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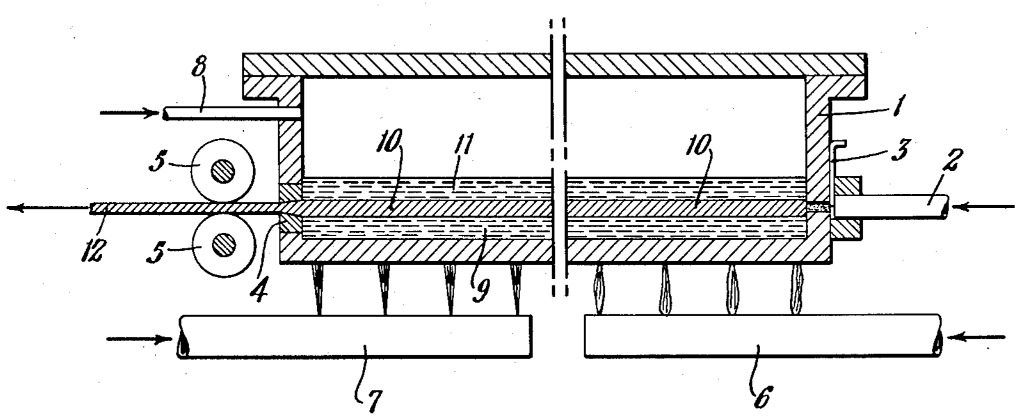

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1

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METHOD FOR THE CASTING OF SHEETS OF A FUSIBLE MATERIAL

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This invention relates to a method for the casting of sheets of a fusible material.

Heretofore various materials such as, for example, metals, plastic and glass have been cast by pouring them in a molten state into a mold and then allowing them to cool to a temperature below that at which they solidify. Molds for such casting have been made from a variety of different materials, but they have had one characteristic in common. They have uniformly been refractory solids, with melting points substantially higher than those of the materials with which they are used.

Now, in accordance with this invention, I make a complete departure from the prior practice and cast solid sheets of fusible material in a liquid mold. By the method in accordance with this invention, I introduce a fusible material to be cast into the interface between two bodies of liquids, positioned in a suitable container, which are immiscible with each other and with the material being cast, which are of low volatility at the temperature at which the material being cast is brought into contact with them, and one of which has a specific gravity lower than that of the material being cast, while the other has a specific gravity higher than that of the material being cast. The fused material is permitted to form a horizontal layer of uniform thickness between the bodies of the two mold liquids, and then cooled to a temperature below its solidification temperature while in the form of the horizontal layer by affirmatively withdrawing heat from at least one of the mold liquids. I then remove the solidified sheet from the mold liquids, while they are still at a temperature above their solidification temperature.

Thus, the mold which I utilize in this method consists of two liquids which have the following essential characteristics:

1. Solidification temperature lower than that of the material being cast.
2. Immiscibility with each other and with the material being cast.
3. Specific gravities higher and lower, respectively, than that of the material being cast.
4. Low volatility or non-volatility at the temperature at which the fused material being cast is introduced into the mold.
5. Chemical non-reactivity with each other and with the material being cast at temperatures at the casting temperatures.

As will be appreciated from these essential characteristics, the particular combination of immiscible liquids which I chose for casting any given material will depend upon its own specific gravity, its melting point, its chemical characteristics and its miscibility characteristics when in the liquid phase. Further it will be appreciated that a mold liquid which forms the heavy phase in one operation may form the light phase in another operation.

The formation of a uniform horizontal layer of the fused material before it begins to freeze is an essential step in my method. To form such a layer, I may bring the molten material to be cast into the interface between

2

the mold liquids in a zone in which the mold liquids are at a temperature at least as high as the melting point of the fused material. However, under some conditions under which I may carry out their method, I may utilize the mold liquids at initial contact temperatures below the freezing point of the fused material being cast, but above their own solidification temperatures.

From a practical standpoint, convenience of operation usually requires that the melt of the material being cast be somewhat above its freezing point at the time it is introduced into the mold to avoid premature solidification. As can readily be appreciated, the material being cast can carry enough heat into the mold to give an overall heat-balance which requires the removal of excess heat before solidification of the material begins, even though the mold liquids are initially at a temperature below its solidification temperature.

When the amount of the fused material is large as compared with the amount of the mold liquids the specific heats of the materials involved are of primary importance, since any interfacial skin which is instantaneously formed on the material being cast will be remelted by the excess heat carried by that material being cast. When the amount of the material being cast is relatively large, the mold liquids may be below the freezing point of the material being cast and excess heat still be present which must be removed before freezing begins, when the amount (I):

$$C_1D_1h_1(T_f-T_m)+C_2D_2h_2(T_f-T_m)$$

is smaller than the amount (II):

$$C_3D_3h_3(T_i-T_f)$$

the C_1, C_2 and C_3, being the specific heats in B. t. u. per pound is degrees Fahrenheit, the D_1, D_2 and D_3 being the densities in pounds per cubic foot, the h_1, h_2, and h_3 being the depths of the layers in feet, of one mold liquid, the other mold liquid and of the fusible material, respectively, and T_i is the temperature of the fusible material as it enters the mold, T_m is the initial temperature of the mold liquids and T_f is the solidification temperature of the fusible material. When the conditions of operation are such that the first of these amounts, i. e. (I) above, is smaller than the second, i. e. (II) above, and excess heat must be removed before the solidification of the material being cast can begin, the material has ample opportunity to form a uniform, horizontal layer in the mold.

When the amount of the fusible material being cast is relatively small as compared with the amount of the mold liquids present, mold temperatures below the freezing point of the material being cast can be used only when there is a favorable rate balance of heat flow. Under these conditions of operation an unfavorable rate balance of heat flow causes an immediate skin formation on the surface of the material being cast which interferes with its spreading into a uniform horizontal layer in the mold. Since the two mold liquids which I may utilize will almost always have different thermal conductivities, the initial temperatures of two interfaces between the material being cast and the respective mold liquids will always be somewhat different, and each must be considered separately.

Freezing of the fusible material will not start immediately, under conditions of operation in which the initial interfacial temperature (T_1) is above the freezing point of the material being cast. The initial interfacial temperature for any given material being cast and any given mold liquid may be determined from the following equation:

$$T_1=\frac{T_3+fT_m}{1+f}$$

in which:

$$f=\frac{K_mD_mC_m}{K_3D_3C_3}$$

and in which T_3 is the initial temperature of the material being cast, T_m is the initial temperature of the mold liquid which forms the interface and K_m and K_3 are the thermal conductivities in B. t. u. per foot, per hour, in degrees Fahrenheit, D_m and D_3 the densities and C_m and C_3 the specific heats, of that mold liquid and of the material being cast, respectively.

It will be noted from the foregoing equations that if "f" above is one, then the initial interfacial temperature is the average of the initial temperature of the material being cast and of the initial temperature of the mold liquid, while if "f" is smaller than one, the initial interfacial temperature approaches the initial temperature of the material being cast, rather than the initial temperature of the mold liquids. In both cases the mold liquid can be below the freezing point of the material being cast and, obviously, the hotter the material being cast is initially, the lower the mold temperature can be without skin formation. On the other hand, if "f" is relatively large the initial interfacial temperature approaches the initial temperature of the mold liquid, so that the mold liquid cannot be very much, if any, below the freezing point of the material being cast without the instantaneous formation of a frozen skin which interferes with the proper leveling of the material in the mold.

Under conditions of operation in which the thermodynamic relationships permit the use of a mold temperature below the freezing point of the material being cast, it is often desirable to use a mold temperature which approaches the minimum usable temperature, since the use of such a temperature minimizes the amount of heat which must be supplied to the mold and withdrawn therefrom in this method.

The method, in accordance with this invention, is suitable for the casting of a wide variety of fusible solids, including metals, glass and plastic materials of both the thermoplastic and thermosetting varieties. The fusible material to be cast may be introduced into the mold in the form of a discontinuous solid and melted while in the mold and subsequently cooled. Alternatively, it may be introduced into the mold as a liquid phase.

I may use as mold liquids molten inorganic salts, molten salt mixtures, molten oxides, molten metals and molten mixtures of metal. I have found that mixtures of different inorganic salts are frequently more suitable for my purpose than single salts for the reason that the mixtures are less viscous in the liquid phase. Thus, for example, a mixture of 80% barium chloride and 20% sodium chloride has a lower viscosity in the liquid phase than barium chloride alone.

Examples of salts which I may use are:

	Melting Point, Degree Centigrade	Boiling Point, Degree Centigrade	Specific Gravity
Barium Chloride	925	1,560	3.856
Barium Fluoride	1,280	2,137	4.83
Cadmium Fluoride	1,100	1,758	6.64
Calcium Chloride	772	1,600	2.512
Copper Chloride	422	1,366	3.53
Lead Chloride	501	950	5.85
Lead Fluoride	855	1,290	8.24
Lithium Bromide	547	1,265	3.464
Lithium Chloride	613	1,353	2.068
Magnesium Chloride	708	1,412	2.316
Magnesium Fluoride	1,396	2,239	2.9–3.2
Potassium Bromide	730	1,380	2.75
Potassium Chloride	776	1,500	1.984
Potassium Fluoride	880	1,500	2.48
Silicon Oxide	1,710	2,230	2.32
Silver Chloride	455	1,550	5.56
Sodium Chloride	801	1,413	2.165
Sodium Cyanide	563.7	1,496	----------

Examples of metals which I may use are:

	Melting Point, Degree Centigrade	Boiling Point, Degree Centigrade	Specific Gravity
Aluminum	660.2	1,220.4	2.699
Cadmium	320.9	765	8.65
Copper	1,083	1,981.4	8.96
Gallium	29.78	2,000	5.093
Lead	327.43	1,613	11.343
Iron	1,535	3,000	7.86
Lithium	186	1,609	.534
Magnesium	651	1,100	1.74
Mercury	−38.89	356.9	13.546
Nickel	1,455	2,900	8.90
Potassium	63	770	.86
Silver	960.5	1,950	10.5
Sodium	97.5	880	0.97
Silicon	1,430	2,300	2.33
Thallium	302	1,457	11.85
Tin	231.9	2,270	5.75
Titanium	1,800	3,000	4.50
Tungsten	3,370	5,900	19.30
Vanadium	1,720	3,000	5.866
Zinc	419.4	907	7.14
Zirconium	1,900	2,900	6.4

The characteristic of immiscibility with the fused material to be cast and with the other mold liquid to be used is an essential prerequisite in the selection of a mold liquid, since during the casting operation the mold liquids and the material to be cast must exist as separate and distinct phases. However, a limited solubility of one mold liquid in the other, or of the material being cast in one or both of the mold liquids is not objectionable, provided that such limited solubility does not destroy the necessary relationship between the specific gravities of the liquids. Such solubility of the material being cast in one or both of the mold liquids will cause some initial loss of that material but this loss ceases as soon as the limited solubility is satisfied. On the other hand, neither mold liquid should have any appreciable solubility in the material being cast, since such solubility causes contamination of the cast product and a continued depletion of the soluble mold liquid.

An example of a combination of mold liquids which I have found satisfactory for use with my method is the combination of lead (sp. g. 11.34) as a heavy mold liquid and barium chloride (sp. g. 3.86) as the light mold liquid. A liquid mold composed of this combination of mold liquids is suitable, for example, for casting iron, steel and steel alloys, as well as copper and its various alloys. Other salts which I may use as light mold liquids in combination with lead are calcium chloride, sodium chloride, potassium chloride and magnesium chloride.

I may carry out my method in either a discontinuous or a continuous manner. The discontinuous or batchwise alternative is the simpler of the two and consists of introducing a predetermined volume or weight of the fused material to be cast into the liquid mold, permitting the fused material to form a uniform, horizontal layer between the mold liquids before it solidifies and then cooling it to a temperature below its freezing temperature. The fused material to be cast may be merely poured into the surface of the lighter of the two immiscible liquids which form the mold and then allowed to position itself under the influence of gravity in a layer between the two immiscible liquids. Alternatively, the fused material may be introduced into the mold at or near the interface between the two liquids forming the mold. Ordinary, I prefer to follow the latter alternative to minimize turbulence in the mold.

In proceeding in such a discontinuous or batchwise manner, I may control the thickness of the cast sheet which I produce by the volume of the fused material which I introduce into the mold. The volume of the fused material is determined by first computing the volume of the desired sheet from its thickness and the area of the interface of the mold, and then correcting that volume in terms of the temperature at which the fused material is measured from the changes in unit volume which take place in cooling to the solidification temperature, any change which occurs during the change of state from the liquid to the solid phase and that which occurs in the solid phase upon cooling to normal atmospheric temperature. Alternatively, the weight of the fused material which is used to secure any desired final sheet thickness can be determined by computing the volume of the desired sheet and then computing the weight of that volume from its density at room temperature.

The shape and dimensions of the perimeter of the sheet which I produce by this batch-wise alternative is determined by the shape and dimensions of the perimeter of the interface between the two liquids which is, in turn, determined by the shape of the container in which the immiscible liquids are held. Since the container can be made any desired shape, I may cast sheets having perimeters of any desired shape and thus avoid any subsequent trimming of the sheet, with the attendant and undesirable formation of scrap.

The shape of the perimeter of the sheet which I cast determines the exact procedure which I follow in removing it from the mold after it has solidified. In the case of regular shapes which cannot be tilted, I remove the lighter of the two immiscible liquids from above the cast sheet, for example, by pumping it to an auxiliary storage tank, and then remove the cast sheet by lifting it vertically from the tank.

Sheets having thicknesses over a wide range may be produced by this alternative of my method. There is no limitation on the maximum thickness of the sheet which can be produced. On the other extreme, it is possible to produce quite thin sheets. The limitation on this extreme is determined by the relationships between the three different interfacial tensions involved, which in turn, determines the minimum thickness in which the fused material will remain as a continuous film in the entire interfacial area and not gather itself into disconnected bodies covering only portions of the entire area.

In this discontinuous method, I must furnish heat to the mold prior to each casting operation and then withdraw heat during the solidification of the sheet being cast.

The temperature to which the mold liquids are heated may alternatively on, one hand, be to the melting point of the material being cast or to a somewhat higher temperature, or, on the other be a temperature below the melting point of the material as determined by the thermodynamic considerations discussed hereinbefore. The necessary heat may be supplied by electric heaters, gas burners, flue gases or other suitable sources. The required withdrawal of heat may be accomplished, for example, by the circulation of a suitable liquid or gaseous coolant through a coil or coils positioned within the lower, heavier liquid of my mold, or by spraying the mold container with cooling fluid. The temperature of the mold liquids in the immediate zone in which the material to be cast is first introduced into the interface between them may be above the solidification temperature of that material or it may be at a lower temperature under favorable thermodynamic conditions which permit the use of such a lower temperature. The thermodynamic considerations applicable here, as well as to the discontinuous embodiment of my method are fully discussed hereinbefore.

I utilize a square or rectangular mold in the continuous alternative of my method, and continuously introduce the fused material to be cast in a steady stream at one side of the mold, preferably, at the original level of the interface between the two immiscible liquids, and continuously withdraw the cast sheet from the opposite side or end of the mold. I maintain a temperature differential in the liquids of the mold in the direction of travel of the material being cast, from a temperature which is high enough to permit it to form a uniform layer while still in the liquid state at the point of its introduction, to a temperature below its solidification point at the opposite end of its travel through the mold.

To maintain this essential temperature differential I may, for example, withdraw heat from the lower, heavier immiscible liquid by means of a coil or coils positioned therein and carrying a circulating coolant. I position my coils in a manner such that I withdraw heat from all parts of the heavier, immiscible liquid, except that immediately adjacent to the side at which the fused material is being introduced into the mold. I may or may not furnish heat to the mold immediately adjacent to the side at which the fused material is being introduced, to supplement the heat carried into the mold itself, depending on the specific thermodynamic conditions involved. In any case I keep the immiscible liquids adjacent to the inlet of the mold at a high enough temperature to allow the formation of a uniform layer of the fused material before it is cooled to a point such that it begins to solidify.

I introduce the fused material being cast through an orifice which is preferably adjustable, and control the thickness of the sheet I am casting by the rate at which the fused material is fed through the orifice and the rate at which the cast sheet is withdrawn from the opposite side or end of the mold.

The incoming fused material being cast seals the inlet orifice against a back-flow of the lighter of the immiscible casting liquids. However, I must utilize special precautions to prevent the leakage of the lighter casting liquid, and to some extent even the heavier casting liquid, at the exit side of the mold. I have found that I can prevent such leakage, for example, by surrounding the orifice by a reduction die, operating the process in a manner such that the cast sheet is slightly larger in dimensions than the orifice and pulling the sheet through the orifie by means of tension applied from its outer side. The necessary tension can be applied, for example, by passing the sheet through suitable rolls. In thus making a slight reduction in the dimensions of the sheet as it passes through the exit orifice, I provide an effective seal to prevent leakage of the casting liquids.

To start the operation of my process in a continuous manner, I position a solid sheet of the material to be cast in the interface between the two casting liquids, start the flow of the fused material to be cast and, at the same time, start withdrawing the solid sheet through the exit orifice. The fused material to be cast attaches itself to the solid sheet in the interface and is pulled through the exit orifice behind the sheet, thus initiating continuous passage of the material to be cast through the mold.

The single figure of the accompanying drawing shows a vertical cross-sectional view of one form of apparatus which I may use to carry out the method in accordance with this invention in a continuous manner. It consists of a square or rectangular container **1**, which may, if desired, be provided with a cover as illustrated. It is provided with an inlet conduit **2**, the orifice of which is adjustable by a gate **3** and an exit die **4**. Adjacent to the exit die **4**, is positioned a pair of rolls **5**, **5**. Beneath the entrance portion of the container is a series of gas conduits, one of which is shown at **6**, which are provided with a plurality of orifices for gas, while beneath the exit portion of the container is a series of conduits for cooling water, one of which is shown at **7**, which are provided with a series of orifices for jets of cooling water. The container **1** may be provided with a conduit **8** for the introduction of mold liquids **9** and **11**.

In carrying out my method in a continuous manner, I continuously introduced a fused material **10** to be cast in a steady stream through the conduit **2** at the original level of the interface between the two mold liquids **9** and **11**. The volume of this stream is controlled by the gate 3. The fused material **10** flows into a flat sheet between the mold liquids, which are maintained at a temperature which permits the material **10** to form a flat sheet while still in the liquid phase in the portion of the container **1** near the entrance end, by heat supplied by gas flames beneath that portion of the container.

The fused material **10** is passed along the length of the container **1** into a cooling zone in which it is cooled by the action of jets of cooling water playing on the bottom of the exit portion of the container **1**. The fused material **10** solidifies in this cooling zone, and is continuously pulled through the exit die **4** by the action of the rolls **5**, **5**. The exit die **4** makes a slight reduction in the thickness of the solidified sheet and maintains a tight seal against any leakage of the mold liquids **9** and **11**.

The thickness of the final sheet **12** emerging from the operation is controlled primarily by the rate at which the fused material **10** is fed into the container **1** through the conduit **2** and by the rate at which the sheet **12** is pulled through the exit die **4**. The exact thickness of the sheet is, of course, determined by the opening of the exit die **4** and the reduction, if any, effected by the rolls **5**, **5**. However, it will be understood that, in general, I prefer to control the rate of flow of fused material into the container **1** and the speed of the rolls **5**, **5** to keep the reduction in the thickness of the sheet made by the exit die **4** to the minimum required to give a tight seal against leakage of the mold liquids **9** and **11**. In this manner I keep to a minimum the power required by the rolls **5**, **5**.

In both the discontinuous and the continuous alternatives, I find that heat can be recovered from the operation by the use of a circulating coolant, instead of jets of cooling water as illustrated by the drawing. In this connection it will be noted that the fused material being cast not only gives up heat due to its temperature drop, but also releases its heat of fusion to the coolant. In the application of my method to the casting of materials which melt at a relatively high temperature, the coolant can be used to generate steam in a waste heat boiler. In some cases steam itself can be utilized as the coolant and superheated in the process.

A specific illustration of my method is an operation in which I cast stainless steel using a combination of molten lead and molten barium chloride as the casting liquids, with the molten lead forming the lower and heavier of the two liquids. In this operation I heat my casting liquids to a temperature of 2600° F. and introduce molten stainles steel into the mold at a temperature of 2900 F. in a discontinuous operation. I then cool the mold to 1800° F. and then remove the stainless steel as a solid sheet of uniform thickness from the still liquid barium chloride and lead. In this operation I produce a stainless steel sheet which is non-porous and entirely free of scale.

I have found that my method offers a number of advantages in the casting of fusible materials. Perhaps the most important of these advantages is the production of sheets of any desired thickness in a single operation. Thus, in the casting of metal sheets, I eliminate the necessity for the use of a blooming mill operation, with its tremendous power requirement. Another important advantage arises from the fact that in my method the material being cast is completely protected from the air and thus is not subject to oxidation. Thus, I am able to produce metal sheets which are entirely free of scale. Other advantages are the adaptability of the method to the production of sheets having accurately predetermined dimensions and perimeter shapes in a single operation. Still another advantage arises from the ease with which the heat normally lost in casting operations can be recovered and converted into power.

This application is a continuation-in-part of my co-

pending application Serial No. 362,221, filed June 17, 1953.

What I claim and desire to protect by Letters Patent is:

1. A method for the casting of fusible materials which comprises introducing the material into the horizontal interface between the two bodies of mold liquids which are at a temperature sufficiently high in relation to the melting point of the said material to permit it to spread into a horizontal layer while still in the liquid state, which are immiscible with each other and with the material being cast, which have solidification temperatures below that of the material being cast and which are of low volatility at the temperature at which the material being cast is brought into contact with them, one of the said mold liquids being characterized by a specific gravity lower than that of the material being cast and the other said mold liquid being characterized by a specific gravity higher than that of the material being cast; withdrawing heat from the material being cast to reduce its temperature below its solidification temperature, while maintaining the mold liquids above their solidification temperatures; and separating a solid, flat, cast sheet of the fusible material from the said mold liquids.

2. A method for the casting of fusible materials which comprises introducing the material into the horizontal interface between the two bodies of mold liquids which are at a temperature above its melting point, which are immiscible with each other and with the material being cast, which have solidification temperatures below that of the material being cast, and which are of low volatility at the temperature at which the material being cast is brought into contact with them, one of said mold liquids being characterized by a specific gravity lower than that of the material being cast and the other said mold liquid being characterized by a specific gravity higher than that of the material being cast; cooling the immiscible liquids by withdrawing heat from one of the said molten bodies to a temperature below the solidification temperature of the material being cast, but above those of the mold liquids; and separating a solid flat cast sheet of the fusible material from the said mold liquids.

3. A method for the casting of a sheet of a fusible material which comprises introducing the material at a temperature above its melting point into the horizontal interface between two bodies of mold liquids which are immiscible with each other and with the molten material being cast and which are at a temperature above the melting point of the said material, cooling the said immiscible liquids by withdrawing heat from at least one of them to a temperature below that at which the said material solidifies and removing the solidified flat sheet of the material from between the said immiscible liquids, the said immiscible, mold liquids being characterized by low volatility at the temperature at which the material being cast is brought into contact with them and one of said mold liquids being characterized by a specific gravity lower than that of the material being cast and the other said mold liquid being characterized by a specific gravity higher than that of the material being cast.

4. A method for the continuous casting of a sheet of a fusible material which comprises continuously introducing the material at a temperature above its melting point into the interface between two bodies of mold liquids which are immiscible with each other and with the material being cast, and which have solidification temperatures below that of the material being cast, along one of its edges in a uniform stream while the immiscible liquids along that edge are at a temperature sufficiently high in relation to the melting point of the said material to permit it to spread into a horizontal layer while still in the liquid state, passing the said material across the said interface in contact with portions of the said bodies of immiscible liquids which are at temperatures below the solidification temperature of the said material, and con-

tinuously withdrawing the said material in the form of a solid, flat sheet from the opposite side of the said interface, the said immiscible liquids being characterized by low volatility at the temperature at which the material being cast is brought into contact with them and one of said liquids being characterized by a specific gravity lower than that of the material being cast and the other said liquid being characterized by a specific gravity higher than that of the material being cast.

5. A method for the casting of fusible materials which comprises introducing the material into the interface between two bodies of mold liquids, in an amount which is large as compared with the total volume of the mold liquids, while the mold liquids and the fusible material are at temperatures such that:

$$C_1D_1h_1(T_f-T_m)+C_2D_2h_2(T_f-T_m)$$

is smaller than:

$$C_3D_3h_3(T_i-T_f)$$

the C_1, C_2 and C_3 being the specific heats in B. t. u. per pound in degrees Fahrenheit, the D_1, D_2 and D_3 being the densities in pounds per cubic foot, the h_1, h_2 and h_3 being the depths of the layers in feet of one mold liquid, the other mold liquid and the fusible material, respectively, and T_i is the initial temperature of the fusible material, T_m is the initial temperature of the mold liquids and T_f is the solidification temperature of the fusible material; the said mold liquids being immiscible with each other and with the material being cast, having solidification temperatures below that of the material being cast and low volatility at the temperature at which the material being cast is brought into contact with them, one of the said mold liquids being characterized by a specific gravity lower than that of the material being cast and the other said mold liquid being characterized by a specific gravity higher than that of the material being cast; withdrawing heat from the material being cast to reduce its temperature below its solidification temperature, while maintaining the mold liquids above their solidification temperatures; and separating a solid, flat, cast sheet of the fusible material from the said mold liquids.

6. A method for the casting of fusible materials which comprises introducing the material into the interface between two bodies of mold liquids, in an amount which is small as compared with the total volume of the mold liquids but which is sufficient to form a uniform layer over the entire area of the interface, while the mold liquids and the fusible material are at temperatures such that the instantaneously attained temperature of each interface between the mold liquids and the said fusible material is above the freezing point of the said fusible material; the said instantaneously attained temperature being defined by the equation:

$$T_i=\frac{T_3+fT_m}{1+f}$$

in which:

$$f=\frac{K_mD_mC_m}{K_3D_3C_3}$$

the T_i being the instantaneously attained interfacial temperature, T_3 and T_m being the initial temperatures of the fusible material and of the particular mold liquid at the interface K_3 and K_m the thermal conductivities of the fusible material and the mold liquid respectively expressed in B. t. u. per foot, per hour, in degrees Fahrenheit, the D_3 and D_m the densities of the fusible material and the mold liquid respectively, and C_3 and C_m the specific heats of the fusible material and the mold liquid respectively; the said mold liquids being immiscible with each other and with the material being cast, having solidification temperatures below that of the material being cast and low volatility at the temperature at which the material being cast is brought into contact with them, one of the said mold liquids being characterized by a specific gravity lower than that of the material being cast and the other said mold liquid being characterized by a specific gravity higher than that of the material being cast; withdrawing heat from the material being cast to reduce its temperature below its solidification temperature, while maintaining the mold liquids above their solidification temperatures; and separating a solid flat, cast sheet of the fusible material from the said mold liquids.

7. A method for the continuous casting of a sheet of a fusible material which comprises continuously introducing the material into the interface between two bodies of mold liquids in a volume which maintains in the mold an amount of the material which is large as compared with the total volume of the mold liquids, while the mold liquids in the zone of initial contact with the said material and the material itself are at temperatures such that:

$$C_1D_1h_1(T_f-T_m)+C_2D_2h_2(T_f-T_m)$$

is smaller than:

$$C_3D_3h_3(T_i-T_f)$$

the C_1, C_2 and C_3 being the specific heats in B. t. u. per pound in degrees Fahrenheit, the D_1, D_2 and D_3 being the densities in pounds per cubic foot, the h_1, h_2 and h_3 being the depths of the layers in feet, of one mold liquid, the other mold liquid and the fusible material, respectively, and T_i is the initial temperature of the fusible material, T_m is the initial temperature of the mold liquids and T_f is the solidification temperature of the fusible material; passing the said material across the said interface in contact with portions of the said bodies of immiscible liquids which are at temperatures below the solidification temperature of the said material; and continuously withdrawing the said material in the form of a solid, flat sheet from the opposite side of the said interface; the said immiscible liquids being characterized by low volatility at the temperature at which the material being cast is brought into contact with them and one of said liquids being characterized by a specific gravity lower than that of the material being cast and the other said liquid being characterized by a specific gravity higher than that of the material being cast.

8. A method for the continuous casting of a sheet of a fusible material which comprises continuously introducing the material at a temperature above its melting point into the interface between two bodies of mold liquids which are immiscible with each other and with the material being cast, and which have solidification temperatures below that of the material being cast, along one of its edges in a uniform stream while the immiscible liquids along that edge are at a temperature above the melting point of the said material, passing the said materail across the said interface in contact with portions of the said bodies of immiscible liquids which are at temperatures below the solidification temperature of the said material, and continuously withdrawing the said material in the form of a solid, flat sheet from the opposite side of the said interface, the said immiscible liquids being characterized by low volatility at the temperatures at which the material being cast is brought into contact with them and one of said liquids being characterized by a specific gravity lower than that of the material being cast and the other said liquid being characterized by a specific gravity higher than that of the material being cast.

9. A method for the continuous casting of a sheet of fusible material which comprises continuously introducing the material at a temperature above its melting point into the interface between two bodies of mold liquids which are immiscible with each other and with the material being cast, and which have solidification temperatures below that of the material being cast, along one of its edges in a uniform stream while the immiscible liquids along that edge are at a temperature sufficiently high in relation to the melting point of the said material to permit it to spread into a horizontal layer while still in

the liquid state, passing the said material across the said interface in contact with portions of the said bodies of immiscible liquids which are at temperatures below the solidification temperature of the said material, and continuously withdrawing the said material in the form of a solid sheet from the opposite side of the said interface through a die which makes a slight reduction in the thickness of the sheet and acts as a seal to the mold liquids by the action of a pair of squeeze rolls positioned adjacent the exit side of the said die, the said immiscible liquids being characterized by low volatility at the temperature at which the material being cast is brought into contact with them and one of said liquids being characterized by a specific gravity lower than that of the material being cast and the other said liquid being characterized by a specific gravity higher than that of the material being cast.

10. A method for the continuous casting of a sheet of a fusible material which comprises continuously introducing the material at a temperature above its melting point into the interface between two bodies of mold liquids which are immiscible with each other and with the material being cast, and which have solidification temperatures below that of the material being cast, along one of its edges in a uniform stream while the immiscible liquids along that edge are at a temperature above the melting point of the said material, passing the said material across the said interface in contact with portions of the said bodies of immiscible liquids which are at temperatures below the solidification temperature of the said material, and continuously withdrawing the said material in the form of a solid sheet from the opposite side of the said interface through a die which makes a slight reduction in the thickness of the sheet and acts as a seal to the mold liquids by the action of a pair of squeeze rolls positioned adjacent the exit side of the said die, the said immiscible liquids being characterized by low volatility at the temperature at which the material being cast is brought into contact with them and one of said liquids being characterized by a specific gravity lower than that of the material being cast and the other said liquid being characterized by a specific gravity higher than that of the material being cast.

11. A method for the casting of a sheet of steel which comprises introducing the steel at a temperature above its melting point into the horizontal interface between a body of molten lead and a body of molten barium chloride which are at a temperature sufficiently high in relation to the melting point of the steel to permit it to spread into a horizontal layer while still in the liquid state, cooling the steel by withdrawing heat from one of the said bodies to a temperature below its solidification temperature but above that of the barium chloride, and removing the steel in the form of a solid flat sheet of uniform thickness from the said molten lead and molten barium chloride.

12. A method for the casting of a sheet of steel which comprises introducing the steel at a temperature above its melting point into the horizontal interface between a body of molten lead and a body of molten barium chloride, cooling the steel by withdrawing heat from one of the said bodies to a temperature below its solidification temperature but above that of the barium chloride, and removing the steel in the form of a solid flat sheet of uniform thickness from the said molten lead and molten barium chloride.

13. A method for the continuous casting of a sheet of steel which comprises continuously introducing the steel at a temperature above its melting point, into an edge of the interface between a body of molten lead and a body of molten barium chloride which are at a temperature sufficiently high in relation to the melting point of the steel to permit it to spread into a horizontal layer while still in the liquid state, which is introduced into the interface between them, passing the steel in a layer of uniform thickness across the said interface in contact with portions of the bodies of lead and barium chloride which are below the solidification temperature of the steel and continuously withdrawing the steel in the form of a solid, flat sheet from the opposite edge of the said interface.

14. A method for the continuous casting of a sheet of steel which comprises continuously introducing the steel at a temperature above its melting point, into an edge of the interface between a body of molten lead and a body of molten barium chloride which have temperatures above the melting point of the steel, which is introduced into the interface between them, passing the steel in a layer of uniform thickness across the said interface in contact with portions of the bodies of lead and barium chloride which are below the solidification temperature of the steel and continuously withdrawing the steel in the form of a solid flat sheet from the opposite edge of the said interface.

References Cited in the file of this patent

UNITED STATES PATENTS

1,831,310	Lindemuth	Nov. 10, 1931
2,022,571	Palm et al.	Nov. 26, 1935
2,298,348	Coxe	Oct. 13, 1942
2,708,617	Magot et al.	May 17, 1955