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Carter et al.

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[45] **Sept. 18, 1973**

[54] **PROCESS AND SYSTEM FOR PUMPING MOLTEN METAL**

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[73] Assignee: **Kaiser Aluminum & Chemical Corporation**, Oakland, Calif.

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[52] **U.S. Cl.** **417/50**, 266/38, 310/87, 417/53

[51] **Int. Cl.** **H02n 4/20**

[58] **Field of Search** 266/38; 310/11, 86, 310/87; 417/50, 53

[56] **References Cited**

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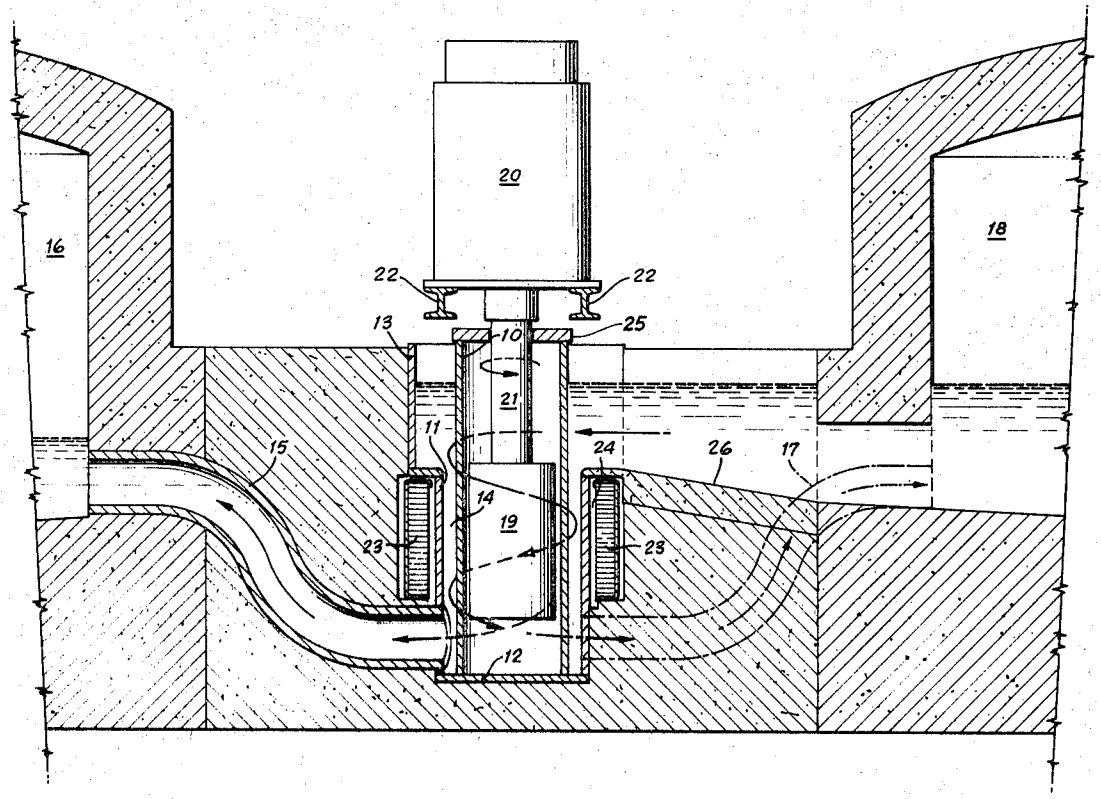
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Primary Examiner—William L. Freeh
Assistant Examiner—John T. Winburn
Attorney—Paul E. Calrow et al.

[57] **ABSTRACT**

This invention relates to an electromagnetic pumping system for molten metal which comprises a device for generating a rotating, helically shaped electromagnetic field which induces downwardly directed molten metal flow in the annular space defined by two concentric upstanding cylindrical surfaces. A preferred embodiment of the invention relates to a process and system for pumping molten metal, wherein one discharge conduit recycles molten metal to a chamber at a predetermined flow rate and when the recycling is completed, the flow rate is substantially increased, thereby pumping metal to a second chamber without increasing substantially the molten metal flow to said first container.

18 Claims, 7 Drawing Figures



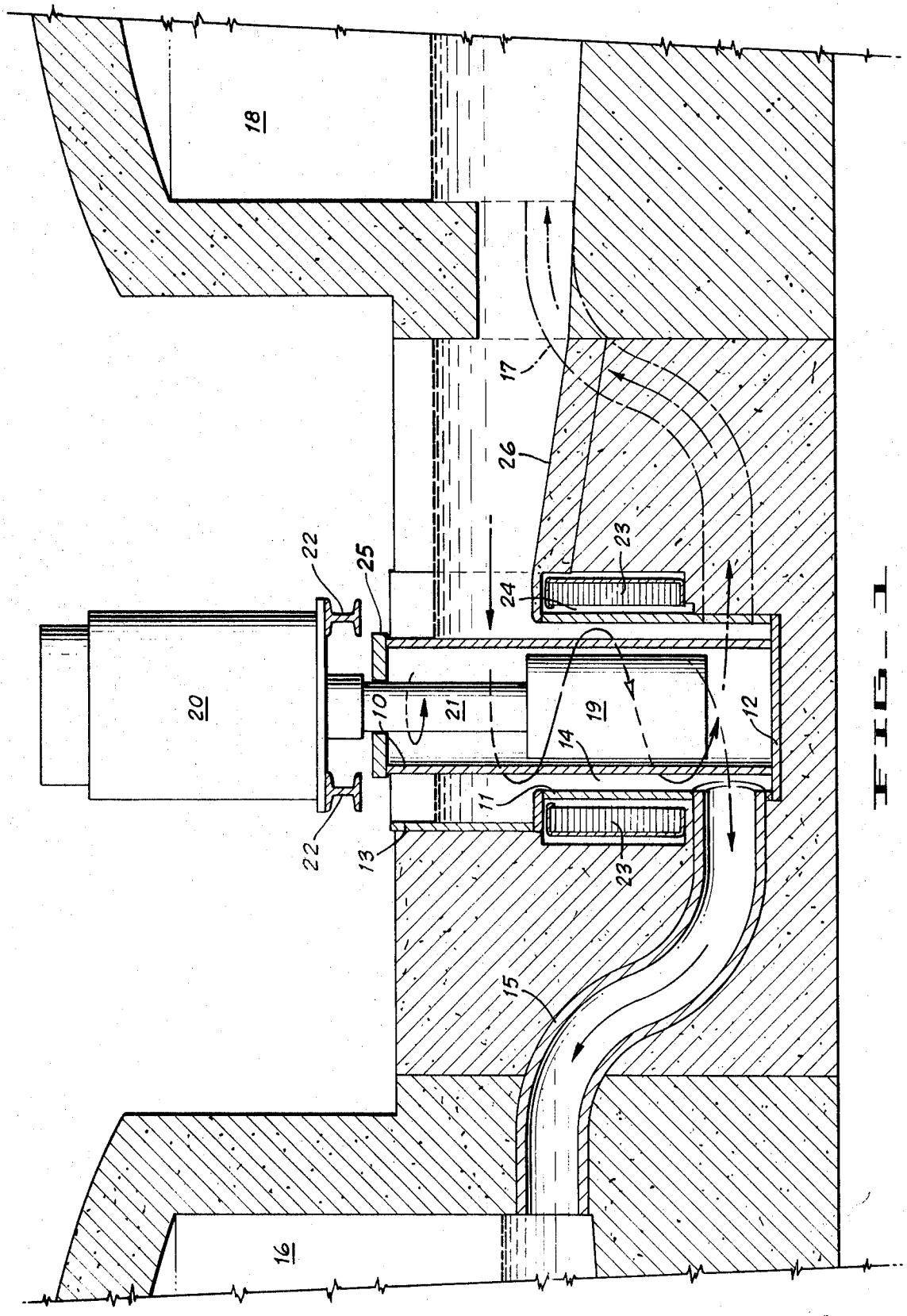


FIG. 1

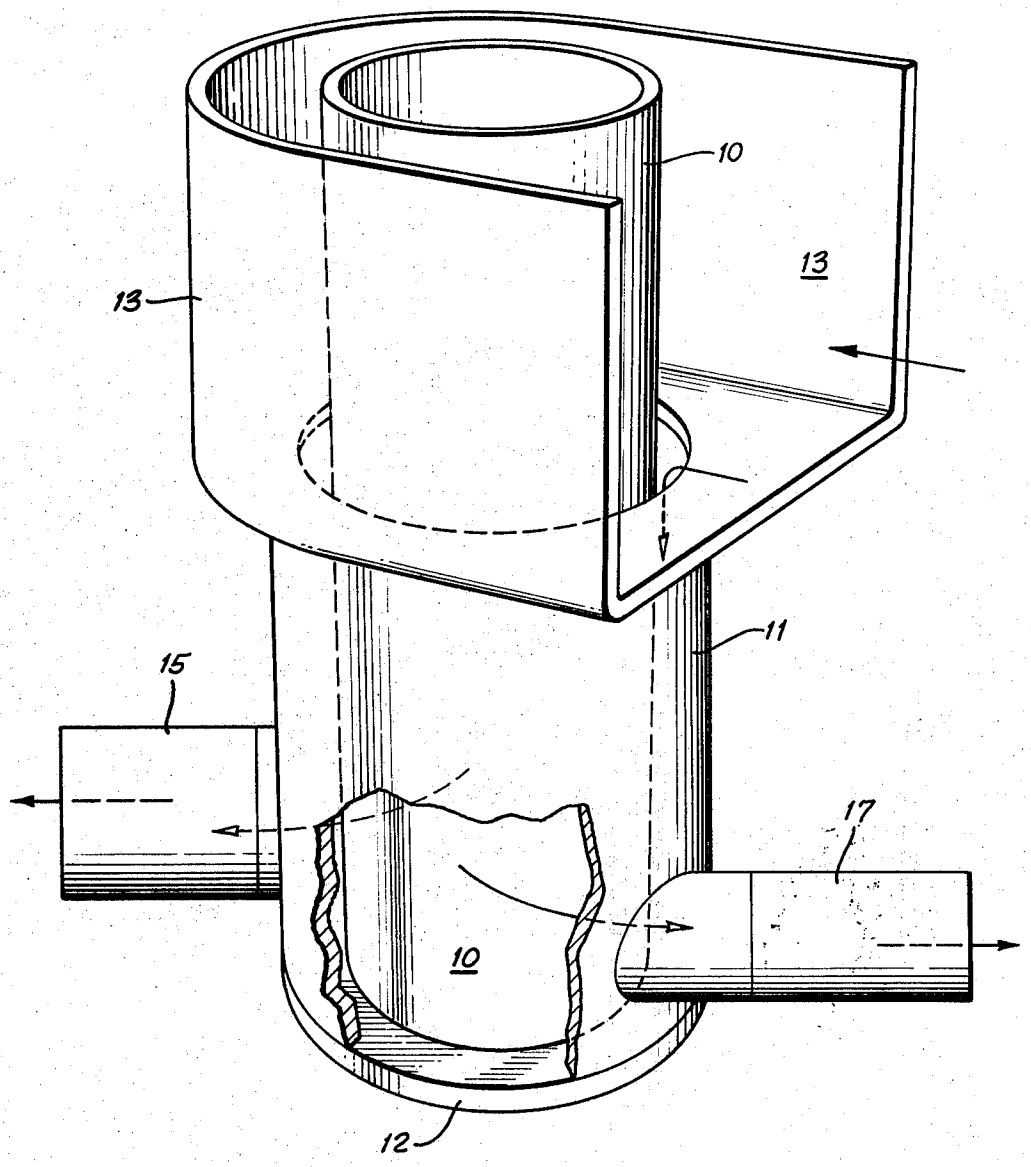


FIG_2

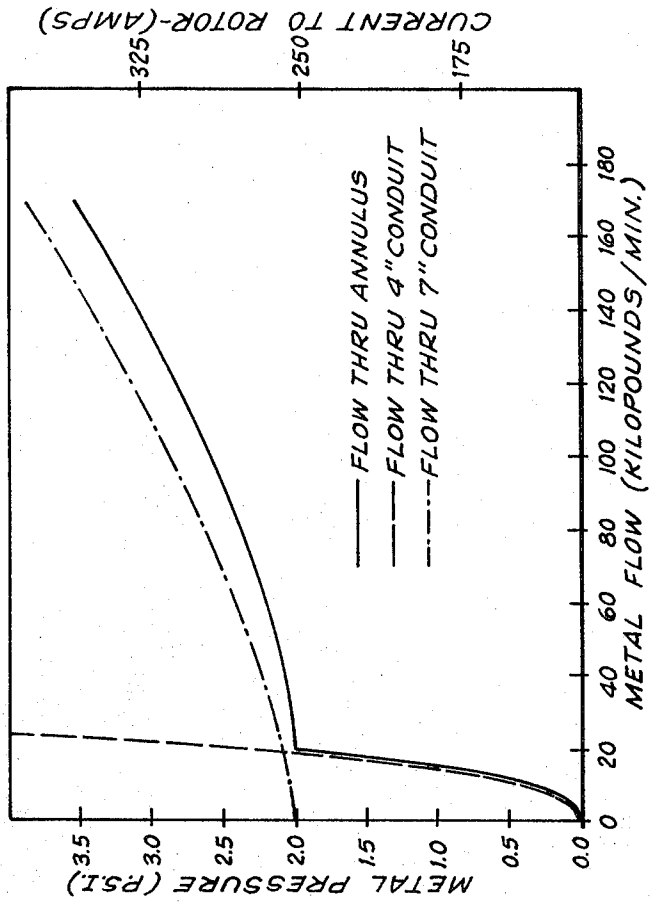

CURRENT TO ROTOR-(AMPS)
325
250
175
FLOW THRU ANNULUS
FLOW THRU 4" CONDUIT
FLOW THRU 7" CONDUIT
METAL FLOW (KILOPOUNDS/MIN.)
0
20
40
60
80
100
120
140
160
180
METAL PRESSURE (PSI)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0

FIG. 2

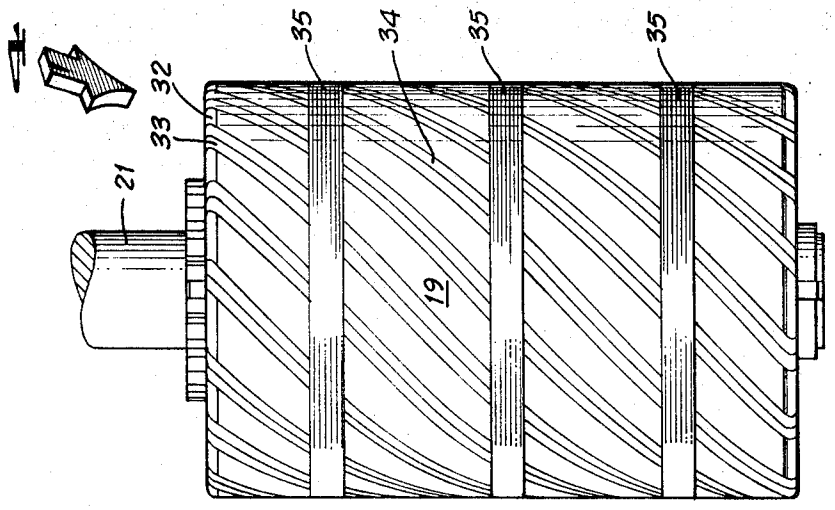

35
34
35
35
32
33
21
19

FIG. 3

FIG_4

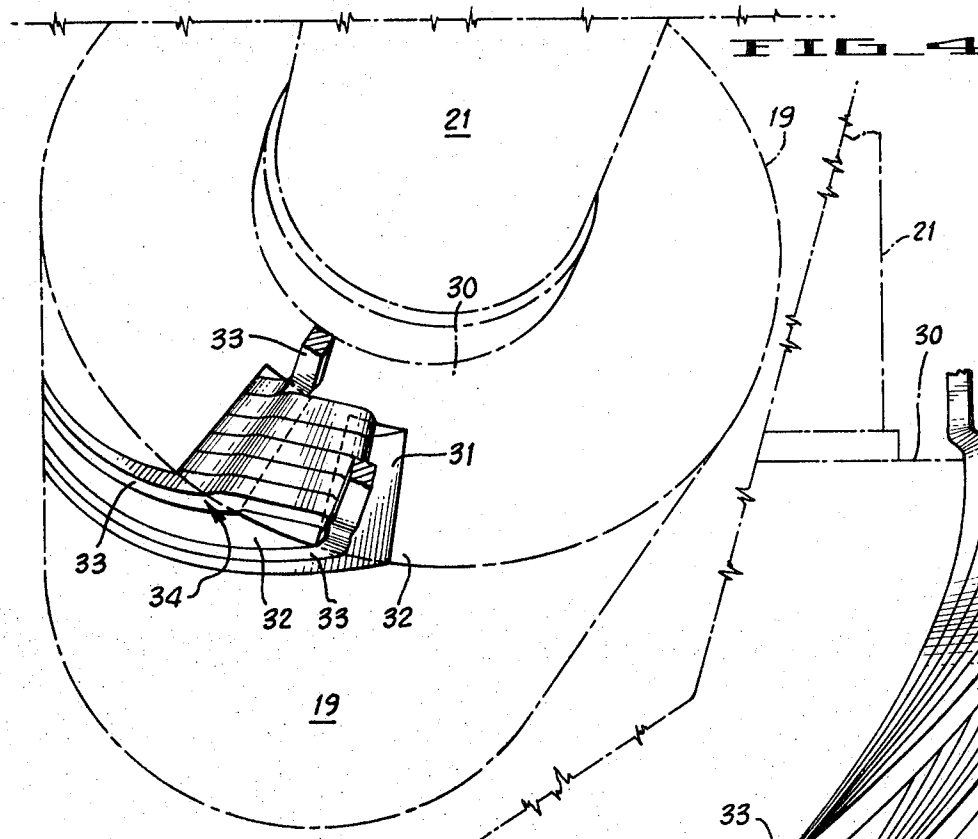


FIG_5

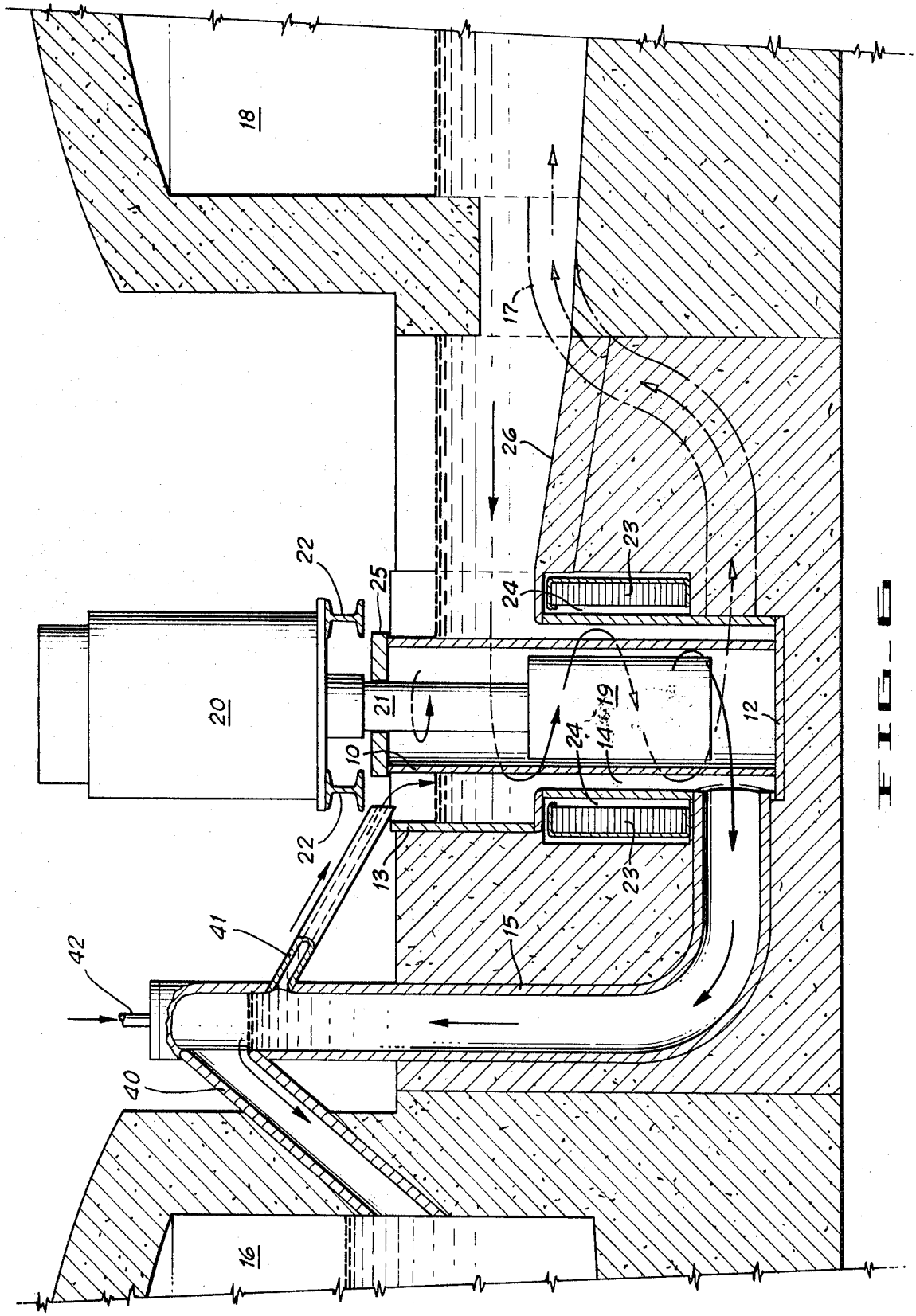


FIG. 6

PROCESS AND SYSTEM FOR PUMPING MOLTEN METAL

BACKGROUND OF THE INVENTION

This invention relates to an electromagnetic pump system for pumping molten conductive materials, particularly molten reactive metals, such as aluminum. Over the years, various types of mechanical and electromagnetic pumps have been used in attempts to pump molten metal. However, these attempts have not met with much commercial success. The mechanical pump presented severe mechanical problems because of the contact of moving parts with a reactive molten metal. Electromagnetic pumps generally were either too expensive or had limited pumping capabilities.

The electromagnetic pump described by Baker in U.S. Pat. No. 3,196,795 was a significant advance in the art because the pump described therein was uncomplicated in design and was capable of efficiently pumping large volumes of molten metal in essentially nonturbulent flow with no moving parts in contact with molten metal. In the operation of the pump described by Baker, the rotor windings are supplied with a direct current which produces a magnetic flux emanating from the rotor poles. The magnetic field penetrates the annulus walls and the molten metal contained therein and returns to an adjacent pole through a flux path. Electromotive forces are induced in the molten metal, as the helical magnetic field rotates with the rotor, causing eddy currents to flow in the molten metal. The interaction of the eddy current field with the magnetic field set up by the rotor windings causes the pumping forces on the molten metal. Efficient molten metal flow results from this pump because the direction of molten metal flow in a helical flow path through the pump is parallel to the driving force. If the molten metal flow is not essentially parallel, molten metal flow will change directions in the presence of a magnetic field causing a braking action with a resultant loss of efficiency. An excellent description and mathematical analysis of this pump is given by R. S. Baker in Atomic Energy Commission Research and Development Report entitled, "Theory, Design and Performance of Helical-Rotor, Electromagnetic Pump" NAA–SR–7455.

However, problems developed in the use of this pump in industrial applications involving the pumping of large volumes of reactive molten metals, such as aluminum. Severe aeration of the molten metal occurred due to the aspiration of air through the joints of refractory members of the pump and the refractory conduits, resulting in the formation of large quantities of oxidized metal or dross. A tenacious layer of nonmetallic carbides and corundum would frequently build up, apparently due to aeration, on the inlet of the annular passageway of the pump restricting metal flow. Backflushing of the pump was normally found inadequate to dislodge the build-up. This build-up, in conjunction with particulate matter, such as carbides, nitrides, refractory particles and other tramp materials, would block the passageway to such an extent that the pump would have to be shut down. Access to remove this build-up by mechanical means was impossible with the pump design of Baker. The refractory life of the pump members was very poor because they are subject to varying thermal stresses during start-up, operation and shut down. This thermal cycling condition, coupled with hydraulic stresses from pumping invariably caused

catastrophic failure of the top flange supported inner annulus refractory member that encased the helical rotor.

Flowing molten metal, particularly aluminum, is very corrosive and erosive and there are few materials which can withstand this environment for extended periods. Silicon nitride or silicon-oxy nitride bonded silicon carbide refractories are two of the few materials other than graphite which can withstand moving molten aluminum for any useful period of time. Conceivably, refractory-coated metallic members could be used, but no such composite materials are presently available which can withstand moving molten aluminum and other reactive metals for the length of time necessary for use of this pump in large foundries.

Against this background, the present invention was developed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of the pumping system of the present invention.

FIG. 2 is a perspective view of the pump members as shown in FIG. 1 with parts exposed for clarification.

FIGS. 3, 4 and 5 are detailed views of the pump rotor shown in FIG. 1.

FIG. 6 is a cross-sectional view of a preferred embodiment.

FIG. 7 is a graph of molten metal flow as a function of the pump discharge pressure and total current for the pumping system shown in FIG. 6.

In all of the Figures, corresponding parts are numbered the same.

SUMMARY OF THE INVENTION

The present invention relates to an improvement in electromagnetic pumps employing a rotating, helical rotor, such as shown in U.S. Pat. No. 3,196,795. The present inventors have found that by inducing a substantially downward flow of the molten metal and by supporting the refractory components of the pump assembly from the bottom portion thereof, the deficiencies of the helical rotor pump can be substantially minimized or eliminated. Moreover, the inventors have developed an improved pumping system and process for transporting molten metal from one container to another while maintaining the capability to recycle molten metal to one of the containers without the use of mechanical valves.

The inventors have found that by pumping in a substantially downward direction, as hereinafter described, essentially the entire pumping system is maintained under positive pressure and no substantial aeration of the molten metal occurs through joints of the refractory members of the pump or the refractory conduits associated therewith. Furthermore, little or no build-up occurs on the surfaces of the members of the pump during pumping operations. Should any build-up occur or should any refractory or tramp particles block the annular passageway of the pump, the present invention provides easy access to this area to remove the obstruction without shutting down and disassembling the pump. The design of the refractory members of the present invention provides for substantially improved service life because all or most of the members are in compression and thus more resistive to thermal cycling than the prior art pumping system.

DETAILED DESCRIPTION OF THE INVENTION

Reference is made to FIG. 1 which depicts a pump system of the present invention. The pump comprises an upstanding, inner member **10** having a substantially cylindrical outer surface. An upstanding outer member **11** is provided having a substantially cylindrical inner surface which is concentric with the outer surface of the inner member and spaced therefrom. Both inner member **10** and outer member **11** are supported in the vertical direction by the bottom surface **12** which may be formed integral therewith. Preferably, the inner member **10** is provided with a collar **25** or other suitable device to apply a force to the inner member to minimize the buoyancy of the molten metal. The collar **25** may be weighted or spring loaded to press the inner member **10** against the support plate **12.** Attached to the upper portion of the outer member **11** is a feed trough **13** which is in fluid communication with the annular space **14** defined by the inner and outer members and also with the container or chamber **18** through conduit **26.** Discharge conduit **15** is attached to the lower portion of outer member **11** and is in fluid communication with the annular space **14** and a container or chamber **16.** One or more additional discharge conduits **17** can be provided as shown in phantom to recycle metal to chamber **18** or other chambers. To minimize turbulence, preferably the discharge conduits are positioned to provide tangential flow from the periphery of outer member **11** and all conduit intake and discharge points are below the molten metal surface. The outer member **11** and conduits are preferably encased as shown in a suitable cast refractory material for insulation and support. The level of the upper portion of the annulus **14** generally must be below a predetermined minimum molten metal level in chamber **18.**

Situated within the chamber of inner member **10** and adjacent to the annular space **14** is a helical rotor **19** which is driven by drive motor **20** through drive shaft **21.** The drive motor **20** is suitably supported by means **22.** The rotor **19** is shown in more detail in FIGS. **3, 4** and **5.** Circumferential to the outer member **11** a flux return **23** is preferably provided to increase the efficiency of the pump. The flux return may be built up from a plurality of laminations of magnetic materials, such as high silicon steel. Preferably each lamination is coated with a suitable insulating material. The flux return may be provided with a plurality of vertical passageways (not shown) and passageway **24** to provide a cooling medium to the flux return to keep the material below the curie point. If, during the operation of the pump, natural convection is not sufficient to maintain the proper temperature, air or other cooling mediums can be forced into the various passageways. A suitable nonmagnetic heat shield (not shown) may be placed on the inner surfaces within the cavity of the inner member **10** or encasing the rotor to protect the rotor from the extreme heat of the molten metal. Preferably, the shaft **21** is hollow to allow a cooling medium, such as air, to be introduced into the cavity of inner member **10** to keep the temperature of the rotor below the curie point of the material.

FIG. **2** is a perspective view with portions removed of the pump members. These members are generally formed of a dense refractory material, such as silicon nitride or silicon-oxy nitride bonded silicon carbide or other molten metal resistive nonmagnetic materials. Preferably, the inner member **10,** outer member **11,** support plate **12** and feed trough **13** are joined into a unitary piece by suitable refractory bonding agents to prevent any leakage of molten metal. Other designs for these members can be utilized, provided that these members are supported from the bottom to maintain the members in compression rather than tension. The inner member **10** and outer member **11** are spaced apart from about 1–3 inches to maintain a large volume flow and for ease in cleaning. Below one inch, the flow rate is too small for large volume pumping operations and the removal of obstructions in the annulus is difficult. Above 3 inches, the efficiency of the pump is severely reduced. The support plate **12** may be sloped in the direction of a tap hole (not shown) in the outer member **11** to allow the pump system to be drained when the pump is not in operation.

Reference is made to FIGS. **3, 4** and **5** which illustrate a rotor construction. The rotor body **30** formed of magnetic material, such as mild carbon steel, is generally of cylindrical shape having a plurality of helically shaped grooves **31** in the periphery thereof, preferably at an angle of 45° with the rotor axis, to form a plurality of poles **32.** An electrical conductor **33,** such as nickel-plated copper, is wrapped around each pole one or more times as shown in the drawings to form each field winding **34.** The number of turns depends upon the magnitude of magnetic flux desired. Each field coil is electrically connected in parallel with an electrical source through means, such as slip rings (not shown), so as to have adjacent field poles of opposite polarity, and preferably the current to each of the field coils is maintained at essentially the same level. The conductors forming the field windings usually are wrapped with an insulating material. Bands **35** encircle rotor **19** to maintain the field coils in position during the rotation of the rotor. In the operation of the pump, metal flow rates can be controlled by adjusting the rotor speed, the current to the field windings (to vary the magnetic field), or both. The most convenient method is to maintain a constant rotor speed and vary the current to the windings. For most applications, the rotor speed can range from about 20–3,000 rpm, and the total current can range from about 10–500 amps. The rotor speed and total current employed will depend on pump output requirements. The rotors shown herein are designed to rotate in a counterclockwise direction to effect the helical flow of the metal in a downward direction as indicated in the drawings. Downward helical flow with clockwise rotation can be effected if the field coils are positioned 90° from that shown in the drawings and the rotation is reversed.

FIG. **6** is a cross-sectional view of another embodiment of the present invention. As shown in FIG. **6,** the pumping system is essentially the same as shown in FIG. **1.** Discharge conduit **15,** however, extends above the level of the molten metal in trough **13** and discharges through conduit **40** into a container or chamber **16** at some point above this level. If desired, a conduit **41** can be provided to recycle molten metal from the discharge conduit **15** to the feeding trough **13** or another container, such as chamber **18,** to maintain the metal within conduit **15** in a molten state. The outlet from discharge conduit **15** to conduit **41** must be below the discharge level of conduit **15** into chamber **16.** The discharge portion of conduit **15** may be provided with an inert gas through conduit **42** to prevent the oxida-

tion of the metal during transfer. As indicated in the figure, the cross section of the conduit **15** is considerably greater than the cross section of conduit **17.** The cross sections of the various conduits and the height of the discharge opening in conduit **16** are designed to provide the desired flow rates relative to pump capacity.

In the operation of the pumping system shown in FIG. **6,** the rotor **19** is rotated at a predetermined speed and a current is passed through the helical coils at a particular level so as to transport molten metal from chamber **18** through the feed trough and pump and back into chamber **18** through conduit **17.** The molten metal will rise in conduit **15** to the discharge opening to chamber **16.** The height of the discharge opening is selected to maintain little or no flow of molten metal into chamber **16** during this period. Preferably, when molten metal is being recycled to chamber **18,** molten metal is returned to the feed trough **13** from conduit **15** through the conduit **41** to maintain the metal in a molten state. When the recycling of the molten metal into chamber **18** is completed, the molten metal flow through the annulus is increased substantially by increasing the rotor speed, increasing the current to the field windings, or both, as described before. With the increased molten metal flow, the molten metal begins to discharge into chamber **16.** However, the flow through conduit **17** is not substantially increased with this increased metal flow. When the desired amount of molten metal has been transferred to chamber **16,** the pump output is reduced a sufficient amount, preferably by reducing the current to the windings, to cease metal flow to chamber **16.**

An example of the flow rates of this embodiment is given in the graph of FIG. **7** wherein molten metal flow (aluminum) is plotted versus pump discharge pressure and total current. In this particular embodiment, conduit **15** was designed to have a 7 inch diameter and conduit **17** a 4 inch diameter. The height of the discharge opening to chamber **16** was 20 inches above the molten metal level of the feed trough. The rotor speed was 860 revolutions per minute. With an initial total current of 250 amps to the field windings, the molten metal flow rate to chamber **18** was 20,000 lbs/min, whereas the flow rate to chamber **16** was nil. By increasing the total current to the field windings to 300 amps, the pump discharge pressure increased from 2 to 2.5 psi and the molten metal flow rate to chamber **16** was increased to approximately 65,000 lbs/min. The flow rate to chamber **15,** however, increased only to about 23,000 lbs/min.

The embodiment shown in FIG. **6** is extremely useful in pumping molten metal from a mixing or heating hearth to a holding hearth. The mixing or heating hearth, such as chamber **18,** is used to melt the metal, such as aluminum, and to adjust the composition to the desired limits. The recycling feature is advantageous in thoroughly mixing the molten metal in chamber **18** to provide a melt of homogeneous composition. When the alloying or mixing is complete, substantial quantities of molten metal can be quickly transported to a holding hearth, such as chamber **18,** which may be used to hold the molten metal prior to casting.

Various modifications and improvements can be made to the invention described herein without departing from the spirit of the invention and the scope of the appended claims.

What is claimed is:

1. A molten metal pumping system comprising

a. an upstanding inner member formed of molten metal resistive material having a substantially cylindrical outer surface which is supported in the vertical direction on the bottom portion of said member by a support surface,

b. an outer member formed of molten metal resistive material having a substantially cylindrical inner surface concentric with the outer surface of said inner member and defining an annular space therebetween, said outer member being supported on the bottom portion thereof by said support surface and thereby closing the lower end of said annular space,

c. a feed trough attached to the upper portion of said outer member, said trough adapted to feed molten metal to said annular space and said trough in fluid communication with a container,

d. at least a first discharge conduit attached to the lower portion of said outer member, said first conduit in fluid communication with said annular space and with a container,

e. a circumferentially extending flux return path means associated with said outer member, and

f. means within said inner member to generate a rotating, helically shaped electromagnetic field resulting in molten metal flow in a downward direction in said annular space.

2. The pumping system of claim **1** in which the means to generate a rotating, helically shaped electromagnetic field comprises a magnetic, cylindrically shaped body having a plurality of helically shaped grooves in the periphery thereof forming a plurality of poles, and an electrical conductor wrapped at least one time around each of said poles to form field windings, said field windings adapted to be electrically connected to a direct current source whereby adjacent poles have opposite polarity.

3. The molten metal pumping system of claim **1** in which at least one discharge conduit is oriented with said outer member to provide for substantially tangential molten metal flow.

4. The pumping system of claim **1** wherein said concentric surfaces of said inner and outer members are spaced apart from about 1–3 inches.

5. The pumping system of claim **1** wherein means are provided to press said inner member against said support plate.

6. The pumping system of claim **1** wherein said inner member, outer member, feed trough and support plate are formed of a refractory material selected from the group consisting of silicon nitride bonded silicon carbide and silicon oxynitride bonded silicon carbide.

7. The pumping system of claim **6** wherein said inner member, outer member, feed trough and support plate are joined in a unitary piece.

8. The molten metal pumping system of claim **1** wherein at least a second discharge conduit is attached to the lower portion of said outer member and is in fluid communication with said annular space defined by said inner and outer members, the cross section of one of said conduits being substantially greater than said other discharge conduit, said conduit having the greater cross section extending above the molten metal level in said feed trough and in fluid communication with a first container and adapted to discharge molten

metal therein and said conduit having the lesser cross section in fluid communication with a second container and adapted to discharge molten metal therein.

9. The molten metal pumping system of claim **8** wherein said conduit having the greater cross section is provided with a discharge conduit, said discharge conduit in fluid communication with the feed trough to thereby recycle molten metal to the feed trough and maintain metal in said conduit having the greater cross section in a molten state.

10. The molten metal pumping system of claim **8** in which said discharge conduit having the smaller cross section is in fluid communication with the container with which the feed trough is in fluid communication.

11. A process of transporting molten metal comprising

a. withdrawing molten metal from a first container,

b. feeding said molten metal to the upper portion of an annular space defined by two upstanding members through a feeding trough attached to the outermost member,

c. inducing substantial downward molten metal flow within said annular space by generating a rotating, helically shaped electromagnetic field of a predetermined magnitude,

d. directing said downwardly moving metal in said annular space to two conduit means, a first conduit means having a cross-sectional area substantially greater than the second conduit means and having at least one discharge opening above the level of the molten metal being fed to said annular space, and

e. discharging at least substantially all of said downwardly moving molten metal from said smaller conduit into said first container.

12. The process of claim **11** wherein at least a portion of the metal in said first conduit means is returned to the feed trough from a second discharge opening in said first conduit positioned below said first discharge opening above the molten metal level in said feed trough, thereby maintaining the metal in said first conduit means in a substantially molten state.

13. The process of transporting molten metal of claim **11** wherein

a. the magnitude of the electromagnetic field is increased to substantially increase the molten metal flow in a downward direction, and

b. discharging at least a portion of said molten metal in said first conduit through a discharge opening into a second container.

14. The process of claim **11** wherein

a. the rotational speed of the helically shaped electromagnetic field is increased to increase the molten metal flow in a downward direction, and

b. discharging at least a portion of said molten metal in said first conduit through a discharge opening into a second container.

15. The process of claim **11** wherein said rotating helically shaped electromagnetic field is generated by rotating a substantially cylindrical shaped magnetic body having a plurality of helically shaped grooves on the periphery thereof forming a plurality of poles, and having a conductor wrapped at least one time around each of said poles, said conductor electrically connected to a direct current source.

16. A process of preparing and transporting a homogeneous melt of molten metal comprising

a. providing a supply of molten metal in a first chamber,

b. withdrawing molten metal from said first chamber,

c. feeding said molten metal to the upper portion of an annular space defined by two upstanding refractory members through a feeding trough attached to the outermost upstanding member,

d. inducing downward molten metal flow within said annular space by generating a rotating helically shaped electromagnetic field of a predetermined magnitude,

e. directing said downwardly moving molten metal in said annular space to two conduits, a first conduit having a cross-sectional area substantially greater than the second conduit, said first conduit extending above and having at least one discharge opening above the level of molten metal in said feed trough,

f. discharging substantially all of said downwardly moving molten metal from said second conduit into said first chamber until a melt of the desired homogenuity is obtained in said first chamber,

g. increasing the magnitude of the rotating helically shaped electromagnetic field, thereby sufficiently increasing the molten metal flow through said annular space to discharge molten metal from the discharge opening in said first conduit,

h. discharging molten metal from said discharge opening in said first conduit to a second chamber until a desired amount of molten metal is transported into said second chamber, and

i. decreasing the magnitude of the electromagnetic field to thereby cease molten metal flow to said second chamber.

17. The process of claim **16** wherein molten metal is returned from said first feed conduit to the feed trough.

18. The process of claim **16** wherein the molten metal is aluminum.

* * * * *