METHOD OF CASTING FUSIBLE MATERIALS

Filed Nov. 19, 1964

Fig. 1.

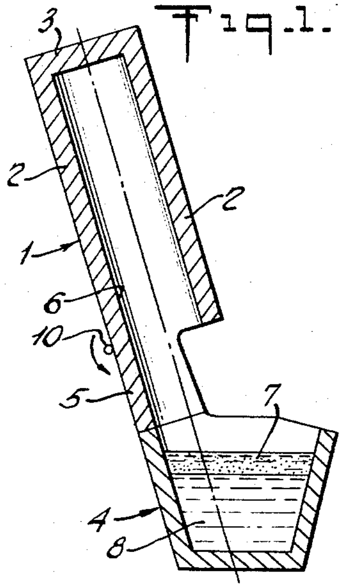


Fig. 2.

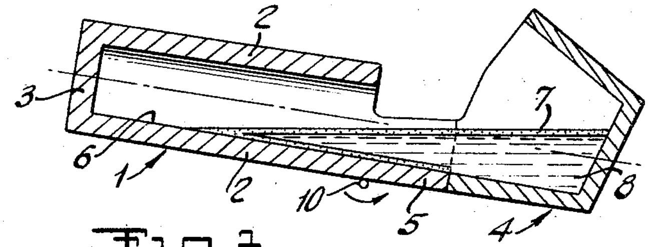


Fig. 3.

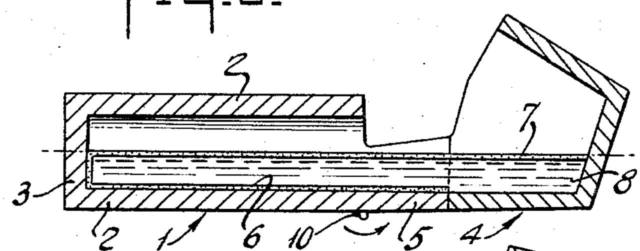


Fig. 4.

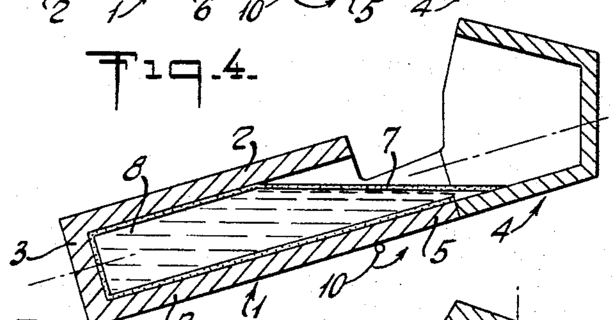


Fig. 6.

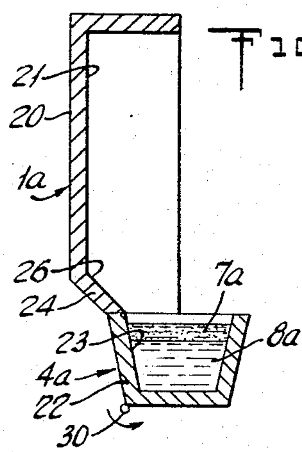
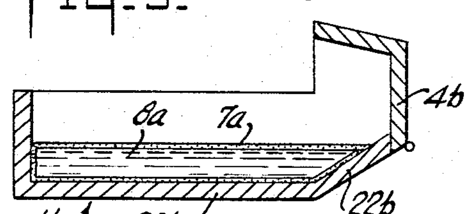


Fig. 9.



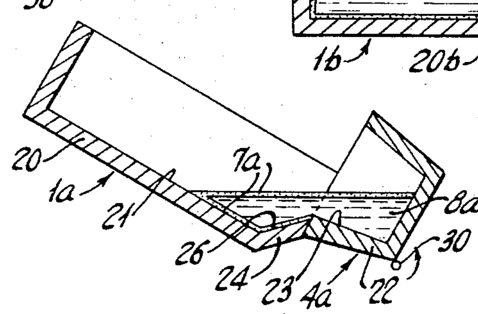
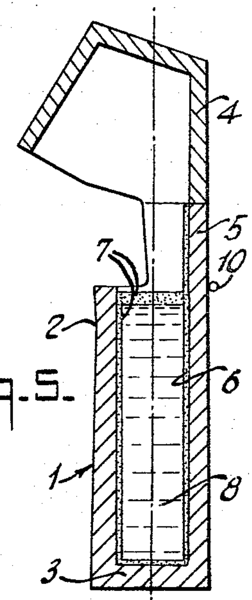


Fig. 7.

Fig. 5.



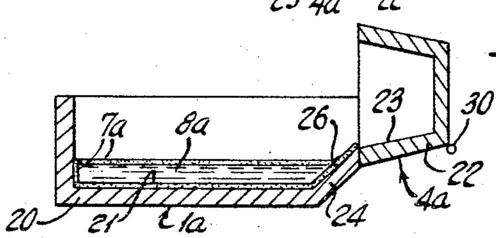


Fig. 8.

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METHOD OF CASTING FUSIBLE MATERIALS

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The present invention relates to a method of casting and in connection therewith, employs some of the basic principles employed in the invention shown and claimed in my U.S. Patent No. 3,151,366 issued Oct. 6, 1964.

In conventional processes for casting such fusible materials as metals, glass and plastics, employed prior to the advent of the aforesaid patented invention, the molds used for such casting have remained completely solid during the casting operation. In accordance with the process disclosed in the aforesaid patent, the fusible material is cast in contact with a surface formed by a mold or retaining material, which lines a backing material in the form of a solid mold body or matrix and which partially melts during the casting operation. This fusible mold material has thermal conductivity lower than that of the backing material in the walls of the solid mold body or matrix which it lines, and a melting point below the solidification temperature of the fused material to be cast, and solidifies the fused material to be cast by withdrawing heat through the matrix or mold body walls at a rate which prevents the complete fusion of the mold material. This departure from prior casting practice affords major advantages set forth in the aforesaid patent.

In certain known casting processes, the liquid metal or other material to be cast is poured from a height into the mold in the form of a stream. This creates eddies in the poured material and intermingles the fluid mass with slag and other nonmetallic substances, as well as with air, thereby creating ingots having metallurgical defects.

In the U.S. Durville Patent No. 1,189,548, there is disclosed an apparatus and process for avoiding the disadvantages attending the pouring of metal or other materials to be cast into a mold and for casting ingots or shapes of such material in homogeneous form free from blow holes and slag. In accordance with the process disclosed in this patent, the metallic liquid is first introduced into a reservoir and is then transferred from said reservoir into the mold without any change of altitude. The surface of the metallic liquid in the reservoir and in the mold remains horizontal throughout and there is no real pouring of the liquid mass of metal but only a change in the position assumed by the metallic liquid, without any change of direction on the part of the metallic surface. By means of this method, the casting process can go on very quickly and since there is no fall, and the surface of the liquid remains in the same position throughout, no intermingling of the metallic liquid with slag or other oxidizing particles, or with air, occurs.

The apparatus for carrying out the Durville process consists of a combined reservoir and mold, the two being rigidly attached together in such a way or so related that the outpour surface of the reservoir and the inpour receiving surface of the mold lie substantially in the same straight line.

One object of the present invention is to apply some of the principles of my invention described in the aforesaid Patent 3,151,366 to some of the principles of the Durville invention described above, to attain not only the benefits and advantages derived from employing these principles separately, but to attain additionally new results derived from using these principles in combination.

In accordance with the present invention, a combined reservoir and mold forming an integrated unit has applied

thereto a fusible mold or retaining material of the character described in my aforesaid Patent 3,151,366. This fusible mold material has a specific gravity lower than that of the material to be cast, and therefore, forms a liquid layer which floats on the surface of the fused material to be cast contained in the reservoir. While the material to be cast is in the reservoir, it is covered by the fused layer of mold material. Casting is effected by tilting the reservoir-mold unit through an angle to cause the liquid material to be cast to pass from the reservoir to the mold. During this transport operation, the fused layer of mold material flows ahead of the material to be cast, to line the mold, so that the fused material to be cast transferred to the mold will be encompassed by the fusible mold material. The excess mold material forms a liquid layer, which floats on the surface of the material being cast, thereby improving the surface quality of the casting and effecting other benefits to be described.

Various other objects, features and advantages of the present invention are apparent from the following description and accompanying drawings, in which

FIGS. 1–5 inclusive show in section a form of reservoir-mold unit in different successive angular positions for carrying out one embodiment of the process of the present invention;

FIGS. 6, 7 and 8 show in section another form of reservoir-mold unit in different successive angular positions for carrying out another embodiment of the process of the present; and

FIG. 9 shows in section still another form of reservoir-mold unit illustrated in final casting position.

The apparatus shown in FIGS. 1–5 consists of a mold **1**, having walls **2** on all sides and a wall **3** at the end, a reservoir **4**, and a connecting channel **5** arranged between the mold and the reservoir. The reservoir-mold unit described is shown made of parts rigidly joined together to form the unit.

The relative arrangement of parts **1**, **4** and **5** of the reservoir-mold unit is such, that along the internal edge **6**, they conjointly define a straight flat surface along which the material to be cast is transported from the reservoir **4** to the mold **1** with minimum of turbulence, as the unit is tilted.

In following the process of the present invention, while the reservoir-mold unit is in position shown in FIG. 1, with the reservoir **4** at the bottom, a layer of fusible mold material **7** is introduced into the bottom of said reservoir. The molten metal or other fused material **8** to be cast is then introduced into the reservoir **4** over the layer of fusible mold material **7**, and since this mold material (1) is immiscible with the molten material to be cast, (2) is in liquid form or has become liquid by contact with the hot material **8** to be cast, and (3) is of a density lower thant that of the material **8** to be cast, the introduction of the material **8** to be cast into the reservoir will cause the fused mold material **7** to rise and to form a top liquid layer over the surface of the material **8** to be cast in said reservoir, as shown in FIG. 1.

Instead of placing a layer of the mold material in the empty reservoir and then introducing the material **8** to be cast over it as described, the material **8** may be introduced into the empty reservoir **4**, and then a layer of the mold material **7** floated on the surface of said material **8** to be cast. In either situation, a layer of liquid mold material **7** is formed over the surface of the fused material **8** to be cast.

As the reservoir-mold unit is tilted about a fixed axis **10** to transfer the material **8** to be cast from the reservoir **4** to the mold **1**, the liquid material **8** retains its horizontal surface in all positions of the unit, until this material takes up the final position shown in FIG. 5 inside the mold

1, where it is able to solidify into the form of an ingot. As this transfer of the liquid material 8 to be cast from the reservoir 4 to the mold 1 takes place, the top layer of mold material 7 in liquid form flows ahead of the material 8 and progressively flows along the walls of the mold 1 and solidifies thereon before this material 8 reaches said walls as shown in the progressive steps of the tilting action illustrated in FIGS. 1–5, causing said mold material 7 to line the walls of said mold, and the excess mold material to form a covering top liquid layer, as shown in FIG. 5. The layer of mold material 7 in contact with the walls of the mold 1, will be solidified by the high thermal conductivity of said walls, while the top layer of said mold material 7 as well as the layer along the walls of the mold in contact with the material 8 being cast remains liquid.

The passage of the material 8 to be cast from the reservoir 4 to the mold 1, is attended smoothly with minimum of turbulence, so that there is no intermingling of the material 8 to be cast with air, slag or other non-metallic substances.

After the material 8 to be cast has solidified, the excess fusible mold material 7 on this material 8 may be drained back to the reservoir 4 by rotating the reservoir-mold unit back towards its initial position shown in FIG. 1. The substantial time lag between solidification of the casting and of the mold material 7 of lower melting point, makes the double transfer operation described feasible.

Any solid material having high thermal conductivity and good structural strength is suitable for use as the backing solid for the mold 1. The mold walls in accordance with the present invention may comprise a backing solid having a high capacity to absorb heat, as well as high thermal conductivity, this capacity being present in an amount to absorb the total heat of fusion of the material being cast together with any super heat carried thereby, while maintaining its solid supporting surface in contact with the mold material 7, below the melting point of this mold material. This form of mold shown in FIGS. 1–5 has no provision for forced cooling, as by means of a circulating coolant and is referred to hereinafter as a "massive mold."

An alternative form of mold is provided with means for force cooling the mold, as for example, by means of cooling pipes or ducts for fluid coolant, embedded or located in the solid walls of said mold. The solid parts of the mold wall would still be of higher thermal conductivity than the mold material 7, but it need not have high heat capacity. The forced cooling capacity of the solid parts of the mold walls must be adequate to remove heat from the backing solid at a rate which keeps its solid supporting surface below its own melting point and below that of the mold material 7 in contact with said supporting surface. The alternative form of the mold is referred to hereinafter as the "fluid-cooled mold."

The structural metals are generally suitable for use as the solid parts of the mold wall where forced cooling is employed. In the form of mold illustrated in FIGS. 1–5, where no means for forced cooling is provided, the particular metal used must be selected in view of the thermodynamic characteristics of the fusible material 8 which is cast in the mold and of the casting operation itself. Copper, the various alloys of copper, aluminum and aluminum alloys, silver and silver alloys are particularly suitable for this purpose, because of their relatively high thermal conductivity, high capacity to absorb heat, and good structural characteristics. Graphite is also a suitable material for the backing solid of the mold 1 and can be used even in the casting of the steel, since the mold material 7 prevents the steel from picking up the graphite. It has been found in accordance with the present invention that copper and its various alloys are widely useful as the backing solid of the mold.

The walls of the reservoir 4 desirably should not be of high thermal conductivity, where it is intended to maintain the material in the reservoir for any period of time,

as for example, to permit it to settle into a quiescent state before transfer to the mold 1, since such delay in transfer operations would initiate solidification in the part of the reservoir-mold unit not desired. For that purpose, the walls of the reservoir 4 may be made of refractory material having low themal conductivity, or of cast steel with a refractory lining. Due to the low heat conductivity of the refractory material on the walls of the reservoir 4, the mold material 7 does not solidify thereon.

The particular mold material 7 which is employed in accordance with the present invention is determined by the characteristics of the material 8 to be cast. In any case, it must have the following characteristics:

(1) A solidification temperature lower than that of the material being cast.

(2) A thermal conductivity which is low relative to the thermal conductivity of the backing material of the mold 1.

(3) Immiscibility when in the fused state with the material 8 being cast.

(4) Non-volatility or low volatility at the maximum temperature to which it is heated during the casting operation.

(5) Chemical non-reactivity with the material 8 being cast and with the backing solid of the mold 1.

It has been found in accordance with the present invention that inorganic salts, mixtures of inorganic salts, inorganic oxides and mixtures of inorganic oxides are generally suitable compounds from which to select a satisfactory mold material. Examples of salts which may be used are barium chloride, barium fluoride, cadmium fluoride, calcium chloride, calcium fluoride, copper chloride, lead chloride, lead fluoride, lithium bromide, lithium chloride, magnesium chloride, magnesium fluoride, potassium bromide, potassium chloride, potassium fluoride, silicon oxide, silver chloride, sodium chloride, sodium cyanide, cryolite (sodium aluminum fluoride), borax, or mixtures thereof.

It has been made apparent from the foregoing discussion that the essential requirements of the present invention is that the mold material 7 with its melting point below the solidification of the material 8 to be cast must be adequately cooled by the walls of the mold so that the temperature of the interface between the mold material 7 and the solid supporting surface of the mold wall will never, for any reason, reach the melting point of the mold material. This essential requirement may be met by correlating the thermo-dynamics characteristics of the fusible material 8 being cast in each operation, by the use of five thermo-dynamic equations set forth in my aforesaid Patent No. 3,151,366.

FIGS. 6, 7 and 8 show a modified form of reservoir-mold unit with an open ended section 1*a* having three closed sides and one closed end and open at the top in final position shown in FIG. 8 to serve as a mold, and a reservoir 4*a* at the other end. The reservoir-mold unit is arranged to be tilted about 90° to its final casting position, instead of 180°, as in the embodiment of FIGS. 1–5, and for that reason, the unit has a wall common to the mold 1*a* and the reservoir 4*a*, and consisting of a mold wall 20 presenting an inpour receiving surface 21 for the mold, a reservoir wall 22, presenting an outpour surface 23 of the reservoir, and an intervening slightly inclined offsetting wall 24 defining a corresponding transfer surface 26. The surfaces 21, 23 and 26 extend substantially along a straight line, or at least, along a line free from abrupt deviations, so that the transfer of the molten material 8*a* to be cast from the reservoir 4*a* to the mold 1*a* takes place smoothly with minimum of turbulence along said surfaces.

At the beginning of operation, with the reservoir-mold unit in upright position and the reservoir 4*a* at the bottom, as shown in FIG. 6, a layer of mold material 7*a* similar to the mold material in the process illustrated in FIGS. 1–5 is introduced in the bottom of the empty reservoir. The molten metal **8a** or other material to be cast is then introduced into the reservoir **4a** over the layer of mold material **7a**, and this causes the fused mold material **7a** to rise along the surfaces of the walls of the reservoir **4a**. When all of the required material **8a** to be cast has been delivered to the reservoir **4a**, the mold material **7a** will form a top liquid layer over the surface of the material **8a** to be cast in said reservoir **4a**, as shown in FIG. 6.

If desired, the material **8a** to be cast may be introduced into the empty reservoir **4a**, and then a layer of the mold material **7a** floated on the surface of said material **8a** to be cast.

As the reservoir-mold unit is tilted counterclockwise about the axis at **30**, the material **8a** to be cast is transferred from the reservoir **4a** towards mold **1a** of the unit, but during this transfer, the layer of liquid mold material **7a** flowing in advance of the material **8a** to be cast lines the walls of the mold and when the unit has turned into the final horizontal casting position shown in FIG. 8, there is formed a slab of material **8a** to be cast, surrounded on all sides including the top horizontal surface with a layer of the mold material **7a**. In this final position, the material **8a** is permitted to solidify under the protective and beneficial action of the blanketing mold material **7a** in a manner described in connection with the process illustrated in FIGS. 1–5.

The wall **22** of the reservoir **4a** is desirably tilted slightly in the final casting position of the reservoir-mold unit, to assure that all of the material **8a** to be cast has been transferred to the mold **1a**, as shown in FIG. 8.

In FIG. 9 is shown a reservoir-mold unit similar to that shown in FIGS. 6, 7 and 8, except that instead of providing an offset in one wall of the unit similar to the offset **24** in the proces shown in FIGS. 6, 7 and 8, the wall **20b** of the mold **1b** and the wall **22b** of the reservoir **4b** merge directly into each other. The reservoir wall **22b** inclines slightly in final casting position of the reservoir-mold unit shown in FIG. 9, and this wall is the same high thermal conductivity as the mold wall **20b**. As a matter of fact, the two walls **20b** and **22b** may be integral with each other as shown.

As a further alternative, the transfer mold wall and the transfer reservoir wall along which the material to be cast flows as the reservoir-mold unit is tilted through an angle of about 90°, may be in the same flat plane, in which case the reservoir serves as part of the mold in final casting position of the reservoir-mold unit. In that case, this reservoir wall as well as the bottom end wall of the reservoir, at least a part thereof adjoining the transfer reservoir wall must be made of material having high conductivity, to assure the lining of the walls of the mold material on all sides of the body being cast.

A particular distinction between the process illustrated in FIGS. 1–5 and the processes illustrated in FIGS. 6, 7, 8, and 9, is that in the process of FIGS. 1–5, shrinkage of the casting takes place along the centerline of the casting, whereas in the process of FIGS. 6, 7, 8 and 9, shrinkage will be accommodated by the free top surface of the casting.

The fusible mold material **7** and **7a** applied in the manner described in connection with all forms of the invention illustrated in FIGS. 1–9, provides lubrication to the mold-casting material interface, thereby reducing the shear forces associated with differential thermal contraction of the casting and expansion of the mold.

Also, the fusible mold material **7** and **7a** performs two important thermal functions.

(a) The initial rate of heat transfer from the material to be cast to the backing material of the mold is less than would be the case if the fusible mold material were not present. This significantly extends the life of the backing material of the mold.

(b) Heat transfer during the later stages of solidification is greater than would be the case if no fusible mold material were used, because the liquid part of the mold form defined by the mold material **7** and **7a** maintains intimate wetted contact between the casting and the mold (i.e., there is no air gap). This results in increased solidification and higher production rates.

The presence of a substantial quantity of fused mold material **7** and **7a**, which is immiscible with and of lower density than the material **8** and **8a** being cast, floating on the materialbeing cast, inhibits any tendency toward uncontrolled flow of the material being cast. In the Durville process where no fusible mold material is employed, transfer of the fused material to be cast from the reservoir to the mold is accomplished at a rate which is dictated by the rotational speed and program of the reservoir-mold unit. When the angle between the axis of the mold and the horizontal is very small, even with low rates of rotation, there is a marked tendency of material being cast to flow at high velocity and in a discontinuous way. The presence of another lighter liquid floating on the material to be cast in accordance with the present invention, reduces this maximum velocity by an amount which depends on the relative densities of the floating liquid and the material to be cast. For example, if the material being cast is steel, the presence of the barium chloride layer reduces the transfer velocity at the critical stage by more than 40%.

Also, the presence of the lighter liquid mold material **7** and **7a** reduces the velocity of propagation of waves or ripples at the two-liquid interface. The effect of buffering the fluid transport greatly reduces the likelihood of developing cold shuts or laps, especially when combined with the effect of the fusible mold material **7** and **7a** in reducing initial freezing rate. This fluid buffering action is especially attained where the flow is through a closed channel, i.e., where the mold is closed on all surfaces except at the feed end, as shown in FIGS. 1–5. In that case, the liquid material **8** and **8a** being cast enters the mold **1** and **1a** only as rapidly as it can displace the excess liquid mold material **7** and **7a** already occupying the mold cavity. Under these conditions, there is counter current flow of the material **8** and **8a** being cast and the fusible mold material **7** and **7a**, which exerts a substantial viscouse drag on the material **8** and **8a** entering the mold. The fluid buffering action described is somewhat less but still present with open channel flow into a mold which is closed on all sides except at the top side and the feed end as shown in FIGS. 6, 7 and 8, because in this case, although the fusible mold material must be displaced, the counter current flow is not so well-defined due to the absence of confining top wall in the mold.

One of the objectives called for by the Durville process is the minimization of turbulent contact with the casting atmosphere. With a fusible floating mold material **7** and **7a** covering the material to be cast in accordance with the present invention, this objective is attained with almost perfection, since there is never any opportunity for the material **8** and **8a** being cast to contact the air.

The combination of the fluid, mechanical and thermal control and the lubricating feature described as the result of the use of the fusible mold material **7** and **7a**, makes possible the transport of the liquid being cast over relatively long distances without the usual problems of uncontrolled flow and the development of lags and cold shuts, and also without tearing problems which often arise due to hindered solid contraction of very large castings.

While the invention has been described with particular reference to specific embodiments, it is to be understood that it is not to be limited thereto but is to be construed broadly and restricted solely by the scope of the appended claims.

What is claimed is:

1. The method of casting in a mold defining a solid supporting matrix surface and having an effective length substantially greater than its effective depth, comprising collecting in a reservoir rigid with the mold to form a unit therewith, a body of fused material to be cast with a layer of fusible mold material floating on the top surface thereof and having (1) a solidification temperature lower than that of the material to be cast, (2) a thermal conductivity less than that of the wall of the mold adjacent its supporting matrix surface, (3) immiscibility with the fused material to be cast when said mold material is in fused state, (4) low volatility at the maximum temperature to which the mold material will be subjected during cast, (5) chemical non-reactivity with the material being cast and with wall material of the mold adjacent to its supporting surface, and (6) a specific gravity when fused less than that of the fused material to be cast, and tilting the unit to cause the body of fused material to be cast to be transferred to the mold with the floating layer of mold material flowing in advance of the material to be cast to line the inner surfaces of said mold before the material to be cast reaches said mold surfaces, whereby there is formed between said mold surfaces and the body of fused material to be cast a layer of mold material solidified in the region in contact with said supporting matrix surface and fused in the region in contact with the material being cast, said unit being tilted until the mold is in mold-lined state and in position with the top horizontal surface of the body of fused material extending along the length of the mold and the depth of the mold being vertically downward from said horizontal surface, and allowing the material to be cast to solidify in said mold while in said mold-lined state.

2. The method as described in claim **1**, wherein said reservoir and said mold are opposite end sections of the unit and said unit is tilted about 90° in its transfer operation.

3. The method of casting as described in claim **1**, wherein said mold material is of the class consisting of

barium chloride, barium fluoride, cadmium fluoride, calcium chloride, calcium fluoride, copper chloride, lead chloride, lead fluoride, lithium bromide, lithium chloride, magnesium chloride, magnesium fluoride, potassium bromide, potassium chloride, potassium fluoride, silicon oxide, silver chloride, sodium chloride, sodium cyanide, cryolite, borax and mixtures thereof.

4. The method as described in claim **1**, wherein said reservoir and said mold are opposite end sections of the unit, and said unit is tilted substantially less than 180° in its transfer operation.

5. The method as described in claim **1**, wherein said reservoir has a depth substantially greater than the effective depth of said mold, and has an effective length substantially less than the effective length of said mold.

6. The method as described in claim **1**, wherein the fused material to be cast is a metal.

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