurring simultaneous with said rotating.

20 48. The method of claim 45, wherein said rotating is unidirectional.

49. The method of claim 45, wherein said rotating is bi-directional.

25 50. The method of claim 45, which further includes gas scrubbing the inner surface of the plurality of layers of material bonded together to define the cavity.

51. The method of claim 45, wherein the inclination is at an acute angle.

30 52. The method of claim 45, which further includes placing a plug in the exit after said passing of the material from the cavity.

53. The method of claim 45, wherein said rotating is within a range of about 0.1 revolutions per minute to about 2 revolutions per minute, and wherein the casting mold is rotated between about fifteen minutes and two days.
- 5 54. The method of claim 53, wherein the casting mold is rotated about two hours.
55. The method of claim 45:
which further includes moving the casting mold along a pathway;
10 wherein at least a portion said moving and said rotating are occurring simultaneously; and
wherein said orienting orients the casting mold at an acute angle.
56. A method, comprising:
15 forming an integral ceramic shell by three dimensional printing, the ceramic shell includes a plurality of layers of a ceramic material bonded together to define a cavity therein for receiving a molten metal material and at least one exit in fluid communication with the cavity;
orienting the ceramic shell at an inclination;
20 rotating the ceramic shell about a first axis to free ceramic material located within the cavity that is not bonded to one of the plurality of layers of material; and
passing the material located within the cavity out of the cavity and through the at least one exit.
- 25 57. The method of claim 56, which further includes moving the ceramic shell along a predetermined pathway.
58. The method of claim 56, wherein said moving is substantially linear.
- 30 59. The method of claim 56, wherein said rotating about an axis is unidirectional.

60. The method of claim 56, which further includes passing a gas through the cavity to scrub the inner surface of the plurality of layers defining the cavity.
- 5 61. The method of claim 56, which further included inverting the ceramic shell to facilitate removal of the ceramic material within the cavity.
62. The method of claim 56, which further includes providing a first gear coupled with the ceramic shell, and which further includes engaging the first gear
10 with a driven second gear to cause said rotating.
63. The method of claim 45, which further includes drying the plurality of layers.
- 15 64. The method of claim 63, wherein said drying is occurring during a preheating act of the mold.

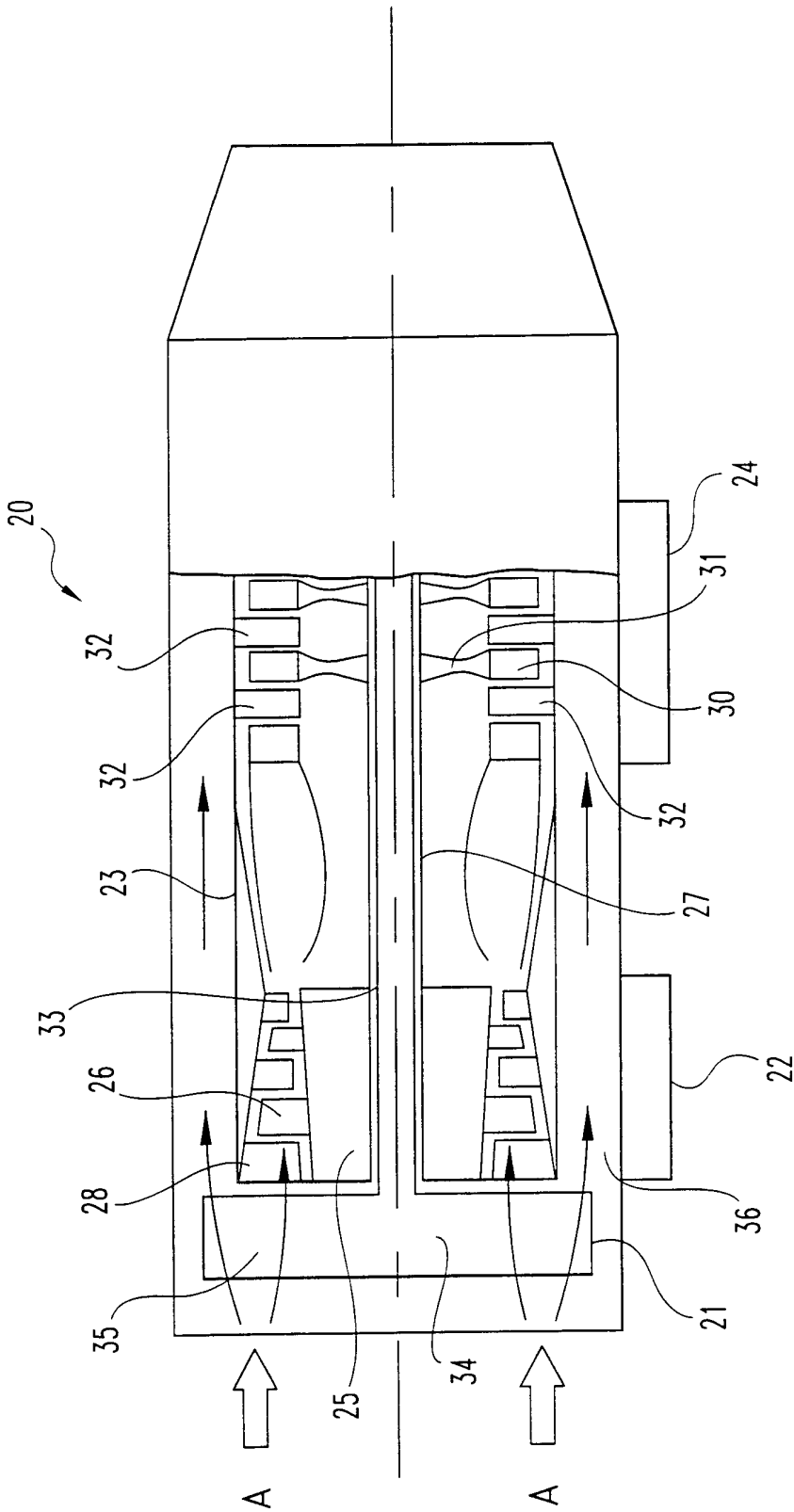


Fig. 1

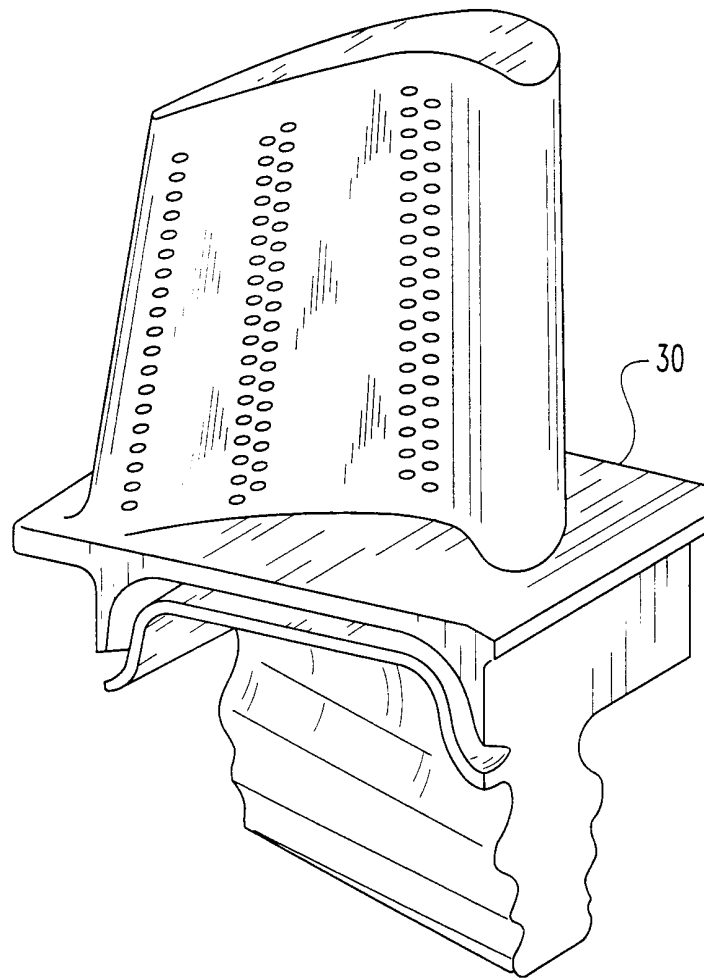
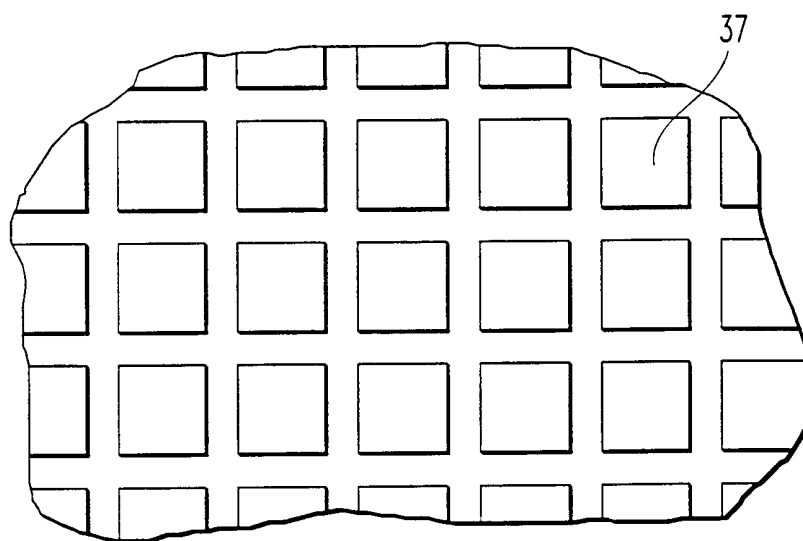
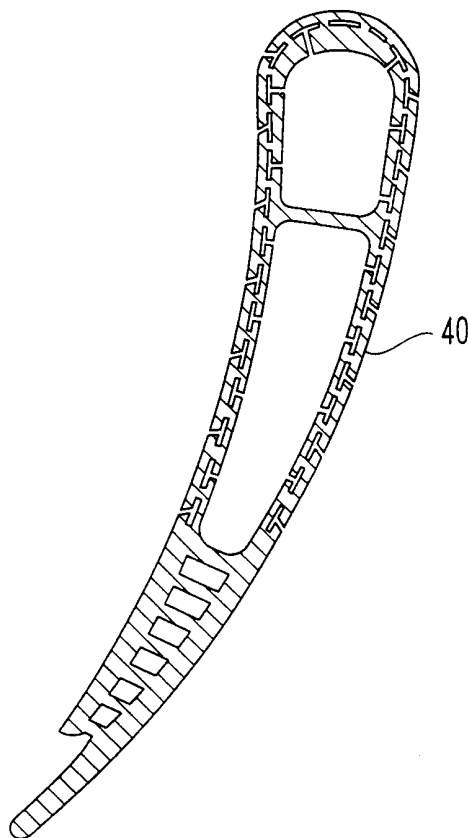


Fig. 2

**Fig. 3****Fig. 4**

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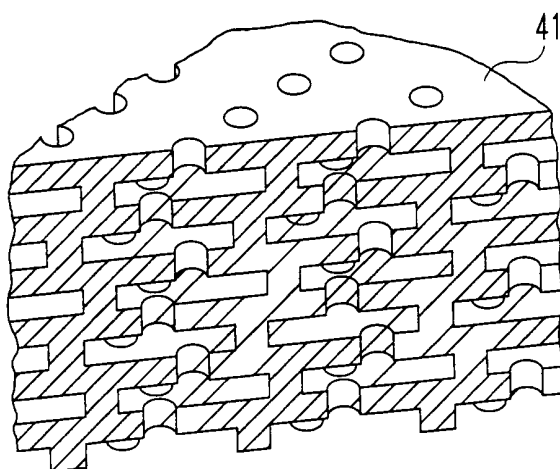


Fig. 5

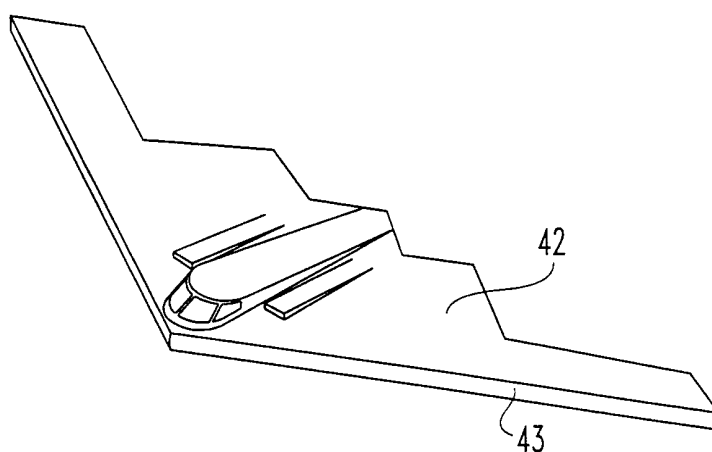


Fig. 6

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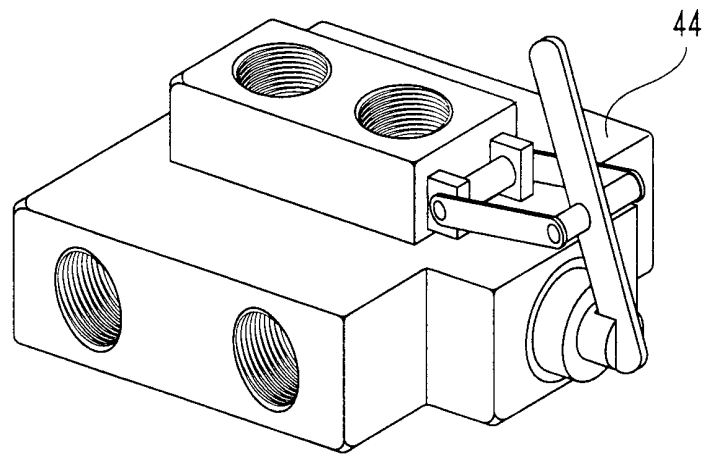


Fig. 7

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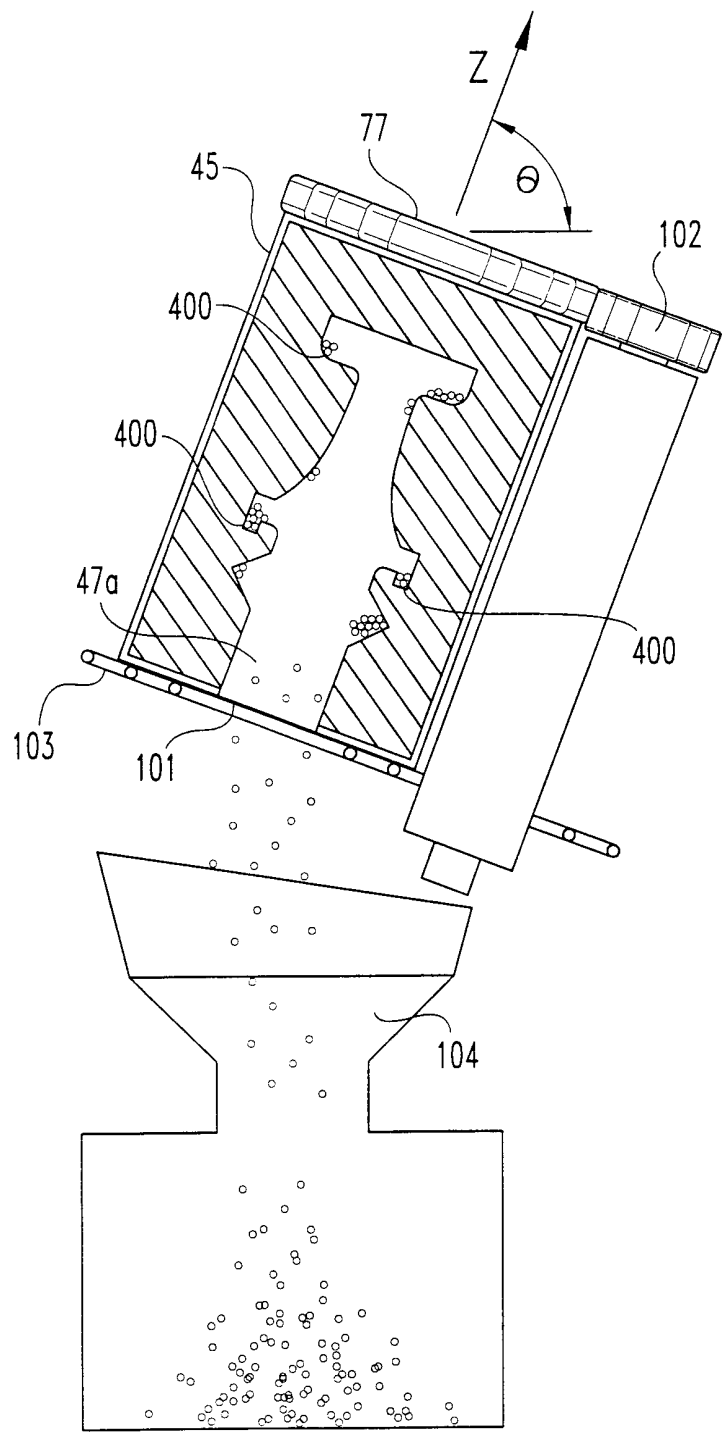


Fig. 8

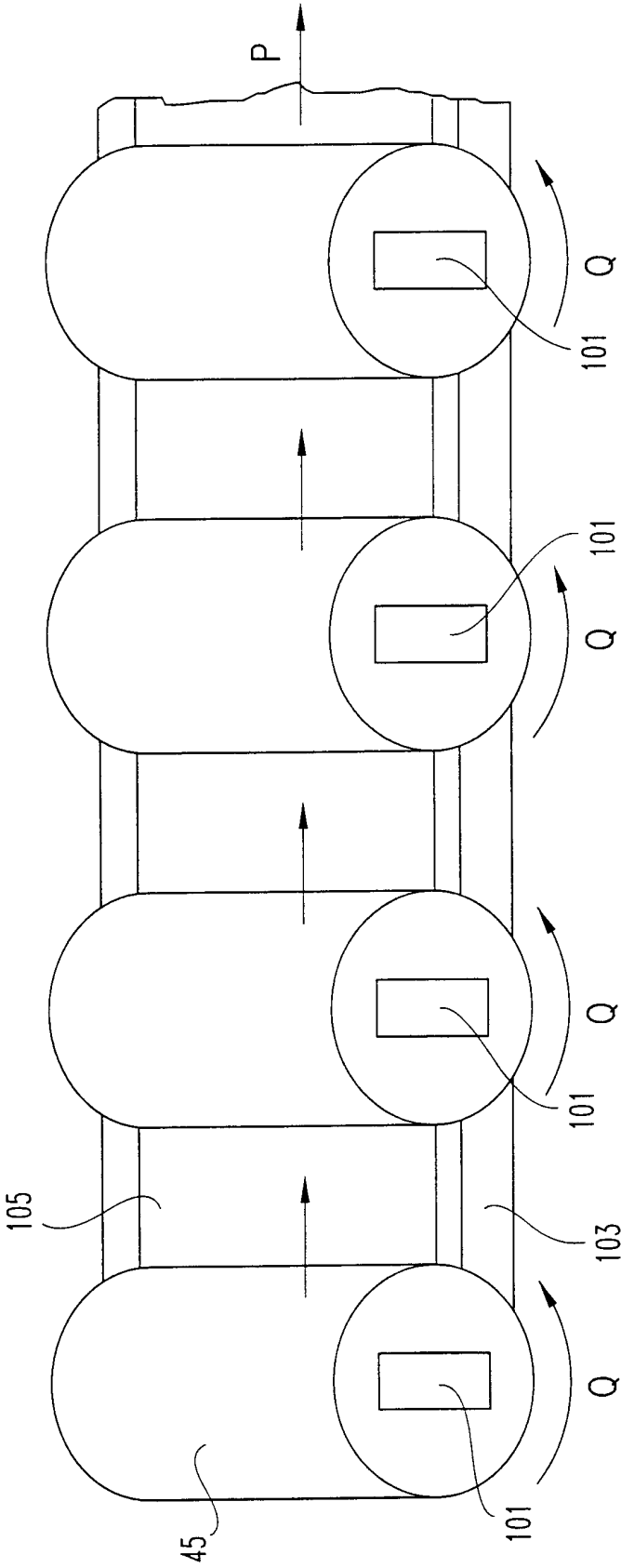


Fig. 9

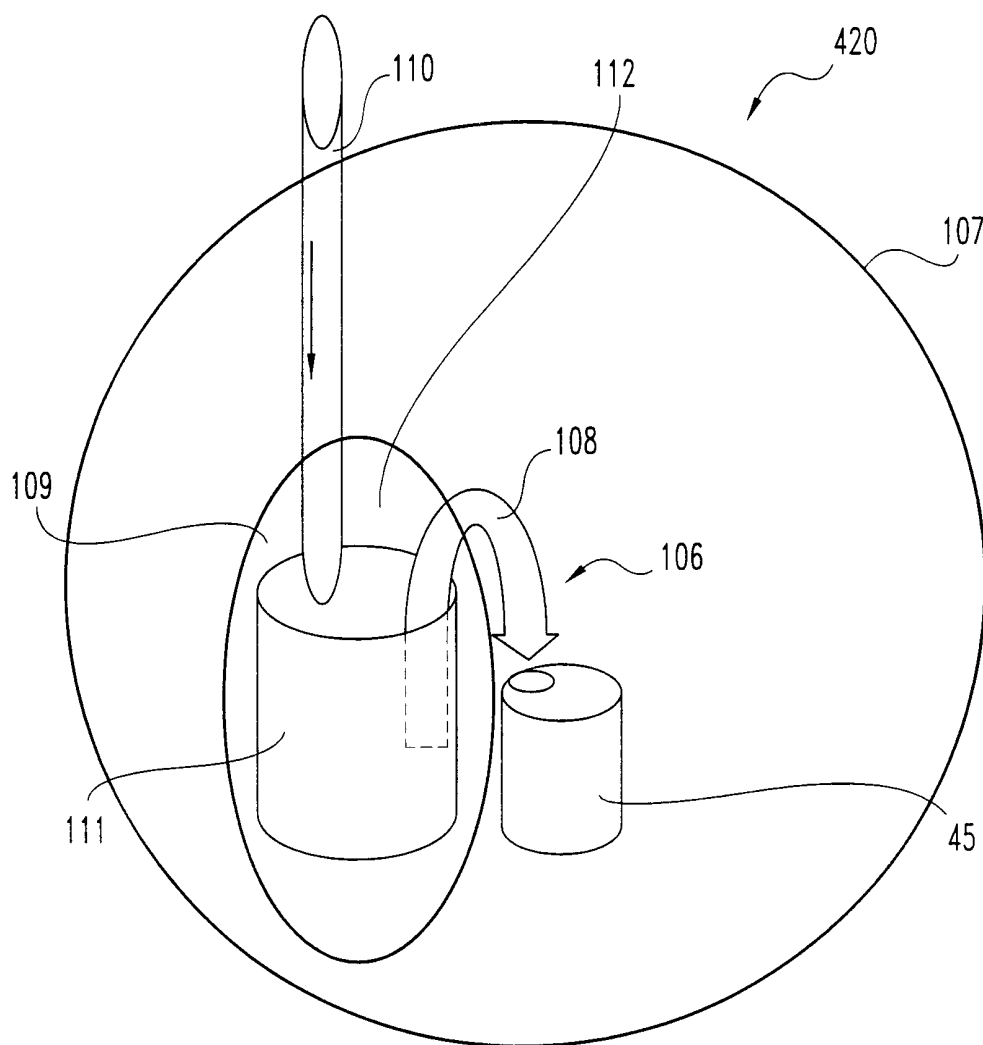
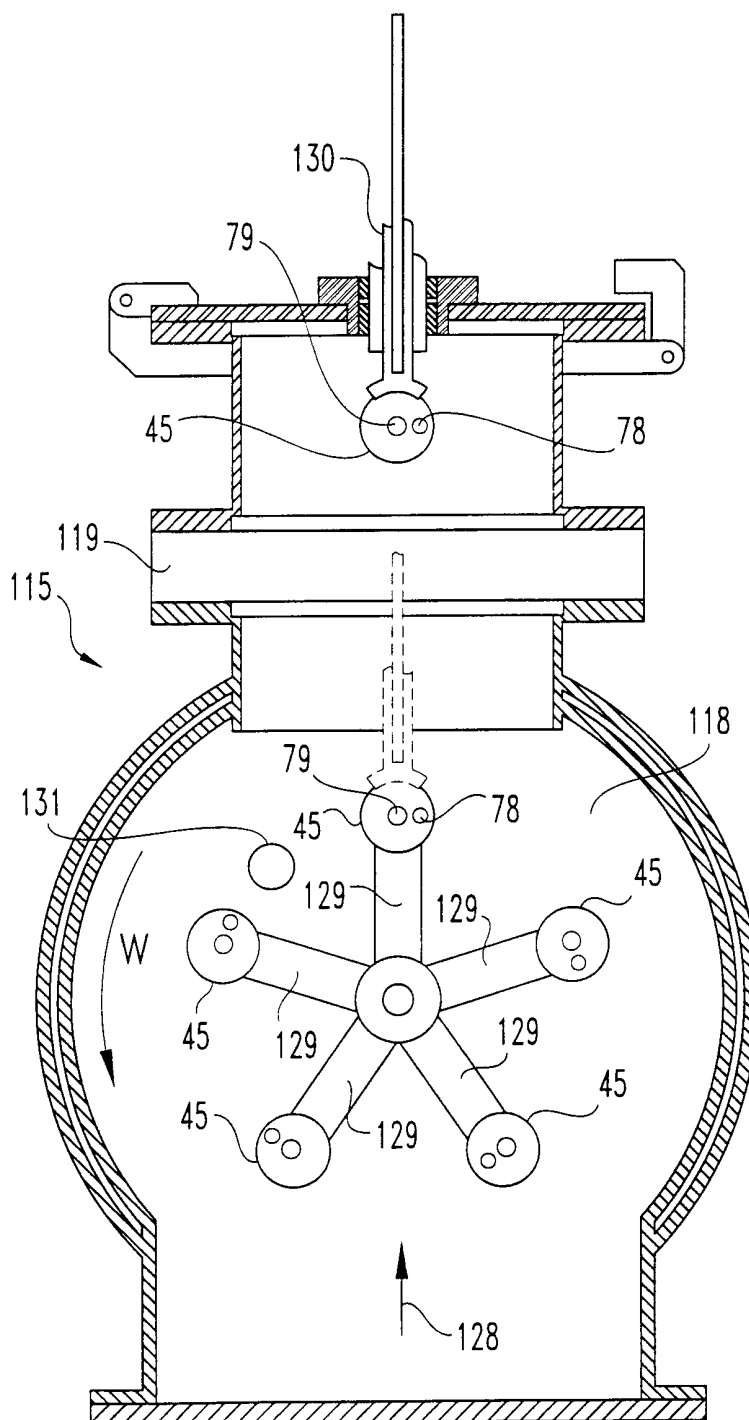


Fig. 10

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**Fig. 12**

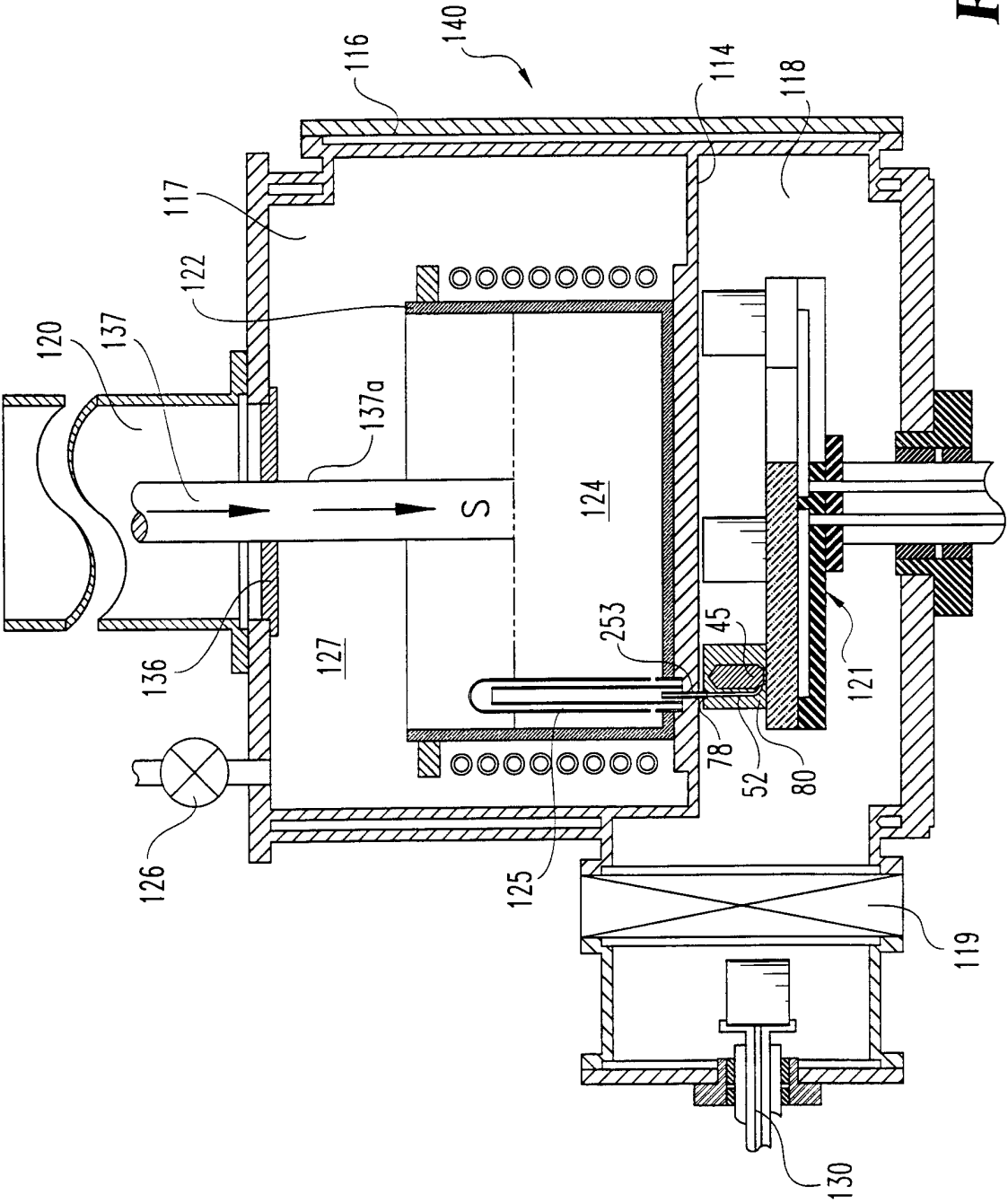
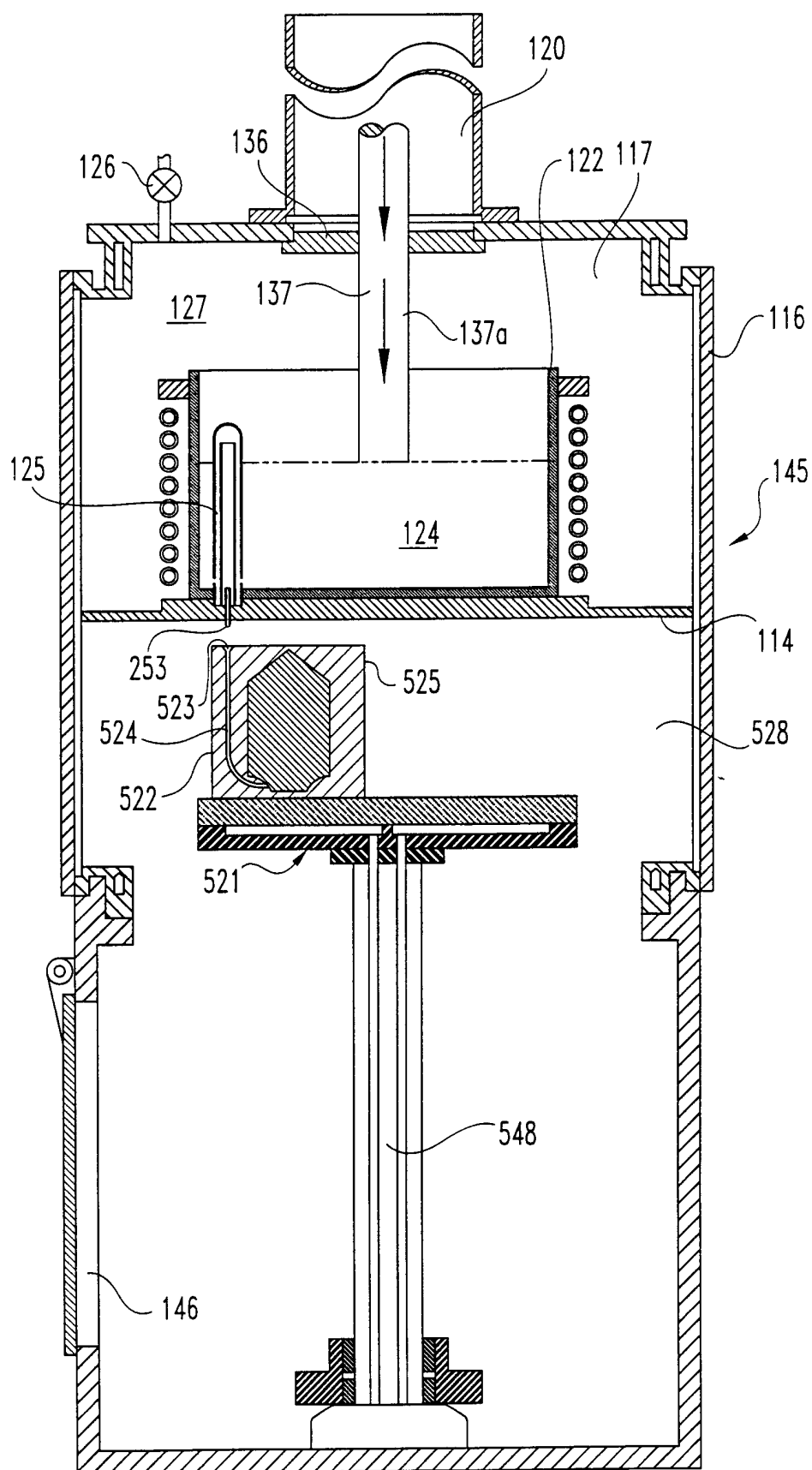


Fig. 14

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**Fig. 15**

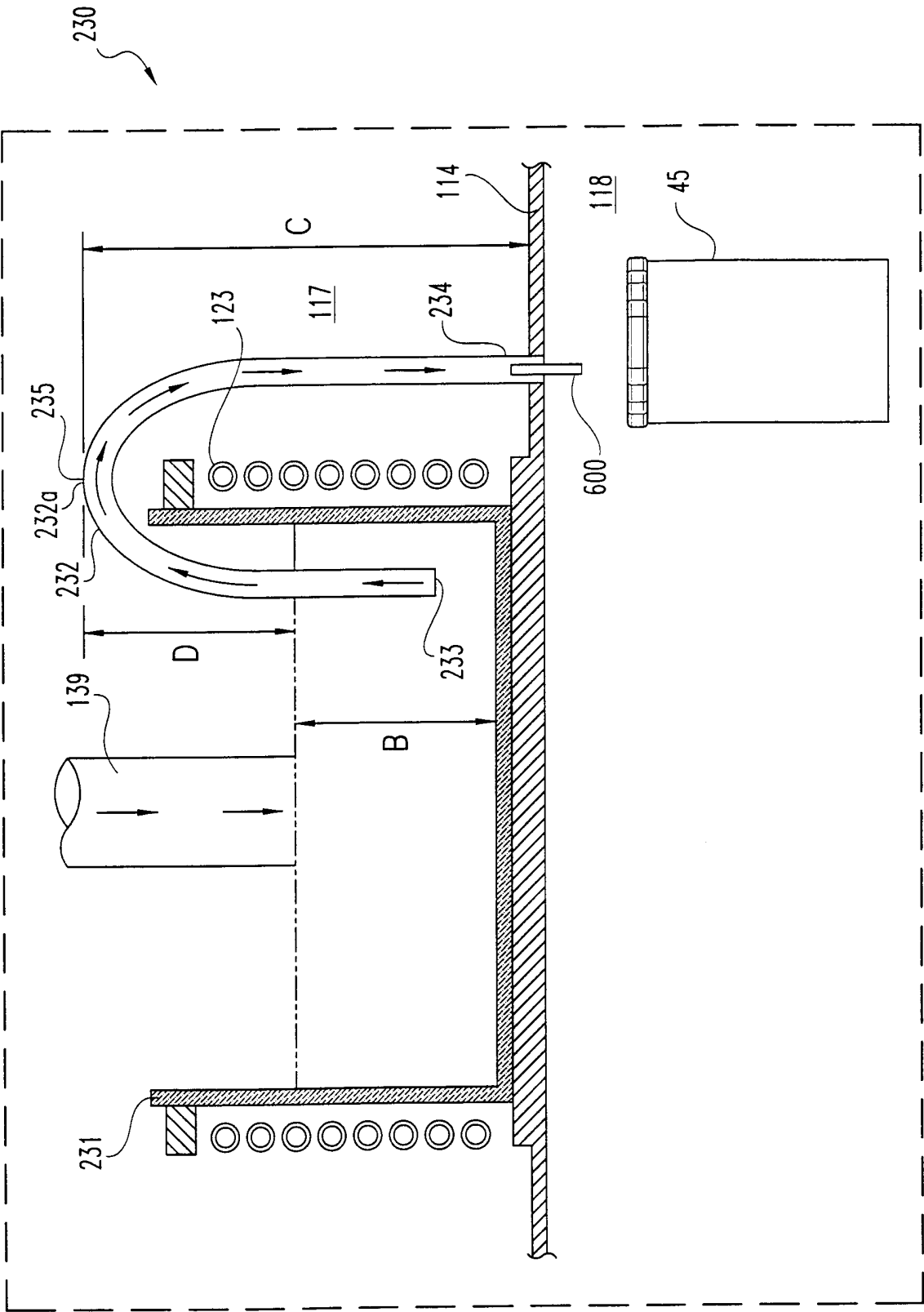
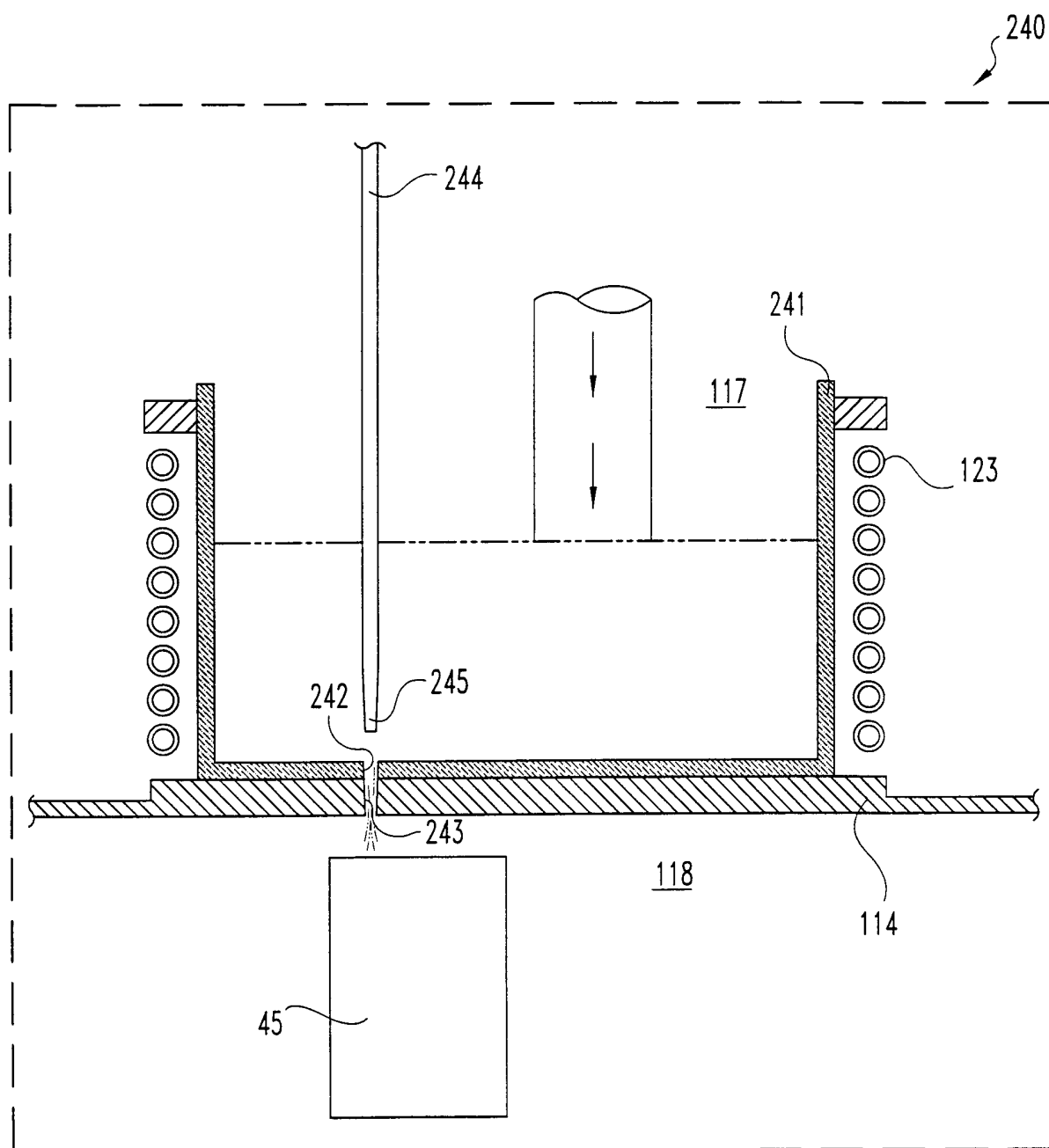
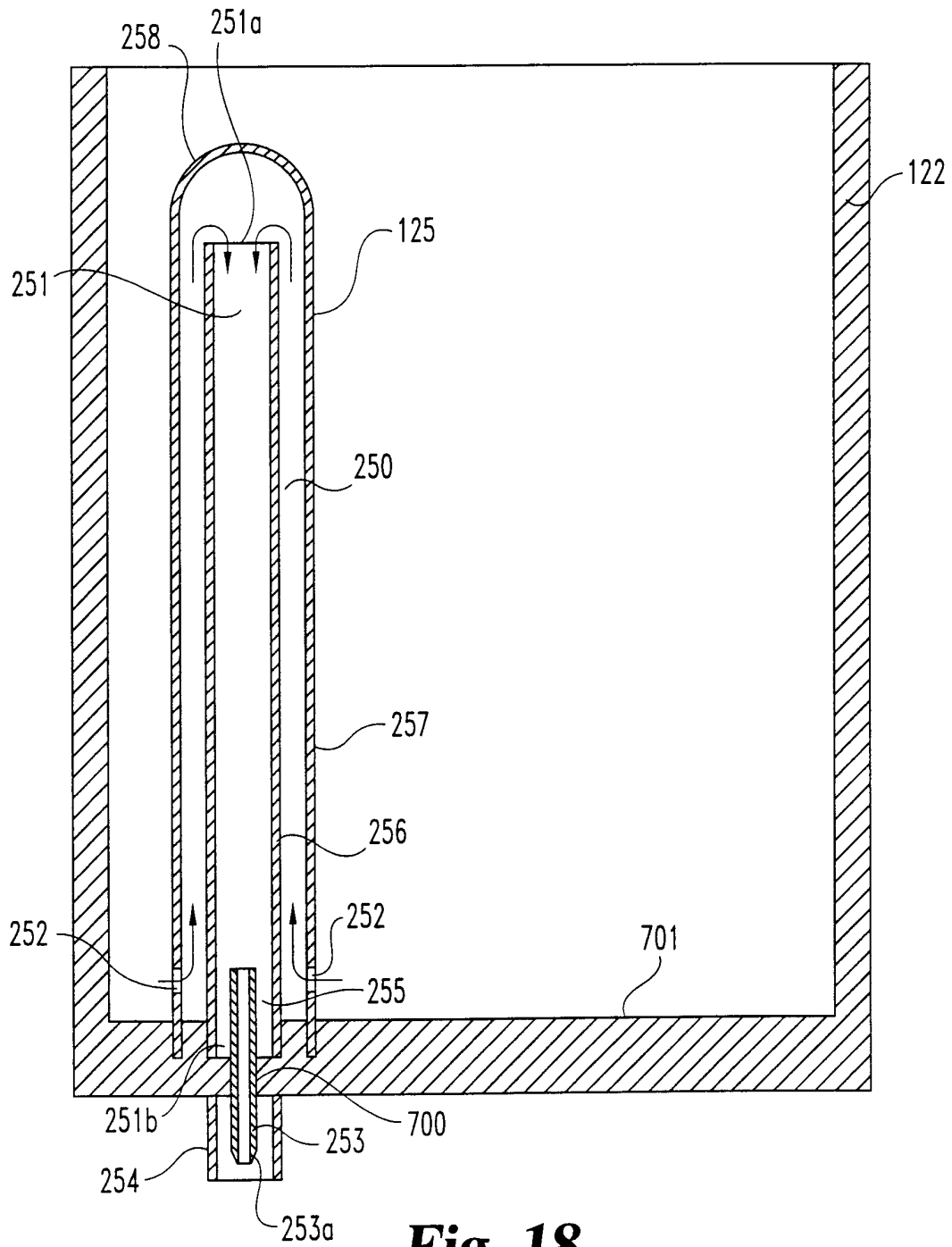
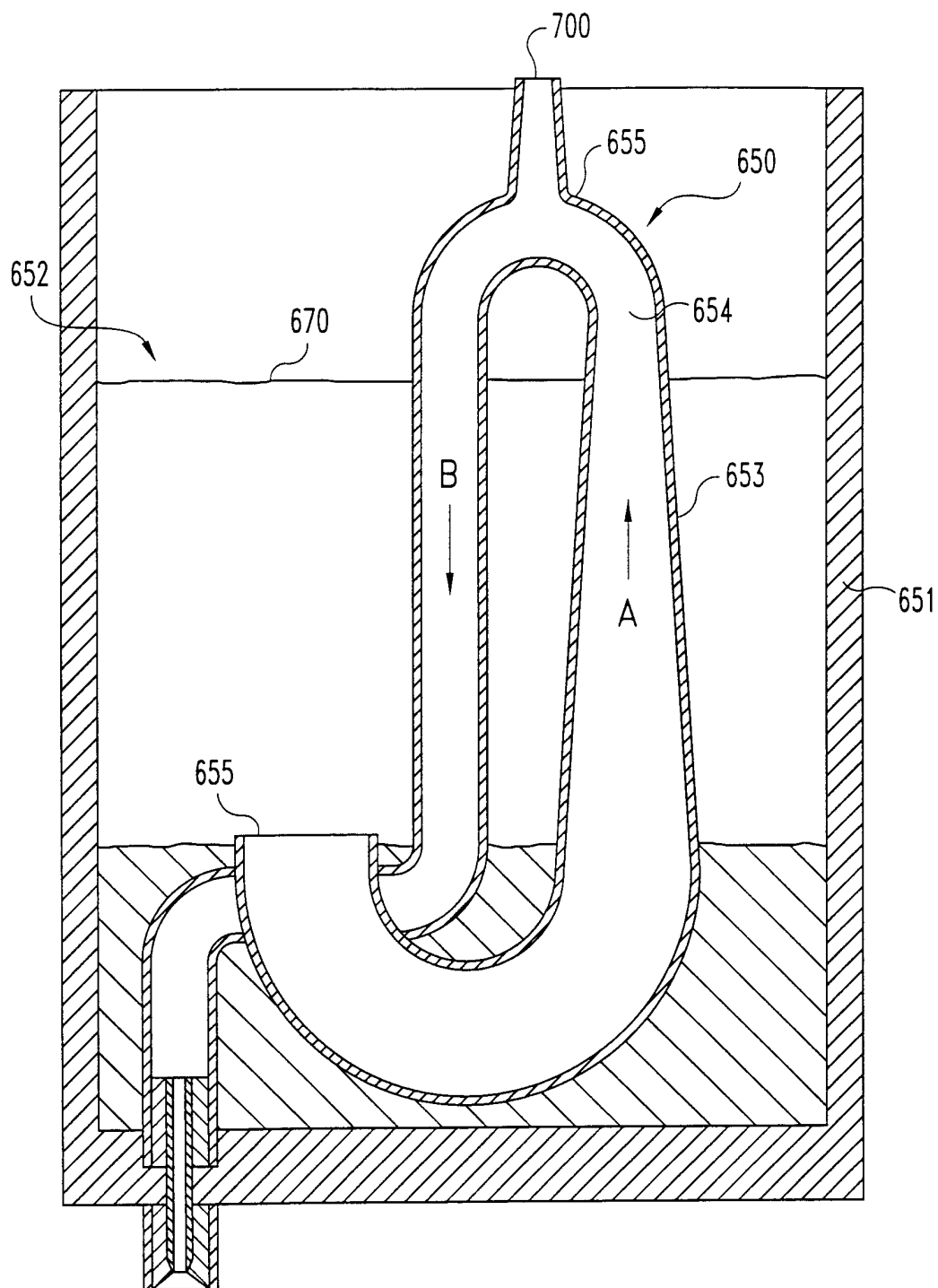


Fig. 16

**Fig. 17**

**Fig. 18**

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**Fig. 19**

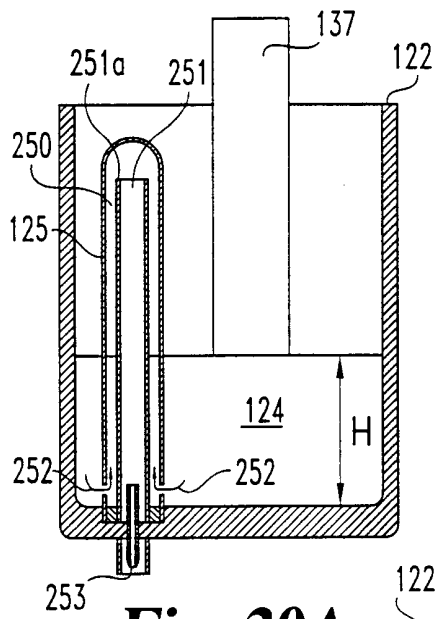


Fig. 20A

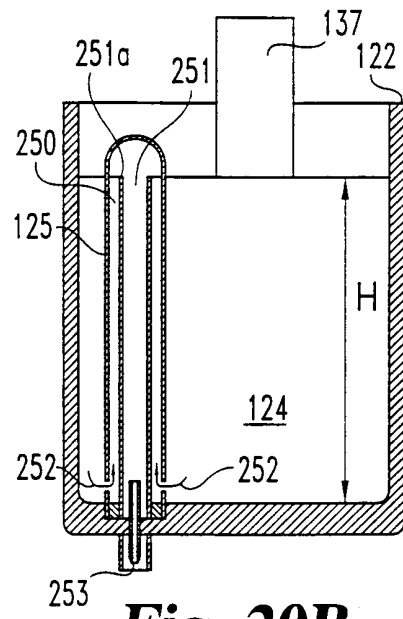


Fig. 20B

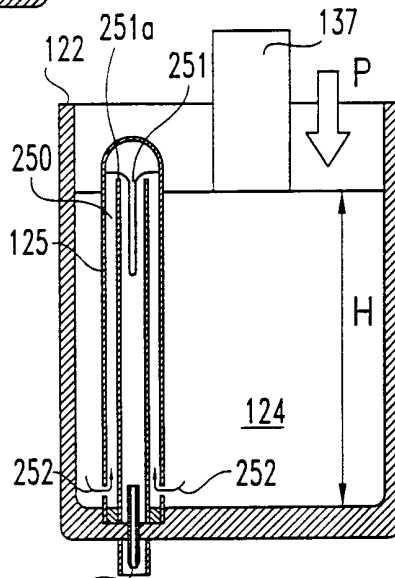


Fig. 20C

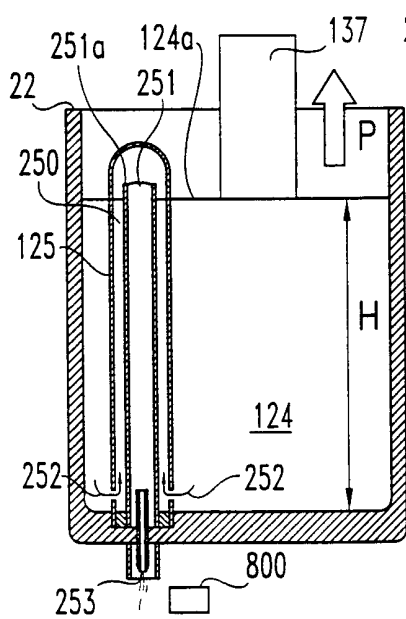


Fig. 20D

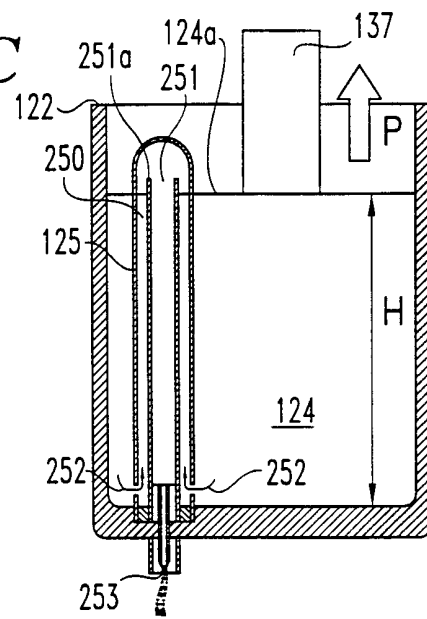
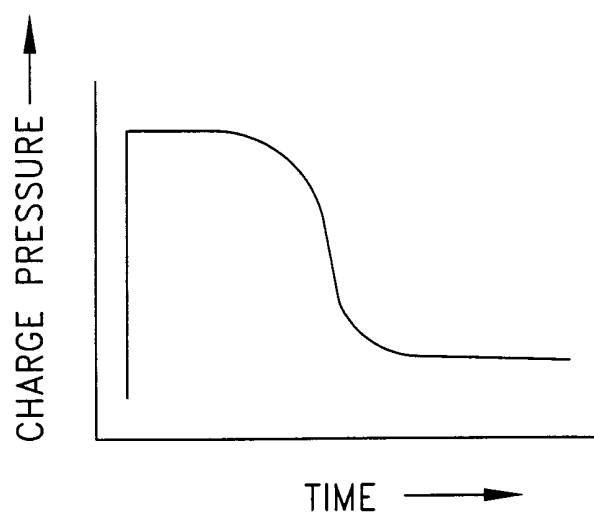
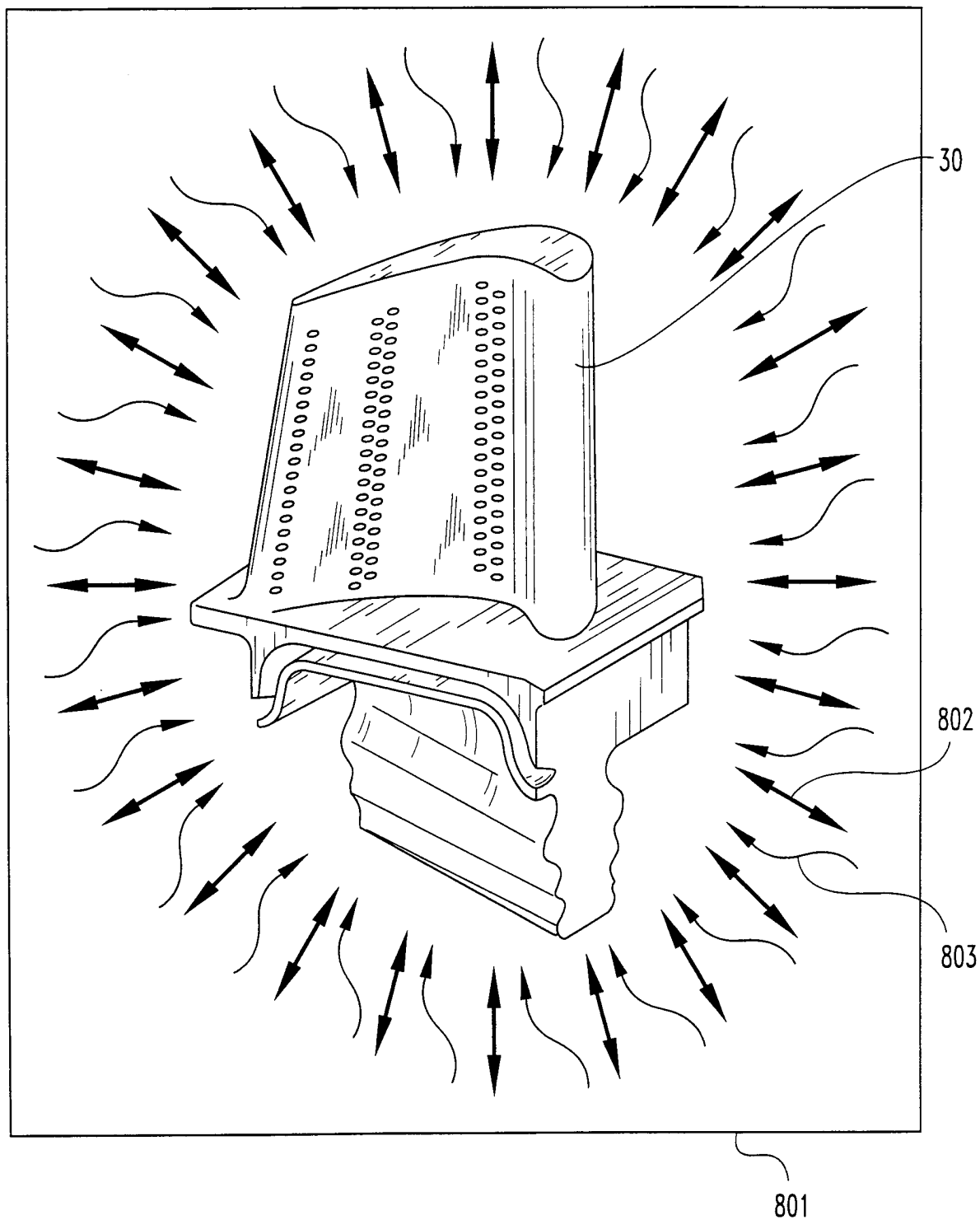


Fig. 20E

***Fig. 21***

**Fig. 22**

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/27469

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B67D 1/04

US CL :222/595

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 222/595, 596, 590, 591; 266/239, 208

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3,608,621 A (BOLLIG et al) 28 September 1971, figure 1.	1-135
A	US 2,185,376 A (MCPARLIN) 02 January 1940, figure 1.	1-135

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
E earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*G* document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 02 MARCH 2000	Date of mailing of the international search report 21 MAR 2000
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer <i>John Kastle</i> SCOTT KASTLER Telephone No. (703) 308-2506