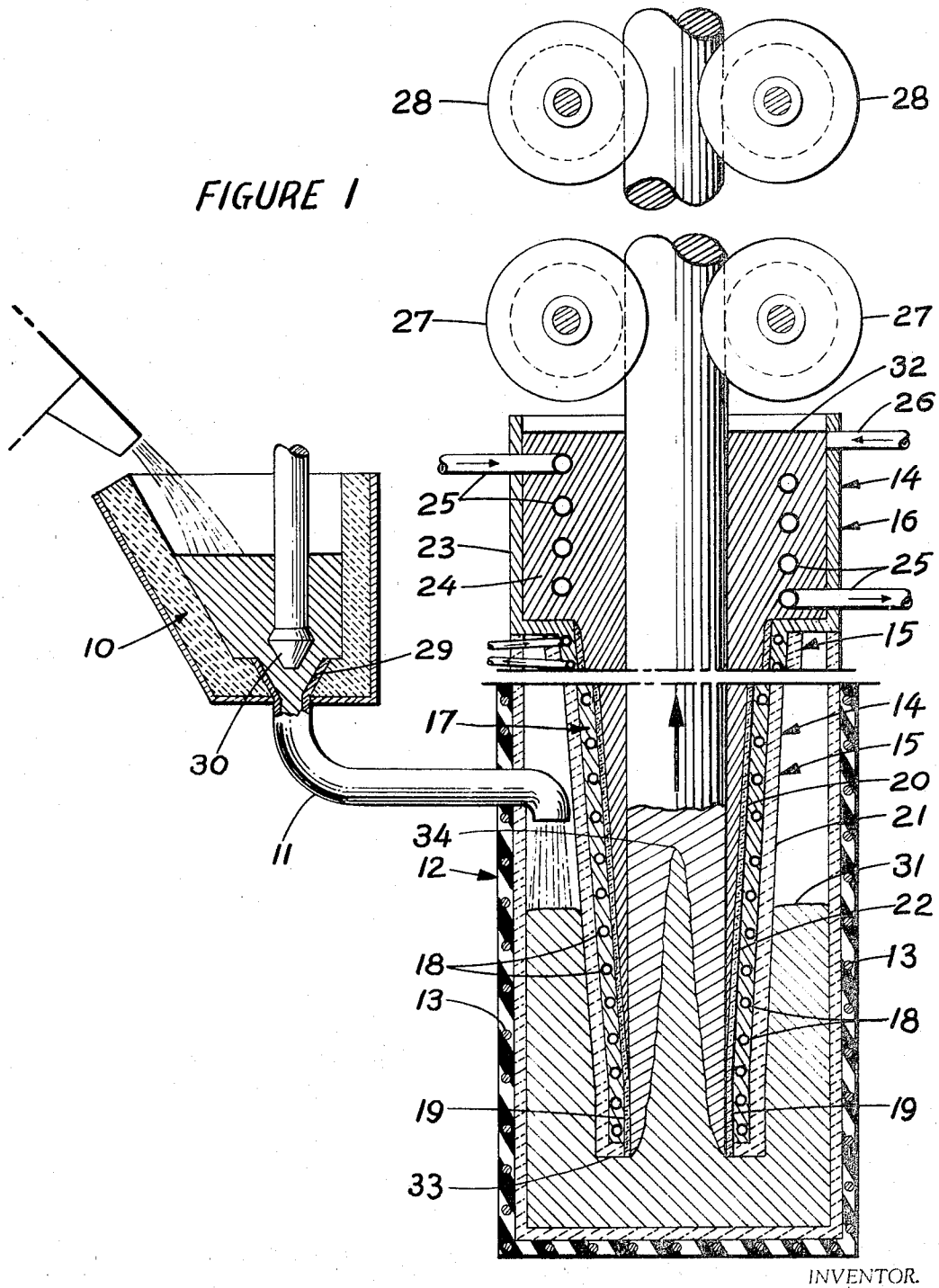
Dec. 27, 1966 H. A. FROMSON 3,293,704

METHOD AND APPARATUS FOR THE CASTING OF FUSIBLE MATERIALS

Original Filed Oct. 5, 1964 2 Sheets-Sheet 1

FIGURE 1



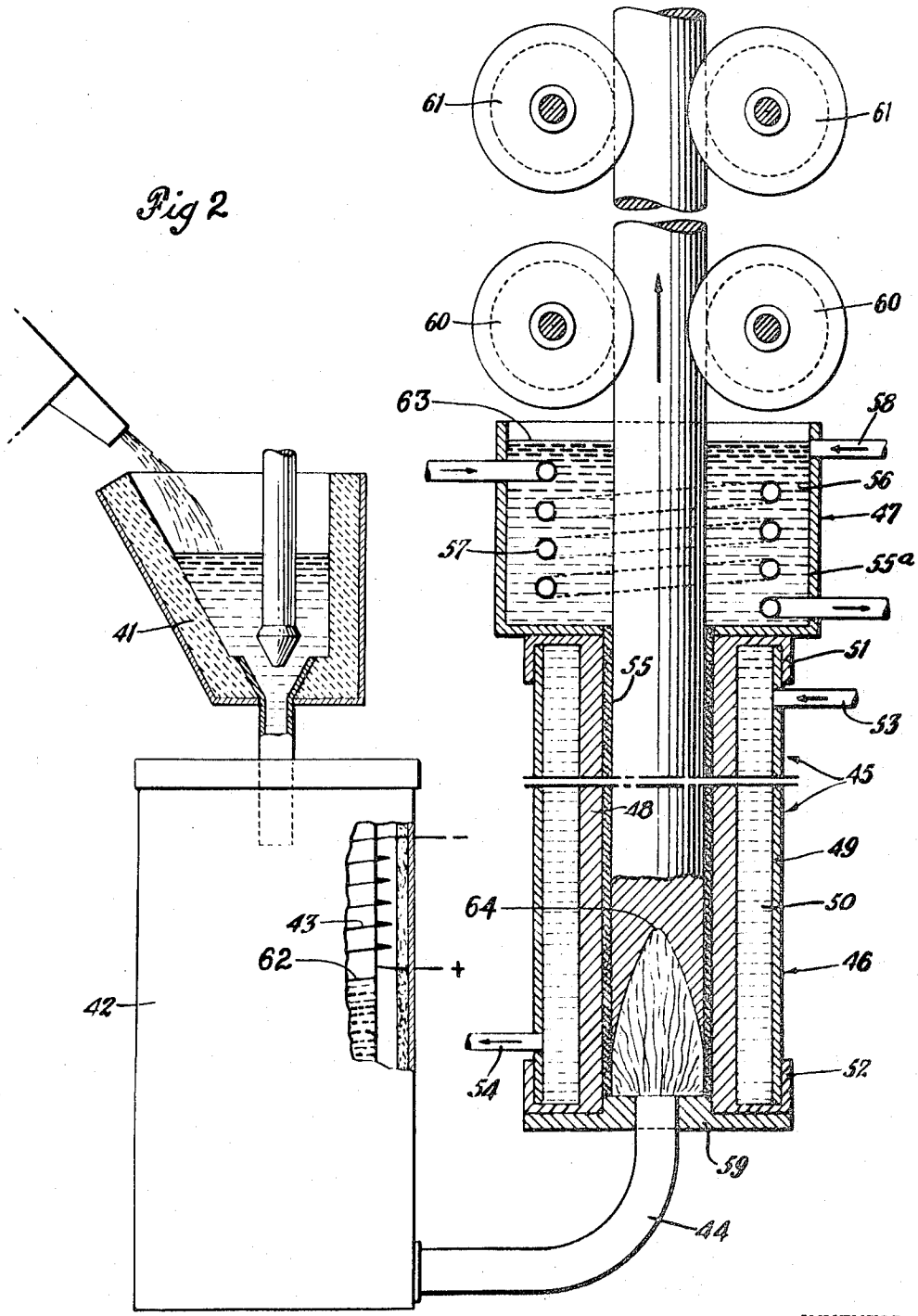
INVENTOR.
HOWARD A. FROMSON
BY
Cleveland B. Hollabaugh.
ATTORNEY

Dec. 27, 1966 H. A. FROMSON 3,293,704

METHOD AND APPARATUS FOR THE CASTING OF FUSIBLE MATERIALS

Original Filed Oct. 5, 1964 2 Sheets-Sheet 2

Fig 2



INVENTOR.
HOWARD A. FROMSON
BY
Cleveland B. Hallabaugh
ATTORNEY

United States Patent Office 3,293,704 Patented Dec. 27, 1966

3,293,704

METHOD AND APPARATUS FOR THE CASTING OF FUSIBLE MATERIALS

Howard A. Fromson, Rogues Ridge Road, Weston, Conn. 06880

Continuation of application Ser. No. 401,732, Oct. 5, 1964. This application Feb. 18, 1966, Ser. No. 534,592
15 Claims. (Cl. 22—57.2)

This invention relates to a method for the continuous upwardly casting of a fusible material in the form of rods, bars or sheets.

This application is a continuation of my application Serial No. 401,732 filed October 5, 1964, which is a continuation-in-part of my application Serial No. 737,176 filed December 11, 1957 and issued October 6, 1964 as United States Patent No. 3,151,366 which is, in turn, a continuation-in-part of my application Serial No. 629,590 filed December 20, 1956 and Serial No. 671,029 filed July 10, 1957, both of which are now abandoned.

By this invention, I provide a specific method and apparatus to carry out this method which apply the principles of the method described in my application Serial No. 598,419. This method is adapted for the continuous production of rods, bars or sheets of a fusible material by casting in an upwardly direction and offers the advantage of providing a casting surface which is continuously renewed during the casting operation, which is a liquid and which is in continuous contact with the surface of the casting being produced, despite the shrinkage of the casting as it is cooled. This continuous contact between the liquid casting surface provides uniform and effective heat withdrawal from the casting which results both in an internal structure and in surface characteristics which are superior to those obtained by prior casting methods.

This method of casting offers the further advantage of producing directly from a molten body of a fusible material a continuous rod, bar or sheet thereof in any desired cross-sectional form and dimensions without the extensive rolling and reheating operations heretofore required to reduce a cast ingot of a fusible material such as iron, steel or copper to a continuous rod, bar or sheet having a cross-section of accurately predetermined dimensions.

Another advantage provided by this invention arises from the fact that the fusible material is protected from the atmosphere both while in the solid state and while cooling during the casting operation. This advantage is particularly important in the casting of iron, steel, copper and other fusible materials which are subject to rapid oxidation when at an elevated temperature.

The method of this invention consists essentially of passing a fusible material into the lower end of an elongated mold which extends upwardly, and preferably, substantially vertically and has a backing material of high thermal conductivity and a surface of a retaining material which is of low thermal conductivity and has a melting point lower than that of the fusible material being cast, while withdrawing the solidified casting from the upper end of the mold. This mold is provided with a reservoir of retaining material at its upper end which is kept in molten condition by heat from the solidified casting emerging from the mold or by a supplemental source of heat. A supplemental source of heat for the reservoir of retaining material is usually desirable to insure that the retaining material is in a molten condition at all times, particularly at the initiation of the continuous operation.

By the use of the combination of a material of low thermal conductivity for the retaining surface and one of high thermal conductivity for backing material of the mold, I am able to keep the supporting surface of the

backing material at a temperature below the melting points of the retaining material and of the backing material, and thereby am able to keep both a major portion of the retaining material and all of the backing material at temperatures considerably below that of the fused material and below their own melting points.

In carrying out this method, I may keep the retaining material below its own melting point as well as below the solidification temperature of the material being cast, by the absorption of heat from the retaining material by a backing material which has a high thermal conductivity and a high capacity to absorb heat and is present in an amount which has a total capacity to absorb the heat of fusion of the material being cast and any superheat carried by that material, which maintaining its supporting surface below the melting point of the retaining material and below its own melting point. In this embodiment of my method, I do not utilize a circulating coolant to withdraw heat from the backing material.

Alternatively, I may affirmatively withdraw heat from the backing solid by the use of a circulating coolant at a rate which keeps its supporting surface below the melting point of the retaining material and below its own melting point rather than relying entirely upon the heat capacity of the backing solid to absorb the heat of fusion and any superheat carried by the material being cast.

In each of these alternative embodiments of my method, the relatively low temperature at which the supporting surface of the backing material is maintained, prevents the complete fusion of a thin layer or skin of the retaining material directly adjacent the surface of the backing material during the casting operation.

In carrying out this method, I merely bring the fused material into contact with the retaining surface of the mold and permit the supporting material of the mold to absorb heat from the fused material through the solid layer of retaining material until at least the outer portions of the material being cast have solidified, and then remove the partially, or completely solidified material from contact with the retaining surface of the mold. In general, I prefer to completely solidify the casting of the fusible material which is in contact with the mold surface to avoid the problems involved in handling a casting which is superficially solidified, but which has a still molten interior.

In this casting operation, the surface of the retaining material in contact with the fused material being cast is usually heated above its melting point, at least at the beginning of the operation, with the result that a surface layer of the retaining material melts. This superficial melting of the retaining material is highly advantageous and is, I believe, an important factor contributing to the advantageous features provided by this invention. However, it is essential that a thin, solid layer or skin of the retaining material be present on the surface of the backing material at all times during the casting operation.

The mold in accordance with this invention comprises in combination a retaining solid and a backing solid. The retaining solid forms the surface with which the fused material being cast comes into contact. It has a relatively low thermal conductivity, a melting point below that of the fusible material being cast, and is immiscible with the fused material being cast when it is itself in a fused state. The backing solid which provides a supporting surface for the retaining solid is one which is capable of absorbing the heat of fusion of the fused material being cast, and any superheat which it may carry with or without the assistance of a circulating coolant, without permitting the temperature of the retaining solid to rise to a point such that it is completely fused during the casting operation.

The mold in accordance with this invention may com-

prise a backing solid having a high capacity to absorb heat as well as high thermal conductivity, which is present in an amount which has the capacity to absorb the total heat of fusion of the material being cast together with any superheat carried thereby, while maintaining its supporting surface in contact with the retaining material, below the melting point of the retaining material. This form of my mold has no provision for forced cooling as by means of a circulating coolant, although in some modifications the backing solid may lose some heat by radiation or by conduction to its surrounding environment. For brevity, this form of my mold will be referred to hereinafter as a "massive mold."

An alternative form of this mold is provided with means for the forced cooling of its backing solid, which is a material of higher thermal conductivity than the material which forms the retaining material of the mold. It may, but need not be, a material of high heat capacity. This forced cooling capacity of the backing solid of this alternative form of my mold must be adequate to remove heat from the backing solid at a rate which keeps its supporting surface below its own melting point and below that of the retaining material carried by its supporting surface. The means for the forced cooling of the backing solid of this mold may be a coolant liquid circulated through channels within the body structure of the backing solid. This alternative form of my mold is referred to hereinafter as the "fluid-cooled mold."

The essential characteristics of the backing solid of this mold are physical strength, a thermal conductivity which is materially higher than that of the retaining solid which it supports, and chemical non-reactivity with respect to the retaining solid. The backing solid may, like the retaining solid, have a melting point lower than that of the fusible material which is cast in the mold. However, the melting point of the backing material need not be lower than that of the fusible material which is cast in the mold, whereas it is essential that the retaining material have such a lower melting point to secure the major advantages provided by this invention. In the alternative form of my mold in which no provision is made for the forced cooling of the backing solid, it also must have the capacity to absorb heat at a relatively high rate and be present in amount such that its total heat capacity is sufficient to absorb the superheat and at least a substantial portion of the heat of fusion of the material being cast.

Any solid material having high thermal conductivity and reasonably good structural strength is suitable for use as the backing solid for my mold. The structural metals are generally suitable for use as the backing solid of the alternative form of my mold which is provided with means for forced cooling. In the form of my mold which includes no means for forced cooling, the particular metal used must be selected in view of the thermodynamic characteristics of the fusible material 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 and can be used even in the casting of steel, since the retaining material prevents the steel from picking up the graphite. In general, I have found that copper and its various alloys are widely useful as the backing solid of my mold.

The particular material which I use to form the retaining surface of the mold in this method is determined by the characteristics of the fused material which is to be cast. As will be appreciated from the foregoing, the retaining material must have the following essential 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,

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

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

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

I have found the inorganic salts, mixtures of inorganic salts, inorganic oxides and mixtures of inorganic oxides are generally suitable materials from which to select a satisfactory material for the formation of the retaining surface of my mold for the casting of the usual fusible materials. 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	

It is to be noted that each of the above-listed inorganic salts are crystalline in nature and have definite melting points and are capable of existing in both the liquid and the solid phases at their melting points, depending upon the thermodynamic balance involved in furnishing or withdrawing the heat of fusion of the salt.

The sharp melting points of these salts are particularly advantageous in their use as a retaining material forming an essential component of the mold in accordance with this invention, since it is quite advantageous to maintain a sharply defined interface within the layer of the retaining material between a solid layer of that material on the internal surface of the supporting material of the mold and a liquid layer of the retaining material adjacent the material being cast. The solid layer protects the surface of supporting material, while the liquid outer layer provides an inherently smooth surface adjacent the solidifying surface of the fusible material being cast, and at the same time acts as an effective lubricant for the upward movement of the casting within the mold. This lubricating action avoids the galling action inherent in the movement of one solid surface over another solid surface.

Slags, although generally in the nature of silicate glasses, may be used as retaining materials provided that their composition is such that their drop in viscosity from an apparently solid phase to a liquid phase which has a reasonably low viscosity occurs over a narrow range of temperature below the melting point of the fusible material being cast. However, inorganic salts having true melting points are generally to be preferred to such slags.

As noted hereinbefore, in carrying out the casting operation in accordance with this invention, it is desirable to have the surface of the retaining material, which is in contact with the fusible material being cast, superficially melted, but it is essential that the retaining layer of the mold not be permitted to completely fuse at any time during a given casting operation. A solid layer or film of the retaining material must be kept on the surface of the backing material of the mold throughout each casting operation. Therefore, the melting point of the retaining

material determines the maximum temperature to which the mold can rise during the casting operation.

The rate at which heat is withdrawn from the layer of retaining material of the mold as compared with the rate at which heat passes from the fused material being cast into the retaining layer determines whether or not the entire thickness of the retaining layer of the mold can reach or exceed its melting point during a casting operation. The rate at which heat passes into the layer of retaining material is determined by the weight of the fusible material which is being cast and upon its thermodynamic characteristics. The rate at which heat passes from the layer of the retaining material to the backing material of the embodiment of my mold in which the backing material is cooled by a circulating coolant is determined by the rate at which heat is delivered to the mold, by the thermal conductivity of the retaining layer and by the thermal conductivity, thickness and mechanism of cooling of the backing material. In steady operation in which no part of the mold is changing temperature, this mold acts only to transfer heat by conduction from the cast metal to the cooling medium. However, from a practical standpoint, even the fluid cooled mold must have the capacity to withstand the sudden transient heating which occurs when liquid metal is brought into contact with the retaining surface, without complete fusion of the retaining layer at any point. This capacity is a property of the metal of which the mold is made, and of the initial temperature of the mold, and has nothing to do with the nature and extent of the fluid cooling. In the alternative embodiment of my mold in which no circulating coolant is used, the rate at which heat passes from the layer of retaining material to the backing material of the mold depends upon the weight of the backing material present and its thermodynamic characteristics.

As will be appreciated from the foregoing discussion, the common and essential requirement in the use of the alternative forms of my mold is that the retaining material, with its melting point below the solidification temperature of the material being cast, must be adequately cooled by the backing material so that the temperature of the interface between the retaining material and the supporting surface of the backing material never, for any reason, approaches the melting point of the retaining material. In carrying out this method, I have found that I am able to meet this common and essential requirement by correlating the thermodynamic characteristics required of the mold with the thermodynamic characteristics of the fusible material being cast in each operation, by the use of ten thermodynamic equations which are given hereinafter.

Of the ten equations given hereinafter, Equations I, II and III apply to the use of the massive mold in a casting operation, while Equations I, II, IV and V apply to the use of a fluid cooled mold. Stated in another way, I have found in the use of a massive mold in a given casting operation, that when the requirements of Equations I, II and III are met, the solid layer of the retaining material is maintained on the supporting surface of the mold at all times, and the casting operation is successful. Similarly, in the use of a fluid-cooled mold in a given casting operation, I have found that when the requirements of Equations I, II, IV and V are met, that a solid layer of retaining material is maintained on the supporting surface of the mold at all times and the casting operation is successful.

The thermodynamic requirements for a massive mold in a given casting operation will first be considered and exemplified with reference to Equations I, II and III. As already noted hereinbefore, a fluid-cooled mold must have the thermal capacity to withstand sudden transient heating which occurs when a fused material is brought into contact with its retaining surface, without complete fusion of the retaining layer at any point. For this reason, the fluid-cooled mold, like the massive mold, must meet the requirements of Equations I and II. The description of the application of Equations I and II to a fluid-cooled mold. Equations IV and V apply only to a fluid-cooled mold specifically exemplified following the discussion of the thermodynamic of the massive mold.

In the casting of any given quantity of a fusible material, the maximum temperature reached by the massive mold is determined by its own heat absorbing capacity as well as by the amount of superheat carried by the fused material at the time it is brought into contact with the retaining surface of the mold, and the thermodynamic characteristics of the fused material. The heat absorbing capacity of the massive mold, as a whole, is for practical purposes, that of its backing material, and is determined by the amount of the backing material present and its thermodynamic characteristics. The heat absorbing capacity of the backing material of the massive mold is its thermal conductivity, multiplied by its density and by its specific heat, which may be expressed as:

$$K\rho C_p$$

in which:

K=thermal conductivity in B.t.u. per foot per hour in degrees Fahrenheit.

ρ=density in pounds per cubic foot.

C_p=specific heat in B.t.u. per pound in degrees Fahrenheit.

The heat capacity required in the massive mold is determined by the amount of the fusible material which is being cast in each operation, the melting point of the fusible material, the amount of superheat which it carries upon its initial contact with the retaining surface of the mold, and its physical and thermodynamic characteristics. Therefore, I determine the quantity of the backing material which is required for a given casting operation in terms of its own thermodynamic properties, the quantity of the fusible material being cast, the thermodynamic characteristics of the fusible material being cast and the thermodynamics of the casting operation itself.

By the use of Equations I and II given below, I determine the heat absorbing capacity which is required of my massive mold for a given casting operation, to give a predetermined, maximum, initial temperature for the mold at the beginning of each casting operation and a predetermined, maximum temperature during the particular casting operation with which I am concerned. As already noted, the maximum temperature which I can permit the mold to reach in this method must be below the melting point of the retaining material of the mold, and I prefer to have it well below that temperature to provide a factor of safety to compensate for unexpected superheat in the fused material being cast, turbulence in the mold when the fused material is poured and other disturbing influences which may enter into the casting operation. I have found that, in routine casting operations, it is desirable to keep the maximum temperature of the backing material of the mold at least 250° F. below the melting point of the retaining material, in the casting of materials such as, for example, steel and copper, which have relatively high melting points. This temperature differential of 250° F. provides a safety factor which more than compensates for the loss in thermodynamic efficiency involved in narrowing the temperature ranges utilized. In the casting of fusible materials which melt at considerably lower temperature than, for example, steel, a smaller safety factor, i.e., a smaller temperature differential, is entirely adequate.

It is desirable, but not essential, to use a massive mold which can be used at a relatively high initial temperature since such a mold does not require complete cooling between successive casting operations. In general, I have found that it is desirable in the practical use of this invention to utilize as my mold a combination of a retaining

material and a backing material in any given casting operation which permits the use of a mold temperature at the beginning of the casting operation which is substantially above ambient temperatures. As can well be appreciated, the higher the permissible initial mold temperature, the less time must be spent between successive casting operations and, hence, the more efficient the operations involved.

After determining the heat absorbing capacity required of my massive mold for the particular casting operation involved by the use of Equations I and II, I then determine the quantity of the backing material which I must include in the mold to cause it to operate within the desired temperature range by the use of Equation III.

EQUATION I

$$\frac{(T_m-T_s)C_p'}{H\sqrt{\pi}}=ne^{n^2}\,erf\ n$$

In this equation:

T_m=melting point of fusible material being cast in degrees Fahrenheit.

T_s=highest temperature which the retaining material is to reach.

C_p'=the specific heat of the fusible material being cast when it is in the solid phase, expressed in B.t.u. per pound in degrees Fahrenheit.

H=heat of fusion of the material being cast in B.t.u. per pound.

erf=error function.

e=2.718 (the base of Naperian logarithms).

n=the parameter relating Equation I to Equation II.

Equations I and II are parametric equations which are related by the parameter "*n*." Equation I is solved to determine the value of "*n*" which is then substituted in Equation II to determine the value of K_pC_p.

Equation I is transcendental as to "*n*," since "*n*" can be evaluated only by a trial and error procedure. In the solution of this equation the numerical value of the left-hand side of the equation is determined by the substitution of the numerical values of the terms of that side of the equation which apply to the contemplated casting operation. To determine the value of "*n*" which will give the product:

$$ne^{n^2}erf\ n$$

equal to the numerical value of the left-hand side of the equation, a value of "*n*" is arbitrarily selected and the value of the product determined. If this product is larger than that of the left-hand side of the equation, another trial value for "*n*" is selected and the process repeated. This process is repeated until a value for "*n*" is found which gives a product equal to that of the left-hand side of the equation.

The "*erf*" or "error function" of a given number is a tabulated factor which is to be found in reference tables. Tables of "error functions" may be found, for example, in the reference entitled "Transcendental Functions" by Flugge or in "Heat Conduction" by Ingersol and Zobel. In the solution of Equation I, the error function corresponding to the trial value selected for "*n*" must be used.

To illustrate the solution of Equation I as applied to a specific set of casting conditions, the casting of copper may be selected in an operation in which the terms on the left-hand side of Equation I have the following numerical values:

T_m=1980° F.
T_s=1760° F.
C_p'=0.10 B.t.u./lb./° F.
H=88 B.t.u./lb.

The substitution of these values in the left-hand side of Equation I gives:

$$\frac{(T_m-T_o)C_p'}{H\sqrt{\pi}}=0.141$$

To determine the value of "*n*" in the right-hand side of the equation a trial value for "*n*" is arbitrarily selected and the product $ne^{n^2}erf\ n$ determined. This process is repeated using different values for "*n*" until a value for "*n*" is found which gives a product of 0.141. The product obtained with three different values of "*n*" are as follows:

Trial Value of n	n^2	e^{n^2}	$erf\ n$	Product ne^{n^2} $erf\ n$
0.30	0.09	1.094	0.3286	0.1078
0.40	0.16	1.1735	0.4284	0.2011
0.34	0.1156	1.1225	0.3694	0.1410

Thus, for the selected conditions for the casting of copper, the correct value for "*n*" for use in the solution of Equation II is 0.34.

Equation I is solved to determine the value of n which is then substituted in Equation II to determine the value of $K\ C_p$. This equation is transcendental and therefore must be solved numerically by trial and error.

EQUATION II

$$\frac{(T_m-T_0)C_o'}{H\sqrt{\pi}}=ne^{n^2}\left(\sqrt{\frac{K'\rho'C_p'}{K\rho C_p}}+erf\ n\right)$$

In this equation:

T_0=the initial temperature of the mold in degrees Fahrenheit,

K'=the thermal conductivity of the fusible material being cast, when it is in the solid phase, expressed in B.t.u. per foot, per hour in degrees Fahrenheit,

ρ'=the density of the fusible material being cast in pounds per cubic foot.

K, ρ and C_p have the same significance as in the formulae given hereinbefore for the heat absorbing capacity of the backing material of the mold.

EQUATION III

$$\frac{W_c}{W_m}=\frac{C_p(T_s-T_o)}{C_p'(T_m-T_s)}+H$$

In this equation:

W_c=weight of the casting of the fusible material being made in mold,

W_m=weight of the supporting material.

The remaining characters in this equation have the same significance as in Equations I and II.

Equations I and II are, in effect, a single equation since they are tied together by the numerical factor "*n*." The solution of Equation I to determine the value of "*n*" for a given combination of a fusible material, a retaining material and a backing material permits the use of Equation II for the determination of the feasibility of using the particular combination and for determining the conditions under which the casting operation can be carried out.

The applications of Equations I, II and III in the method of this invention are specifically illustrated in my application Serial No. 737,176 filed December 11, 1957. In that illustration, the casting of steel and copper, respectively, in barium chloride-copper and barium chloride-steel massive molds are considered. The casting of steel and copper were chosen for illustrating the invention for the reason that both are recognized to be difficult casting operations. Steel is difficult because of its high melting point, while copper is even more difficult due to its high heat capacity. While as brought out by these examples, a barium chloride-steel mold is barely operable for the casting of steel and is inoperable for the casting of copper, such a mold is entirely suitable for the casting of many less difficult fusible materials.

The thermodynamics of the fluid-cooled mold will now be considered and exemplified. The use of a fluid-

cooled mold for a single casting is governed by the foregoing Equations I and II. When such a mold is used for continuous or for semi-continuous casting, the thermodynamics involved must fulfill the requirements of Equations I and II, but also must meet the requirements of Equations IV and V. In the application of Equations I and II to a fluid-cooled mold, the various symbols of those equations have the same meaning as when applied to a massive mold with the single exception of T_o which is defined as follows for application to a fluid-cooled mold:

T_o=temperature of the surface of the backing material from which heat is withdrawn by a coolant.

Equations IV and V apply to the functioning of a fluid-cooled mold as a continuous conductor of heat from the fusible material being cast to the fluid cooling medium. These equations are as follows:

EQUATION IV

$$\frac{T_b-T_o}{F}=\frac{t}{K_b}+\frac{L}{K}$$

EQUATION V

$$\frac{T_i-T_o}{T_b-T_o}=\frac{L/K}{t/K_b+L/K}$$

In these equations as in Equations I and II:

K=the thermal conductivity of the backing material of the mold in B.t.u. per foot per hour in degrees Fahrenheit.

The remaining symbols in these equations have the following meanings:

T_b=the melting point of the retaining material of the fluid-cooled mold,

T_i=the temperature of the surface of the backing material which carries the retaining material of the fluid-cooled mold,

F=rate of heat flow per unit area in B.t.u. per square foot per hour,

t=thickness of the layer of the retaining material in feet,

K_b=thermal conductivity of the retaining material in B.t.u. per foot per hour per degrees Fahrenheit,

L=thickness of the backing material in feet between its surface carrying a retaining material and its surface from which heat is withdrawn by a coolant.

When Equations IV and V are applied to a fluid-cooled mold used in intermittent or semi-continuous casting, the terms F, t, and T_i must be regarded as average values, since each of these quantities fluctuate during such casting.

It will be noted that Equations IV and V do not take into account the specific heat of the backing material or of the retaining material of the fluid-cooled mold, and are concerned only with the thermal behavior of the mold in the transfer of heat by conduction from the fused material being cast to the fluid coolant. Since the mold functions entirely as a continuous conductor, not as a heat absorber as in the case of the massive mold, no specific heat term is required by either Equation IV or Equation V.

The application of Equations IV and V to the use of a fluid-cooled mold is illustrated by my application Serial No. 737,176 filed December 11, 1957 by the casting of steel using a mold having a water-cooled backing and using barium chloride as a retaining material. The particular form of the mold chosen for that illustration is different from that used in the specific method of this invention. However, the thermodynamic facts shown by that illustration are fully applicable to the form of mold used in the method of this invention.

The method in accordance with this invention provides a series of important advantages disclosed in my application Serial No. 737,176 which are summarized hereinbefore. In the operation of the method in the specific manner disclosed for continuous upwardly casting, I have found that I achieve an important additional advantage in carrying out this specific method by the control of the pressure exerted on the inner surface of the initially solidified skin of the fusible material being cast by the molten fusible material in contact therewith with respect to the pressure exerted on the outer surface of the skin by the molten retaining material in contact therewith.

At the bottom of the mold, the solidifying is the thinnest and the hottest and therefore the weakest that it is at any point in the casting operation. The control of the pressure differential across this solidifying skin can be utilized to eliminate any tearing of the thin skin of the solidified skin with resulting defects in the surface of the finished casting. Usually, it is desirable to keep the pressures on the two surfaces of the solidifying skin substantially the same. However, there are conditions of operation in which it is desirable to have either a higher or lower pressure on the inner surface of the solidifying skin.

The pressure on the inner and outer surfaces of the solidifying skin of the casting by the molten material being cast and by the molten layer of retaining material, respectively, are controlled by the adjustments of their respective hydrostatic heads. The pressure differential across the solidifying skin can be calculated as described hereinafter with reference to Equations VI, VII and VIII.

Although the method of this invention is ordinarily carried out to cast a fusible material in a substantially vertical upwardly direction, it may be operated at an angulation to the vertical. In either case, the pressures exerted by the fused retaining material and by the molten material being cast at the points at which the molten material is being cast depends upon the vertical altitude of this upper surface above some fixed reference point. This reference point is taken for the purposes of Equations VI, VII and VIII as the bottom of the cooled mold support and is considered zero altitude for the purposes of these equations.

Within this frame of reference, the pressure at any point within the fused material being cast which is above zero altitude is given by the following equation:

EQUATION VI

$$P_m=(h_m-h)\rho_m$$

in which:

h=altitude at a given location above zero altitude in the fused material being cast,

P_m=gage pressure in the fused material being cast in pounds per square inch at altitude, h, inches,

h_m=altitude in inches of the top surface of body of fused material from which the lower or entrance end of the mold is fed,

ρ_m=density of fused material being cast in pounds per cubic inch.

At any point within the fused portion of the retaining material of the mold, with reference to the same zero altitude used for Equation VII, the pressure is given by the following equation:

EQUATION VII

$$P_r=(h_r-h)\rho_r$$

in which:

h=altitude at a given location above zero altitude in the liquid portion of the retaining material,

P_r=guage pressure in the liquid part of the mold in pounds per square inch at altitude, h, inches,

h_r=altitude in inches of the top surface of the retaining material of the mold,

ρ_r=density of the liquid retaining material in pounds per square inch.

The pressure difference across the solidifying skin of a casting at an altitude h, is given by subtracting Equation VII from Equation VI to give the following equation:

EQUATION VIII

$$\Delta P=(h_m\rho_m-h_r\rho_r)-h(\rho_m-\rho_r)$$

in which:

ΔP=pressure difference across the solidifying skin. Since Equation VII was subtracted from Equation VI to obtain Equation VIII, the sign convention of Equation VIII is that when ΔP has a positive value, the pressure in the liquid region of the material being cast exceeds that in the liquid retaining material at the alitude h. On the other hand, ΔP has a negative value when the pressure in the liquid retaining material is the greater of the two pressures at altitude h.

It will be appreciated from a consideration of Equation VIII that its first group of terms in parenthesis or the second group in parenthesis may be positive or negative depending upon the liquid heights which are used are used and the relative densities of the two liquids involved. Thus, it will be appreciated that this method for the adjustment of pressure on the casting is flexible as to the pressure which can be applied and convenient to use.

In the apparatus of this invention, the altitude h_m of the top surface of the material being cast or the altitude h_r of the top of the molten retaining material of the mold is determined generally by specific design and dimensions of the apparatus involved, but either can, within limits, be readily adjusted. The basic design of the apparatus, particularly as to the relative altitudes involved is determined in view of the density of the retaining material which forms a part of the mold and that of the fusible material to be cast by the use of the apparatus.

Example I illustrates a specific application of Equation VIII to the operation in which molten steel is cast in a mold of this invention which includes barium chloride as its retaining material. In the illustration of Example I, the effect of the altitude h_r of the top of the molten barium chloride on the pressure in the solidification is considered in connection with an apparatus in which the altitude, h_m, of the top surface of the molten steel is 72 inches.

Example I

The constants for use in Equation VIII are:

h_m=72, the altitude of the top of the molten steel.
ρ_m=0.26 lbs. per cubic inch, the density of molten steel.
ρ_r=0.15 lbs. per cubic inch, the density of molten barium chloride.

As noted hereinbefore, it is desirable to maintain the pressure difference across the solidifying skin of the casting near the bottom of the mold where the skin is the thinnest and therefore the weakest at a minimum. At the entrance to the mold ($h=o$), it is desirable to have no pressure differential ($\Delta P=0$). Equation VIII, using:

$$\Delta P=0$$

and

$$h=o$$

is reduced to:

EQUATION IX

$$h_m\rho_m=h_r\rho_r$$

$$h_r=\frac{h_m\rho_m}{\rho_r}=\frac{72\times 0.26}{0.15}=125 \text{ inches}$$

Therefore, to obtain a zero pressure differential at the bottom entrance of the mold, the depth of the liquid barium chloride above the bottom of the mold must be maintained at 125 inches. When the bottom of the mold is maintained at zero pressure, the first group of terms of Equation VIII is cancelled out of the equation, since it becomes zero. The pressure difference ΔP at any given location above the bottom of the mold is therefore given by the equation:

EQUATION X

$$\Delta P=-h(\rho_m-\rho_r)$$

The minus sign in Equation X means that the external pressure applied by the molten barium chloride is greater than the opposing pressure exerted by the molten steel. For a mold using barium chloride as a retaining material in the casting of steel, Equation X becomes

$$\Delta P=-h(0.26-0.15)=-h\ 0.11$$

Thus, in the case of a sump of molten metal extending upwardly for a height of 9 feet within the solidifying casting, the external pressure ($-\Delta P$) on the relatively thick wall of the casting at its upper end is a rather high 12 pounds per square inch. At an altitude of 4.5 feet halfway up the sump, the external pressure ($-\Delta P$) on the solidifying wall of the casting is 6 pounds per square inch.

This Example I illustrates the value of this control of the pressures exerted on the casting by this method of controlling the hydrostatic heads of the material being cast and of the liquid retaining materials. The advantage of maintaining a zero pressure differential of the initial thin skin of the casting is noted hereinbefore. As shown by Example I, when this zero pressure differential is maintained at the bottom of the mold when using barium chloride as a retaining material, another retaining material having a lower density than the molten steel or other fusible material being cast, a positive external pressure is exerted on the outer solidified surface of the casting, which progressively increases as the wall of the casting becomes progressively thicker. This positive external pressure on the external wall of the solidifying casting is advantageous in that it maintains the integrity of the casting and results in improved internal grain structure.

A consideration of the foregoing shows that it is possible to reverse the above-described progressive increase in pressure by the use of a retaining material which in the molten state has a density higher than that of the fused material being cast. When maintaining a zero initial pressure at the bottom of the mold, this combination results in a progressively higher pressure differential with the internal pressure within the sump being the higher pressure. This positive internal pressure pushes outwardly and is advantageous in the casting of materials which have a low resistance to plastic deformation after solidification, but while still hot. The outward pressure keeps the external surface of the casting in close contact with the mold surface and avoids any plastic deformation while the external walls are relatively hot.

This method for the control of the pressure applied to the casting is particularly well adapted for use in the upwardly casting molds of this invention which utilize the basic principles set forth by my application Serial No. 737,176 of which this application is a continuation-in-part. It is, however, by no means limited to applications involving this type of mold, since it does not involve the thermal characteristics of either the backing material of the mold or of its retaining material. Nor does it involve the maintenance of a solid film of a retaining material on the surface of a backing material. Therefore, this method of pressure control can be utilized in connection with conventional upwardly casting molds by the substitution for the specific retaining material of any material which has the following characteristics:

(1) Relatively low volatility at the casting temperature,

(2) A solidification temperature lower than the lowest temperature to which the casting is cooled while in the mold; and

(3) Immiscibility with the material which is being cast.

In the application of this method for pressure control

in the use of conventional upwardly casting molds, the liquid used need not have a low thermal conductivity such as that required in the case of the retaining material used in the method involving the principles of my application Serial No. 737,176. To the contrary, a high thermal conductivity is advantageous and metals may be advantageously used as the liquid material which controls the pressure on the casting. For example, molten lead may be advantageously used as the pressure control liquid in the casting of steel.

Specific embodiments of both the method and the mold of this invention will be described with reference to the accompanying drawings in which like reference characters are used to refer to like parts. In the drawings:

FIGURE 1 is a diagrammatic elevational view, in partial cross-section, of the fluid cooled casting mold and associated apparatus in accordance with this invention for the continuous casting of a fusible material in an upwardly direction; and

FIGURE 2 is a diagrammatic elevational view, in partial cross-section, of a second embodiment of a fluid cooled mold for the continuous casting of a fusible material in an upwardly direction.

The apparatus illustrated by FIGURES 1 and 2 are specifically described hereinafter as using copper as the "backing material" and barium chloride as the "retaining material" of each of the casting molds described with reference to those figures. Further, the description refers to molten steel as the "fusible" material which is cast in each of the forms of the apparatus. These particular materials are specified for the purpose of simplifying the description of the figures. It will be appreciated from the foregoing disclosure of the basic principles involved in the selection of the retaining material and the backing material of the casting mold of this invention that they are specifically selected in view of the particular fusible material being cast. Materials other than the combination of copper and barium chloride can be used in the apparatus for the casting of steel in the apparatus of FIGURES 1 and 2. Other combinations can also be used for the casting of other fusible materials, and as will be appreciated from the principle set forth above, barium chloride cannot be used for the casting of a fusible material having a melting point below its own melting point.

Referring specifically to FIGURE 1, the numeral **10** designates a tundish from which molten steel can be poured in an accurately controllable stream into receptacle **12** through the thermally insulated conduit **11**. The receptacle **12** is thermally insulated and provided with heating means such as, for example, an electrical resistance winding **13**. In the operation of the apparatus, the receptacle **12** provides a hydraulic leg and is the source of molten steel entering the bottom of the casting mold designated generally by the numeral **14**.

The mold **14** consists of a lower section **15** and an upper section **16**. The lower section **15** consists of a copper shell **17** which carries a cooling coil **18** which has inlet and exit conduits for a cooling fluid not shown by the drawing. A lower section **19** of the copper shell **17** is cylindrical in cross-section, while its upper section **20** is slightly tapered. The length of the lower section **19** is that required to form a solid shell of steel which is thick enough to retain its shape as the casting emerges from the upper end of this section. The outer surfaces and lower end of the copper shell **17** carry a layer **21** of a refractory insulating material such as, for example, a magnesium oxide cement. The lower end of the copper shell is open forming an orifice for the entrance of steel into the interior of the mold.

The inner surface of the copper shell carries a solid layer of barium chloride **22** the thickness of which is automatically adjusted by the conditions under which the mold is operated as explained hereinbefore. The inner surface of the layer of solid barium chloride on the inner surface of the lower section **19** of the shell **17** has in cross-section the shape and cross-section desired for the cross-section of the casting which is formed in and by the mold. This shape is controlled by the shape of the inner surface of the section **19** of the shell **17**. Although this section **19** has been referred to as cylindrical and FIGURE 1 illustrates the production of a cylindrical casting, the cross-section of the section **19** can be varied widely and may be complex to produce delicate molding of the casting.

The upper section **16** of this casting mold consists of a chamber **23** containing a body of molten barium chloride **24**. The chamber **23** is an enlarged continuation of the channel formed by the copper shell **17**. The cooling or heating coil **25** is adapted to carry a circulating stream of a coolant or a heating fluid to control the temperature of the molten barium chloride within the chamber **23**. The chamber **23** is provided with an inlet conduit **26** for the molten barium chloride.

Two pairs of friction rollers **27, 27** and **28, 28** are located one above the other directly above the channel formed by the inner surface of the solidified barium chloride liner **22** with their nips in alignments with the axis of the mold channel. These rolls are provided with synchronized, variable speed drivers and are spaced a distance which will permit the cutting of the casting, for example, by a flame as it passes upwardly from the lower to the upper pair of rolls.

To start the continuous casting of molten steel by the apparatus illustrated by FIGURE 1, a length of a steel casting having a cross-section which is of the same cross-sectional shape and dimensions as that which is to be continuously produced is inserted downwardly between the friction rolls **28, 28** and **27, 27** to the lower end of the copper shell **20**. The circulation of a coolant through the coil **18** is then started to chill the copper shell **20** to a temperature below the melting point of barium chloride. The space in the copper shell **20** and in the chamber **23** is then filled with the body **24** of molten barium chloride. The molten barium chloride freezes on the inner surface of the copper shell **20** to form the solid liner **22** of barium chloride on its inner surface. Molten steel is then poured into the receptable **12** to fill it to a level above the lower end of the mold **14**. The friction rolls **27, 27** and **28, 28** are then placed into operation to pull the initial length of the precast steel from the mold and continued in operation to pull the newly produced casting from the mold as it forms therein. It will be appreciated that the initial end of the newly forming casting welds itself to the lower end of the precast steel casting inserted into the mold in this initial operation.

Molten metal is then continuously poured into the receptacle **12** at a uniformly controlled rate. I prefer to utilize underpouring in which the metal is tapped from the bottom of molten metal in the tundish **10** and introduced into the receptacle **12** by means of a tubular duct **11**, since it insures a casting free of slag inclusions and delivers the metal to the receptacle **12** with minimized metal oxidation. To further protect the metal from oxidation, I prefer to maintain a reducing atmosphere over the furnace pouring spout, tundish **10** and within the receptacle **12**.

The circulation of the coolant through the coil **18** withdraws heat from the copper shell **17**, from the internal lining layer of solid barium chloride and from the molten metal. The rapid withdrawal of heat from the layer of solid barium chloride prevents its complete fusion by the heat from the molten metal and the withdrawal of heat from the molten metal causes it to form a skin of frozen metal over its surface which porgressively thickens and tends to pull away from the surface of the solid barium chloride as the metal moves upwardly through the mold. As the casting shrinks in moving upwardly through the mold, the layer of frozen barium

chloride thickens since there is a lessening of the thermal contact between its surface and that of the moving casting until its thickness reaches a point such that no further increase can occur due to a reduction of the rate of heat transfer through the solid film. At this point, the molten barium chloride fills the void between the moving casting and maintains effective heat transfer. This also maintains a solid and liquid support for the surface of the moving casting and avoids any localized remelting of the frozen shell which has heretofore created serious difficulties in continuous casting operation of this general type.

The outer shell of the casting continues to thicken as it passes upwardly through the molten barium chloride, while good thermal contact is maintained at the solid-liquid interface between the solid outer surface of the casting and the molten barium chloride. Upon emerging from the mold, the casting passes through the nip of the driven friction rolls **27**, **27** and then through the nip of the friction rolls **28**, **28**. If desired, the casting may be subjected to further cooling between the point at which it leaves the molten barium chloride **24** and the point at which it enters the nip of the rolls **27**, **27** as, for example, by an air blast or a spray of a liquid coolant, such as, for example, water. When the casting has reached the desired length in passing through the nip of the rolls **28**, **28** it is cut between the rolls, for example, by the known flame cutting technique in which a torch assembly is attached to the moving casting.

In this operation, the rate at which molten steel is poured into the receptacle **12** and the speed of the friction rolls are kept in balance to maintain a substantially constant liquid level in the receptacle **12**. The rate at which the molten steel is poured into receptacle **12** is adjusted by the spacing provided between the valve seat **29** and the valve closure **30**. This constant liquid level maintains a uniform hydrostatic pressure and a uniform rate of delivery of the molten metal at the bottom of the mold **14**.

In the operation of this apparatus, the temperature of the steel entering the mold **14** and the rate at which heat is withdrawn from copper shell **17** are kept in balance so that the inside of the copper shell is at all times coated with a solid layer of barium chloride. This solid layer barium chloride acts to protect the copper shell from melting and offers the numerous other advantages described elsewhere in this specification.

In utilizing the apparatus illustrated by FIGURE 1 to carry out the preferred embodiment of the method in accordance with this invention, I prefer to maintain a precalculated differential between the level of the surface **31** of the molten steel in receptacle **12** and the level of the surface **32** of the molten barium chloride in chamber **23** to control the pressure to which the thin skin of steel forming in the lower section **19** of the mold is subjected. The desired differential is calculated as described and illustrated hereinbefore with reference to Equation VIII and specifically illustrated by Example I. In general it is desirable to keep this pressure at a minimum to prevent any tearing of the thin skin of metal as the casting is pulled upwardly.

In the use of Equation VIII in connection with the apparatus illustrated by FIGURE 1, the zero reference point for determining altitude is the bottom of the mold **14** designated by the numeral **33**, while h_r is the distance in inches from the bottom **33** to the top **32** of the barium chloride. The symbol h_m of Equation VIII designates the vertical distance between the bottom **33** of the mold and the top **31** of the molten steel. The top of the sump within the solidifying casting is designated by the numeral **34**.

After the desired values for h_m and h_r are established by the use of Equation VIII, the level of **31** and **32** are adjusted to secure the values calculated for h_m and h_r which are, respectively, maintained by the adjustment of the feed of molten metal to receptacle **12** from the tundish **10** and the replenishment of the barium chloride **24** by a regulated feed of molten barium chloride through the conduit **25**.

FIGURE 2 illustrates an alternative form of a casting mold and associated apparatus for the continuous casting of metal in an upwardly direction by the method of this invention. Referring specifically to that figure, the numeral **41** designates a tundish from which molten steel can be poured in an accurately controllable stream into receptacle **42**. The receptacle **42** is thermally insulated and provided with heating means, such as, for example, an electrical resistance winding **43**. The receptacle **42** acts as a hydraulic leg and is connected by a thermally insulated conduit **44** to the bottom of the casting mold designated generally by the numeral **45**.

The mold **45** consists of a lower section **46** and an upper section **47**. The lower section **46** consists of an inner shell **48** and an outer shell **49** spaced apart to form a coolant chamber **50** which is closed at its upper and lower ends by the end sections **51** and **52**, respectively. The inner shell **48** is made of copper, while the outer shell **49** may be made of any structural metal. The outer shell **49** is provided with inlet and exit conduits **53** and **54**, respectively, through which a coolant, such as, for example, water is circulated through chamber **50** to cool the copper shell **48**. The chamber **50** may, if desired, be provided with suitable baffles to direct the flow of the coolant to insure uniform cooling of the copper shell **48**.

The inner surface of the copper shell **48** carries a solid layer of barium chloride **55** the thickness of which is automatically adjusted by the conditions under which the mold is used in a continuous casting operation as explained hereinbefore. The inner surface of the solid barium chloride linner **55** has in cross-section the shape desired for the cross-section of the casting which is formed in and by the mold. This shape is controlled by the shape of the inner surface of the copper shell **48** and can be varied widely and be complex to produce delicate molding of the casting.

The upper section **47** of the casting mold consists of a chamber **55***a* containing molten barium chloride **56**. The chamber **55***a* is an enlarged continuation of the channel formed by the copper shell **48**. The cooling or heating coil **57** is adapted to carry a circulating stream of a coolant or a heating fluid to control the temperature of molten barium chloride within the chamber **55***a*. The chamber **55***a* is provided with an inlet conduit **58** for molten barium chloride.

The lower end of the mold channel formed by the copper shell **48** and the layer of solid barium chloride **55** which it carries is closed by a bottom section **59**, through which passes the molten metal conduit **44**.

Two pairs of friction rolls **60**, **60** and **61**, **61** are positioned directly above the mold channel formed by the barium chloride layer **55** with their nips aligned with the axis of the mold channel. These rolls are provided with synchronized, variable speed drives and are vertically spaced apart a distance which will permit the cutting of the casting, for example, by a flame as it passes upwardly from the lower to the upper pair of rolls.

To start continuous casting of molten steel by the apparatus illustrated by FIGURE 2, a length of a steel casting having a cross-section which is of the same cross-sectional shape and dimensions as that which is to be continuously produced is inserted downwardly between the friction rolls **61**, **61** and **60**, **60** to the inner face of the bottom section **59** of the apparatus. The circulation of a coolant through the chamber **50** is then started and molten steel is poured into the receptacle **42** filling the conduit **44**. Molten barium chloride is then introduced through the conduit **58** to fill the chamber **55***a* and space between the copper shell **48** and the precast steel casting positioned therein. Molten steel is then poured into the

receptacle 42 to fill the conduit 44 and to establish a hydrostatic head in the receptacle 42. The friction rolls 60, 60 and 61, 61 are then placed in operation to pull the initial length of precast steel from the mold and continued in operation to remove the newly produced casting from the mold as it forms therein. It will be appreciated that the initial end of the newly forming casting welds itself to the lower end of the precast steel casting inserted into the mold in this initial operation.

Molten metal is then continuously poured into the receptacle 42 at a uniformly controlled rate. I prefer to utilize underpouring in which the metal is tapped from the bottom of molten metal in the tundish 41 and introduced into the mold by means of a tubular duct, since it insures a casting free of slag inclusions and delivers the metal to the receptacle 42 with very little turbulence and minimized metal oxidation. To further protect the metal from oxidation, I prefer to maintain a reducing atmosphere over the furnace pouring spout, tundish 41 and receptacle 42.

The circulation of the coolant through the chamber 50 withdraws heat from the copper shell 48, from the internal lining layer of solid barium chloride and from the molten metal. The rapid withdrawal of heat from the layer of solid barium chloride prevents its complete fusion by the heat from the molten metal and the withdrawal of heat from the molten metal causes it to form a skin of frozen metal over its surface which progressively thickens and tends to pull away from the surface of the solid barium chloride as the metal moves upwardly through the mold. As the casting shrinks in moving upwardly through the mold, the layer of frozen barium chloride thickens since there is a lessening of the thermal contact between its surface and that of the moving casting until its thickness reaches a point such that no further increase can occur due to a reduction of the rate of heat transfer through the solid film. At this point, the molten barium chloride fills the void between the moving casting and maintains effective heat transfer. This also maintains a solid and thin liquid support for the surface of the moving casting and avoids any localized remelting of the frozen shell which has heretofore created serious difficulties in continuous casting operations of this general type.

The outer shell of the casting continues to thicken as it passes upwardly through the molten barium chloride, while good thermal contact is maintained at the solid-liquid interface between the solid outer surface of the casting and the molten barium chloride. Upon emerging from the mold, the casting passes through the nip of the driven friction rolls 60, 60 and then through the nip of the friction rolls 61, 61. If desired, the casting may be subjected to further cooling between the point at which it leaves the molten barium chloride 56 and the point at which it enters the nip of the rolls 60, 60 as, for example, by an air blast or a spray of a liquid coolant, such as, for example, water. When the casting has reached the desired length in passing through the nip of the rolls 61, 61 it is cut between the rolls, for example, by the known flame cutting technique in which a torch assembly is attached to the moving casting.

In this operation, the rate at which molten metal is poured into the receptacle 42 and the speed of the friction rolls are kept in balance to maintain a substantially constant liquid level in the receptacle 42. This constant liquid level maintains a uniform hydrostatic pressure on the metal passing through conduit 44 and a uniform rate of delivery of the molten metal at the bottom of the mold 45.

In the operation of this apparatus, the temperature of the steel entering the mold 45 and the rate at which heat is withdrawn from copper shell 48 are kept in balance so that the inside of the copper shell is at all times coated with a solid layer of barium chloride. This solid layer barium chloride acts to protect the copper shell from melting and offers the numerous other advantages described elsewhere in this specification.

The preferred embodiment of the method in accordance with this invention can be carried out by the use of the apparatus illustrated by FIGURE 2 by maintaining a precalculated differential between the level of the surface 62 of the molten steel in the receptacle 42 and the level of the surface 63 of the body of molten barium chloride in the chamber 55*a*. As in the case of the similar height differential in the operation of the apparatus of FIGURE 1, the desired differential can be calculated as described and illustrated hereinbefore with reference to Equation VIII. This height differential controls the pressure on the skin of steel forming in the lower end of the mold 45. As noted hereinbefore, it is generally desirable to keep this pressure at a minimum.

In the use of Equation VIII in connection with the apparatus illustrated by FIGURE 2, the zero reference point for determining the altitude is the upper surface of the bottom 59 of the mold 45. The symbol h_r of this equation is the vertical distance in inches from the upper surface of 59 to the upper surface 63 of the body of molten barium chloride in the chamber 55*a*, while the symbol h_m is the vertical distance in inches from the upper surface of 59 to the horizontal of the lever 62 of the upper surface of the body of molten steel in the reservoir 42. The upper end of the sump of molten steel in the bottom of the solidifying casting is designated by the numeral 64.

After the desired value for h_m is selected, the reservoir is filled to the level required to give the indicated number of inches between the inner surface of the bottom 59 of the mold and the horizontal level of the surface 62 in the reservoir 42 and maintained at that by the continuous addition of molten steel to the reservoir 42 from the tundish 41 during the operation of the apparatus. Similarly, surface 63 of the molten barium chloride is adjusted to the level indicated by the valve calculated for h_r and during the operation of the apparatus maintained at that level by the continuous introduction of molten barium chloride through the conduit 58.

The embodiment of the apparatus of this invention illustrated by FIGURES 1 and 2 both include fluid type molds. The mold 14 illustrated by FIGURE 1 is readily converted to a massive type mold of the type discussed hereinbefore merely by an appropriate thickening of its copper shell 17, the elimination of the cooling coil 18 and the elimination of the insulating refractory layer 21 from the portion of its outer surface adjacent the unheated and uninsulated upper portion of the receptacle 12. Similarly, the mold 45 illustrated by FIGURE 2 can be converted to a massive type of mold by the elimination of its chamber 50 through which a coolant is circulated while increasing the thickness of its copper shell 48.

In carrying out the method of this invention using either the apparatus of FIGURE 1 or that of FIGURE 2, with or without using my advantageous method of controlling the pressure exerted on the casting as it is being formed, the casting emerging from the body of molten retaining material at the top of the mold is coated with a film of the molten retaining material which solidifies as the casting cools. This film of retaining material protects the casting from air as it is further cooled. This is a particularly advantageous feature of this method when used for the casing of a fusible material which is subject to atmospheric oxidation, such as, for example, iron and the majority of the steels. When using a retaining material such as, for example, barium chloride which is water soluble, it can be removed from the cooled casting by a water spray leaving the casting with a clean surface free of corrosion.

Although in the embodiments of the invention described, means are disclosed for introducing the fused material from the refractory container for the fused mate-

rial into the lower end of the mold channel under a hydrostatic head created by the depth of the fused material above the lower end of the said mold channel, the desired delivery of this fused material to the lower end of the mold channel can be accomplished by other form of hydraulic energy, as for example, by subjecting the fused material to pressure. The fused material possesses hydraulic energy by virtue of its velocity, its pressure and its elevation or hydrostatic head, and as far as certain aspects of the invention are concerned, any one of these forms of hydraulic energy can be employed to carry the fused material to the lower end of the mold channel for upward flow thereinto.

In the foregoing, I have given numerous details as to the manner in which this invention can be carried out and have disclosed numerous combinations of materials for use as casting molds in accordance with this invention. It will be fully understood that the details I have given have been for the purpose of fully disclosing and illustrating the invention, and that many substitutions of materials and variations in the details of the casting procedures described can be made without departing from the spirit of my invention or the scope of the claims which follow.

What is claimed is:

1. Apparatus adapted for the continuous upwardly casting of a fusible material which comprises:

(a) a refractory container for a fusible material in its fused state;

(b) an elongated mold extending in an upwardly direction which comprises a backing material having a high thermal conductivity and an internal channel having the cross-sectional shape and slightly larger dimensions than the cross-section of an elongated casting which is to be produced by the use of the apparatus;

(c) a means for cooling the said backing material which provides means for contacting a surface thereof other than its inner surface with a circulating cooling fluid; and

(d) a solid layer on the inner surface of the backing material which forms the internal channel of a retaining material which has a thermal conductivity substantially lower than that of the said backing material and a melting point lower than that of the material to be cast in the mold;

(e) a container for a fused body of the retaining material positioned above the said mold with an orifice in its bottom of the same shape and dimensions as the upper end of the channel formed by the backing material of the mold;

(f) a means above the said container for the fused body of retaining material for continuously withdrawing upwardly a casting from the channel of the said mold formed by its internal layer of solidified retaining material, through the said upper container; and

(g) a means for introducing the fused material from the refractory container for the fused material into the lower end of the mold channel with sufficient hydraulic energy to cause the fused material to flow upwardly into said mold channel.

2. A mold adapted for the continuous upwardly casting of steel which comprises:

(a) a refractory container for fused steel;

(b) an elongated mold extending in an upwardly direction which comprises a copper backing and an internal channel having the cross-sectional shape and slightly larger dimensions than the cross-section of an elongated casting which is to be produced by the use of the apparatus;

(c) a means for cooling the said copper backing which provides means for contacting a surface thereof other than its inner surface with a circulating cooling fluid;

(d) a solid layer of barium chloride on the inner surface of the backing material which forms the internal channel of the mold;

(e) a container for a fused body of the barium chloride positioned above the said mold with an orifice in its bottom of the same shape and dimensions as the upper end of the channel formed by the backing material of the mold;

(f) a means above the said container for the fused body of barium chloride for continuously withdrawing upwardly a casting from the channel of the said mold formed by its internal layer of solidified retaining material, through the said upper container; and

(g) a means for introducing the fused steel from the refractory container therefor into the lower end of the mold channel with sufficient hydraulic energy to cause the fused material to flow upwardly into said mold channel.

3. Apparatus adapted for the continuous upwardly casting of a fusible material which comprises:

(a) a refractory container for a fusible material in its fused state;

(b) an elongated mold having an open lower end located within the said refractory container with its open lower end near, but not in contact with the bottom of the container and extending upwardly within the container;

(c) the said mold comprising a backing material having a high thermal conductivity and an internal vertically extending channel having a cross-sectional shape and slightly larger dimensions than the cross-section of an elongated casting which is to be produced by the use of the apparatus;

(d) a fluid conduit within the body of the said backing material which provides means for cooling the inner surface of the said backing material by the circulation of a cooling fluid through the conduit;

(e) a layer of a refractory insulating material on the outer and lower surface of the said backing material; and

(f) a solid layer on the inner surface of the backing material which forms the internal channel of a retaining material which has a thermal conductivity substantially lower than that of the said backing material and a melting point lower than that of the material to be cast in the mold;

(g) a container for a fused body of the retaining material positioned above the said mold with an orifice in its bottom of the same shape and dimensions as the upper end of the channel formed by the backing material of the mold;

(h) a means above the said container for the fused body of retaining material for continuously withdrawing upwardly a casting from the channel of the said mold formed by its internal layer of solidified retaining material, through the said upper container; and

(i) a means for introducing the fused material into the said refractory container with sufficient hydraulic energy at the bottom of the mold within the said refractory container to cause said fused material to flow upwardly into said mold.

4. Apparatus adapted for the continuous upwardly casting of a fusible material which comprises:

(a) a refractory container for a fusible material in its fused state;

(b) an elongated mold having an open lower and located within the said refractory container with its open lower end near, but not in contact with the bottom of the container and extending upwardly within the container;

(c) the said mold comprising a backing material having a high thermal conductivity and an internal vertically extending channel having a cross-sectional shape and slightly larger dimensions than the cross-

section of an elongated casting which is to be produced by the use of the apparatus;

(d) a layer of a refractory insulating material on the outer and lower surface of the said backing material; and

(e) a solid layer on the inner surface of the backing material which forms the internal channel of a retaining material which has a thermal conductivity substantially lower than that of the said backing material and a melting point lower than that of the material to be cast in the mold;

(f) a fluid conduit within the body of the said backing material which provides means for cooling the inner surface of the said backing material by the circulation of a cooling liquid through the conduit having a cooling capacity which keeps the inner surface of the backing material at a temperature below the melting point of the said retaining material when its inner surface is in contact with a fusible material being cast within the mold;

(g) a container for a fused body of the retaining material positioned above the said mold with an orifice in its bottom of the same shape and dimensions as the upper end of the channel formed by the backing material of the mold;

(h) a means above the said container for the fused body of retaining material for continuously withdrawing upwardly a casting from the channel of the said mold formed by its internal layer of solidified retaining material, through the said upper container; and

(i) a means for introducing the fused material into the said refractory container with sufficient hydraulic energy at the bottom of the mold within the said refractory container to cause said fused material to flow upwardly into said mold.

5. Apparatus adapted for the continuous upwardly casting of steel which comprises:

(a) a refractory container for fused steel;

(b) an elongated mold having an open lower end located within the said refractory container with its open lower end near, but not in contact with the bottom of the container and extending upwardly within the container;

(c) the said mold comprising a copper backing having an internal vertically extending channel having the cross-sectional shape and slightly larger dimensions than the cross-section of the elongated casting which is to be produced by the use of the apparatus;

(d) a fluid conduit within the body of the said copper backing material which provides means for cooling the inner surface of the backing material by circulating a cooling fluid through the conduit;

(e) a layer of a refractory insulating material on the outer and lower surface of the said backing material; and

(f) a solid layer of barium chloride on the inner surface of the copper backing material;

(g) a container for a fused body of barium chloride positioned above the said mold with an orifice in its bottom of the same shape and dimensions as the upper end of the channel formed by the copper backing material of the mold;

(h) a means above the said container for the fused barium chloride for continuously withdrawing upwardly a steel casting from the channel of the said mold formed by its internal layer of solidified barium chloride, through the said upper container for fused barium chloride; and

(i) a means for introducing molten steel into the said refractory container with sufficient hydraulic energy at the bottom of the mold within the said refractory container to cause said fused material to flow upwardly into said mold.

6. Apparatus adapted for the continuous upwardly casting of steel which comprises:

(a) a refractory container for fused steel;

(b) an elongated mold having an open lower end located within the said refractory container with its open lower end near, but not in contact with the bottom of the container and extending upwardly within the container;

(c) the said mold comprising a backing material selected from the group consisting of copper and copper alloys having an internal vertically extending channel having the cross-sectional shape and slightly larger dimensions than the cross-section of the elongated casting which is to be produced by the use of the apparatus;

(d) a solid layer of barium chloride on the inner surface of the copper backing material;

(e) a fluid conduit within the body of the said backing material which provides means for cooling the inner surface of the backing material by circulating a cooling fluid through the conduit; having a cooling capacity which keeps the inner surface of the copper backing at a temperature below the melting point of the barium chloride when its inner surface is in contact with steel being cast within the mold;

(f) a layer of a refractory insulating material on the outer and lower surface of the said backing material; and

(g) a container for a fused body of barium chloride positioned above the said mold with an orifice in its bottom of the same shape and dimensions as the upper end of the channel formed by the copper backing material of the mold;

(h) a means above the said container for the fused barium chloride for continuously withdrawing upwardly a steel casting from the channel of the said mold formed by its internal layer of solidified barium chloride, through the said upper container for fused barium chloride; and

(i) a means for introducing molten steel into the said refractory container with sufficient hydraulic energy at the bottom of the mold within the said refractory container to cause said fused material to flow upwardly into said mold.

7. A mold adapted for the continuous upwardly casting of a fusible material which comprises:

(a) a refractory container for a fusible material in its fused state;

(b) an elongated mold extending in an upwardly direction which comprises a backing material having a high thermal conductivity and an internal channel having the cross-sectional shape and slightly larger dimensions than the cross-section of an elongated casting which is to be produced by the use of the apparatus;

(c) a solid layer on the inner surface of the backing material which forms the internal channel of a retaining material which has a thermal conductivity substantially lower than that of the said backing material and a melting point lower than that of the material to be cast in the mold;

(d) a container larger than the external cross-section of the backing material positioned around the said mold and provided with a top and bottom to form an annular chamber for a cooling liquid around the said mold;

(e) inlet and exit conduits for a cooling liquid connected to the said annular chamber;

(f) the said mold and its outer container for cooling liquid being located adjacent the said refractory container at a level such that a hydraulic head is provided between a fused material partially filling the refractory container and the lower end of the mold;

(g) a conduit connecting the said refractory container

at a low level which is lower than the lower end of the internal channel of the mold;

(h) a container for a fused body of the retaining material positioned above the said mold with an orifice in its bottom of the same shape and dimensions as the upper end of the channel formed by the backing material of the mold;

(i) a means above the said container for the fused body of retaining material for continuously withdrawing upwardly a casting from the channel of the said mold formed by its internal layer of solidified retaining material, through the said upper container; and

(j) a means for introducing the fused material from the refractory container for the fused material into the lower end of the mold channel with sufficient hydraulic energy to cause the fused material to flow upwardly into said mold channel.

8. A mold adapted for the continuous upwardly casting of a fusible material which comprises:

(a) a refractory container for a fusible material in its fused state;

(b) an elongated mold extending in an upwardly direction which comprises a backing material having a high thermal conductivity and an internal channel having the cross-sectional shape and slightly larger dimensions than the cross-section of an elongated casting which is to be produced by the use of the apparatus;

(c) a solid layer on the inner surface of the backing material which forms the internal channel of a retaining material which has a thermal conductivity substantially lower than that of the said backing material and a melting point lower than that of the material to be cast in the mold;

(d) a container larger than the external cross-section of the backing material positioned around the said mold and provided with a top and bottom to form an annular chamber for a cooling liquid around the said mold;

(e) inlet and exit conduits for a cooling liquid connected to the said annular chamber;

(f) the said annular chamber and the inlet and exit conduits forming a means for cooling the said backing material having a cooling capacity which keeps the inner surface of the backing material at a temperature below the melting point of the said retaining material when its inner surface is in contact with a fusible material being cast within the mold;

(g) the said mold and its outer container for cooling liquid being located adjacent the said refractory container at a level such that a hydraulic head is provided between a fused material partially filling the refractory container and the lower end of the mold;

(h) a conduit connecting the said refractory container at a low level which is lower than the lower end of the internal channel of the mold;

(i) a container for a fused body of the retaining material positioned above the said mold with an orifice in its bottom of the same shape and dimensions as the upper end of the channel formed by the backing material of the mold;

(j) a means above the said container for the fused body of retaining material for continuously withdrawing upwardly a casting from the channel of the said mold formed by its internal layer of solidified retaining material, through the said upper container; and

(k) a means for introducing the fused material from the refractory container for the fused material into the lower end of the mold channel with sufficient hydraulic energy to cause the fused material to flow upwardly into said mold channel.

9. A mold adapted for the continuous upwardly casting of a fusible material which comprises:

(a) a refractory container for molten steel;

(b) an elongated mold extending in an upwardly direction which comprises a backing material selected from the group consisting of copper and alloys of copper having an internal channel having the cross-sectional shape and slightly larger dimensions than the cross-section of an elongated casting which is to be produced by the use of the apparatus;

(c) a solid layer of barium chloride on the inner surface of the backing material;

(d) a container larger than the external cross-section of the backing material positioned around the said mold and provided with a top and bottom to form an annular chamber for a cooling liquid around the said mold;

(e) inlet and exit conduits for a cooling liquid connected to the said annular chamber;

(f) the said mold and its outer container for cooling liquid being located adjacent the said refractory container at a level such that a hydraulic head is provided between a fused material partially filling the refractory container and the lower end of the mold;

(g) a conduit connecting the said refractory container at a low level which is lower than the lower end of the internal channel of the mold;

(h) a container for a fused body of the barium chloride positioned above the said mold with an orifice in its bottom of the same shape and dimensions as the upper end of the channel formed by the backing material of the mold;

(i) a means above the said container for the fused body of barium chloride for continuously withdrawing upwardly a casting from the channel of the said mold formed by its internal layer of solidified retaining material, through the said upper container; and

(j) a means for introducing the molten steel from the refractory container therefor into the lower end of the mold channel with sufficient hydraulic energy to cause the molten steel to flow upwardly into said mold channel.

10. A mold adapted for the continuous upwardly casting of steel which comprises:

(a) a refractory container for molten steel;

(b) an elongated mold extending in an upwardly direction which comprises a backing material selected from the group consisting of copper and alloys of copper having an internal channel having the cross-sectional shape and slightly larger dimensions than the cross-section of an elongated casting which is to be produced by the use of the apparatus;

(c) a solid layer of barium chloride on the inner surface of the backing material;

(d) a container larger than the external cross-section of the backing material positioned around the said mold and provided with a top and bottom to form an annular chamber for a cooling liquid around the said mold;

(e) inlet and exit conduits for a cooling liquid connected to the said annular chamber;

(f) the said annular chamber and the inlet and exit conduits forming a means for cooling the said backing material having a cooling capacity which keeps the inner surface of the backing material at a temperature below the melting point of the barium chloride when the inner surface of the barium chloride is in contact with molten steel being cast within the mold;

(g) the said mold and its outer container for cooling liquid being located adjacent the said refractory container at a level such that a hydraulic head is provided between molten steel partially filling the refractory container and the lower end of the mold;

(h) a conduit connecting the said refractory container at a low level which is lower than the lower end of the internal channel of the mold;

(i) a container for a fused body of the barium chloride positioned above the said mold with an orifice in its bottom of the same shape and dimensions as the upper end of the channel formed by the backing material of the mold;

(j) a means above the said container for the barium chloride for continuously withdrawing upwardly a casting from the channel of the said mold formed by its internal layer of barium chloride, through the said upper container; and

(k) a means for introducing the molten steel from the refractory container therefor into the lower end of the mold channel with sufficient hydraulic energy to cause the molten steel to flow upwardly into said mold channel.

11. A method for the continuous casting of steel in an upwardly direction which comprises

(a) continuously flowing a stream of molten steel into the lower end of an internal channel of a mold which extends generally in an upwardly direction and which comprises

(b) a lining layer of barium chloride supported by a backing material selected from the group consisting of copper and copper alloys having a cross-sectional shape which forms an internal channel which has the same cross-sectional shape but slightly larger dimensions than desired in the elongated casting being produced;

(c) passing the molten steel upwardly through the mold channel formed by the layer of the barium chloride on the said backing material while withdrawing heat from the molten steel as it passes upwardly to cause its solidification;

(d) at a rate which keeps a layer of barium chloride adjacent the backing material in the solid state while permitting a layer thereof adjacent the molten steel to melt, while continuously pulling the solidified casting from the upper end of the mold channel.

12. A method for the continuous casting of molten steel in an upwardly direction which comprises

(a) continuously flowing a stream of the molten steel into the lower end of an internal channel of a mold which extends generally in an upwardly direction and which comprises

(b) a lining layer of barium chloride which is supported by a backing material selected from the group consisting of copper and alloys of copper which forms an internal channel which has the same cross-sectional shape but slightly larger dimensions than desired in the elongated casting being produced;

(c) passing the molten steel upwardly through the mold channel formed by the layer of the barium chloride on the said backing material;

(d) while withdrawing heat from the said backing material by the circulation of a coolant liquid in contact with a surface thereof other than that which carries the barium chloride which, in turn, withdraws heat from the layer of barium chloride and from the fusible material in contact with its inner surface as the said molten steel passes upwardly to cause its solidification;

(e) at a rate which keeps a layer of the barium chloride adjacent the backing material in the solid state while permitting a layer thereof adjacent the steel to melt while continuously pulling the solidified casting from the upper end of the mold channel.

13. A method for the continuous casting of molten steel in an upwardly direction which comprises

(a) continuously flowing a stream of the molten steel into the lower end of an internal channel of a mold which extends generally in an upwardly direction and with sufficient substantially constant hydraulic energy to cause said molten steel to flow upwardly into said channel and which comprises

(b) a lining layer of barium chloride which is under pressure exerted by a predetermined and substantially constant hydrostatic head exerted by a body of the barium chloride in molten form in contact with the upper end thereof;

(c) the said lining layer of the barium chloride being supported by a backing material selected from the group consisting of copper and alloys of copper having a cross-sectional shape which forms an internal channel which has the same cross-sectional shape but slightly larger dimensions than desired in the elongated casting being produced;

(d) passing the molten steel upwardly through the mold channel formed by the layer of the barium chloride on the said backing material while withdrawing heat from the molten steel as it passes upwardly to cause its solidification at a rate which keeps a layer of the barium chloride adjacent the backing material in the solid state;

(e) while permitting a layer thereof adjacent the molten steel to melt;

(f) while continuously pulling the solidified casting from the upper end of the mold channel;

(g) the said hydraulic energy of said molten steel and the said barium chloride being predetermined to produce a controlled pressure in the solidification zone of the molten steel.

14. A method for the continuous casting of molten steel in an upwardly direction which comprises

(a) continuously flowing a stream of the molten steel which is under pressure exerted by a predetermined and substantially constant hydrostatic head of the molten steel into the lower end of an internal channel of a mold which extends generally in an upwardly direction and which comprises

(b) a lining layer of barium chloride which is under a pressure exerted by a predetermined and substantially constant hydrostatic head exerted by the molten barium chloride including that in molten form in contact with the upper end thereof;

(c) the said lining layer of the retaining material being supported by a backing material selected from the group consisting of copper and alloys of copper having a cross-sectional shape but slightly larger dimensions than desired in the elongated casting being produced;

(d) passing the molten steel upwardly through the mold channel formed by the layer of the barium chloride on the said backing material while withdrawing heat from the steel as it passes upwardly to cause its solidification;

(e) at a rate which keeps a layer of the barium chloride adjacent the backing material in the solid state while permitting a layer thereof adjacent the steel to melt;

(f) while continuously pulling the solidified casting from the upper end of the mold channel;

(g) the said predetermined hydrostatic heads on the said molten steel and on the barium chloride required to produce a desired pressure differential ΔP at any particular location in the solidification zone of the steel being calculated from the equation:

$$\Delta P=(h_m\rho_m-h_r\rho_r)-h(\rho_m-\rho_r)$$

in which the meaning of the characters is:

ΔP=the pressure difference in pounds per square inch across the solidifying skin of the steel as the casting is formed, which with a positive value shows that the pressure in the steel exceeds that of pressure in the liquid barium chloride at the altitude h;

h=the altitude in inches above the bottom of the casting mold which is the zero altitude for this equation;

h_m=the altitude in inches of the top surface of the body of molten steel from the entrance of the mold;

ρ_m=the density of the molten steel in pounds per cubic inch;

h_r=the altitude in inches of the top surface of the liquid barium chloride included in that which is above the barium chloride of the mold from the entrance end of the mold; and

ρ_r=the density of the molten barium chloride in pounds per cubic inch.

15. A method for the continuous casting of molten steel in an upwardly direction which comprises

(a) continuously flowing a stream of the molten steel which is under pressure exerted by a predetermined and substantially constant hydrostatic pressure of the molten steel into the lower end of an internal channel of a mold which extends generally in an upwardly direction and which comprises

(b) a lining layer of barium chloride which is under a pressure exerted by a predetermined and substantially constant hydrostatic head exerted by the molten barium chloride including that in molten form in contact with the upper end thereof;

(c) the said lining layer of the barium chloride being supported by a backing material selected from the group consisting of copper and alloys of copper having a cross-sectional shape which forms an internal channel which has the same cross-sectional shape but slightly larger dimensions than desired in the elongated casting being produced;

(d) passing the fused material upwardly through the mold channel formed by the layer of the retaining material on the said backing material while withdrawing heat from the fusible material as it passes upwardly to cause its solidification at a rate which keeps a layer of the retaining material adjacent the backing material in the solid state while permitting a layer thereof adjacent the fusible material to melt while affirmatively pulling the solidified casting from the upper end of the mold channel;

(e) the said predetermined hydrostatic heads on the

said fused material and on the said retaining material being such that there is substantially no pressure differential at the bottom of the mold on the thin solid skin of the fusible material which is beginning to form, and being calculated from the equation:

$$h_m\rho_m=h_r\rho_r$$

in which the meaning of the characters is:

h_m=the altitude in inches of the top surface of the body of fused material from the entrance end of the mold;

ρ_m=the density of the fused material being cast in pounds per cubic inch;

h_r=the altitude in inches of the top surface of the liquid retaining material of the mold from the entrance end of the mold, and

ρ_r=the density of the molten retaining material in pounds per cubic inch.

References Cited by the Examiner

UNITED STATES PATENTS

2,363,695	11/1944	Ruppik	22—200.1
2,405,355	8/1946	Harrison	22—57.2
2,473,221	6/1949	Rossi	22—57.2
2,493,394	1/1950	Dunn et al.	22—209
2,631,344	3/1953	Kennedy	22—200
2,667,673	2/1954	Harrison	22—57.2
2,702,419	2/1955	Mattson	22—57.2 X
2,734,244	2/1956	Herres	75—10
2,825,947	3/1958	Goss	22—57.2 X
2,955,334	10/1960	Pulsifer	22—57.2

OTHER REFERENCES

Materials and Methods, "Salt Baths for Metal Treating," October, 1951, TA 401.M5, page 118.

J. SPENCER OVERHOLSER, *Primary Examiner.*

R. S. ANNEAR, *Assistant Examiner.*