May 11, 1937. E. R. WILLIAMS 2,079,644

METHOD AND APPARATUS FOR CONTINUOUS CASTING

Filed May 5, 1936

Fig. 1.

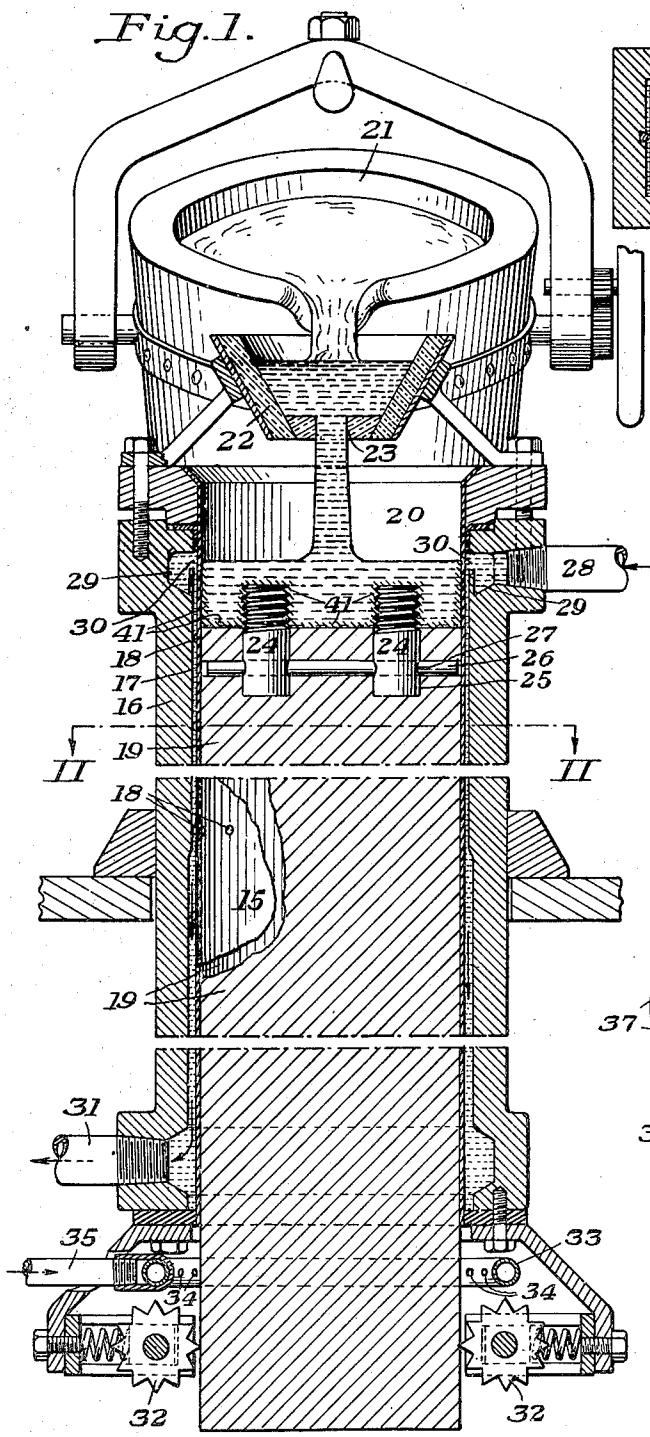



Fig. 4.

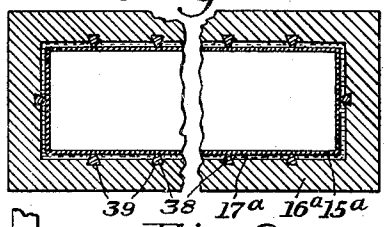



Fig. 2.

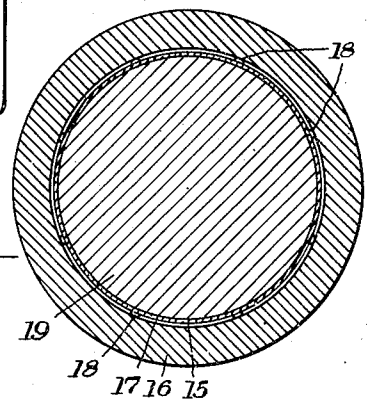
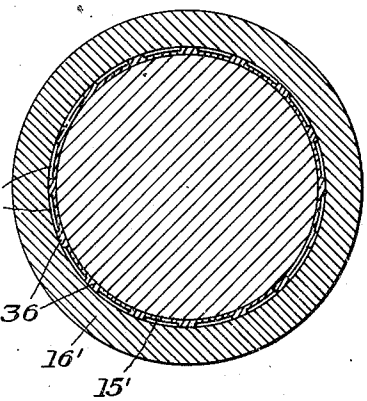



Fig. 3.

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# UNITED STATES PATENT OFFICE

2,079,644

## METHOD AND APPARATUS FOR CONTINUOUS CASTING

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Application May 5, 1936, Serial No. 77,971

7 Claims. (Cl. 22—206.1)

My invention relates to method and apparatus for continuous casting in a definite shape and form of both ferrous and non-ferrous metals, and is particularly applicable to what is hereinafter referred to as "continuous casting". The supply of molten metal may be continuously fed to one end of a mold and the cast ingot be withdrawn from the opposite end of the mold without interrupting the continuity of the ingot during the entire process, thereby allowing ingots of indefinite length and having superior properties to be cast.

In casting metal the usual procedure employed is what may be termed intermittent, wherein the previously prepared mold is filled with molten metal which is allowed to solidify within the mold cavity and is then withdrawn therefrom. This cavity, unless the mold is of the temporary type sometimes employed, may be again used in carrying out the procedure.

This application is a continuation-in-part of my application Serial No. 715,433, filed March 14, 1934, which is a continuation-in-part of my application Serial No. 650,595, filed January 7, 1933.

The present, commonly used, methods of casting metal ingots from which various shapes are later to be rolled or forged are not entirely satisfactory because of defects which appear on the butt of the ingot along the sides of the ingot and the pipe or cavity which forms at the top. Further treatment of such ingots to prepare the ingots for further working are expensive and necessary. For example, surface imperfections have to be chipped or ground out before further operations are performed on the ingot and the pipes or cavities which form at the top of the ingot due to uneven contraction of the molten metal during the casting operation have to be cut off and this necessitates that from ten to twenty percent of the top of each ingot has to be cropped off and discarded. To overcome these and other defects it is desirable to form the ingot so that surface imperfections and pipes are obviated, and various continuous casting operations have been suggested from time to time, but in so far as I am aware no procedure or apparatus has been heretofore developed which is commercially acceptable. This is due to the failure to solve the problem of heat removal from the metal as it is received and formed in the mold cavity.

By my invention it is possible to extract heat from molten metal during the casting operation at a relatively high rate so that the casting operation is improved, simplified and expedited whether it be a continuous or intermittent operation. I have found that the solution of the problem of continuous casting depends upon proper heat removal from the metal which has been poured. In order to successfully accomplish continuous casting at a commercially acceptable rate it is necessary to almost instantaneously congeal the molten metal contacting the lateral walls of the mold cavity so as to form a thin shell or skin, and this shell must be maintained in heat-transferring relation with the lateral wall of the mold cavity for a substantial period of time and it must be so formed and of such thickness that it is of sufficient strength to resist, without rupture, such force as it is subjected to during the operation of moving it along the wall of the mold cavity, in order to provide for the continuous casting operation. By the use of my method and apparatus it is possible to produce a homogeneous ingot of indefinite length without butt irregularities, surface imperfections or pipes or cavities.

I employ a mold having a mold cavity provided with a wall having high thermal conductivity and means outside the mold wall whereby the heat conducted therethrough may be rapidly scoured away from the outer surface of the wall and dissipated. By employing a thin mold wall having high thermal conductivity and supplying a cooling fluid to the external surfaces of these walls at such a velocity and at such a pressure to insure that the fluid will neither be vaporized nor give off gases in contact with the walls I cannot only extract the necessary heat to accomplish substantially instantaneous solidification of the metal coming in contact with the mold walls, but also cause a contraction or shrinkage of the metal so solidified as to substantially reduce its frictional engagement with the walls of the mold tube and thus make withdrawal of it from the mold a relatively simple matter.

In the drawing I have illustrated one form of apparatus for carrying out my invention. As shown there I employ a thin walled molding tube open at both ends and made of material having a relatively high thermal conductivity, such as copper. This tube should be as thin as structurally possible. The tube is enclosed within a jacket member or casing to provide therebetween a shallow cooling chamber through which a cooling medium is circulated in intimate contact with the tube. By the term "shallow cooling chamber" I mean to designate a chamber the radial depth of which is as small as structurally possible so that the chamber will not be readily clogged by excrescences which are

liable to form in the chamber. I have found that the radial depth approximately the thickness of the wall tube is satisfactory and is comparatively simple to construct. The stream of cooling fluid of such dimensions as will pass through the shallow cooling chamber will be designated as a "shallow stream". An element which may be considered as the equivalent of a mold stool is inserted into one end of the tube and is movable with relation thereto. In its initial position this element supports the molten metal and provides with the mold tube a mold cavity into which the molten metal is introduced.

When a liquid such as water is employed as the cooling medium it is desirable to obtain it from a low temperature source, or, again, it may be artificially cooled. It is also desirable to deliver the liquid to the cooling chamber under sufficient pressure to maintain the water unvaporized along the tube.

It will be apparent that the stool element provides a heat absorbing agent and that the metal directly contacting with it will solidify more or less rapidly and the arrangement must be such as to insure this condition. The stool is withdrawn at a rate depending on the rate of introducing metal into the mold cavity, and this, in turn, depends on the rate of heat dissipation. The metal previously introduced moves with the stool and is thereby subjected to the cooling effect of the portions of the tube uncovered by the receding stool. The thickness of the solidified shell is thus increased as the formed ingot moves along the tube, and it is desirable to have the tube of such length that the shell so formed will reach such a thickness before being withdrawn from the tube that it will retain such metal as remains in molten condition and will not be ruptured by the force necessary to withdraw it from the mold, nor melted through by the molten metal in the center. It is obvious that the cooling operation may be continued even after the cast metal leaves the tube and that, therefore, auxiliary means may be employed for cooling this portion of the casting.

One of the advantages of my invention is that the metal can be cast in such a form and in such a length as to obviate the necessity of employing the usual preliminary hot rolling operations as ordinarily termed the "roughing down" operation. For example, the metal may be cast in the form of a billet ingot or a slab ingot of desired and convenient dimensions. This is of advantage where the ingots are to be subjected to further working, for example, in a continuous mill, and one of the objects of my invention is to produce ingots in such form as will minimize hot rolling operations.

In the accompanying drawing I have illustrated a present preferred embodiment of my invention. In the drawing—

Figure 1 is a view, partly in section and more or less diagrammatic, showing one form of apparatus which is suitable for carrying out my invention;

Figure 2 is a cross section along the line II—II of Figure 1;

Figure 3 is a transverse section showing a slightly modified form of a detail of the apparatus; and

Figure 4 is a section of an apparatus suitable for casting metal in slab form.

In the drawing 15 represents a thin walled molding tube of cylindrical form which is open at both ends and is housed within a casing or jacket 16 in such a way as to provide a relatively narrow or shallow cooling chamber or jacket space 17 between it and the casing 16. The tube 15 has a ring-like series of lugs 18 which bear against the casing 16 and serve to support the tube therein and insure a water passage between the casing and the tube. A stool element 19 in the form of an ingot blank is located within and has a sliding fit with tube 15. At the beginning of the pouring operation the blank is located at such a position within the tube 15 as to provide a pouring cavity 20 at the top thereof. Molten metal to be cast is delivered from the furnace by any suitable means such as a tiltable ladle 21 and is received by a pouring box 22 secured adjacent the top of the apparatus. In the bottom of the pouring box is an orifice 23, so arranged that the molten metal will be discharged into the mold cavity 20 in the form of a continuous stream. The molten metal poured into the cavity 20 is supported on the upper end of the ingot blank or stool 19 and for the purpose of forming a bond between the bottom of the molten metal as it congeals and the top of the ingot blank 19, a series of lugs 24 are mounted in recesses 25 formed in the end of the ingot blank. These lugs project into the mold cavity 20 and are held in position in the recesses 25 by means of a pin 26 which extends through a transverse opening in the end of the ingot blank 19 and through openings 27 in the ends of the lugs 24. In order to maintain a substantially constant temperature differential between the inner and outer surfaces of the molding tube and to effectually remove the heat from the outer surface of the mold tube 15, a cooling medium such as water is introduced into the chamber 17 through a pipe 28 leading from a suitable source of water supply. Pipe 28 discharges into an annular recess 29 having a series of spaced openings 30 therein arranged so as to uniformly direct the water entering the annular recess 29 through chamber 17 along the outer surface of tube 15. The liquid passing through chamber 17 absorbs and scours away the heat transferred through the wall of the tube 15 and is withdrawn from the bottom of the chamber through a discharge pipe 31.

In order that the ingot blank or stool and the ingot being formed in the molding tube 15 may be readily and continuously removed therefrom, the blank 19 is preferably of such a length that when it is in its initial position within the tube 15 the lower end of the blank may be engaged by a suitable extracting or withdrawing mechanism such as toothed rollers 32. The rollers 32 are spring pressed against the blank and may be driven in any suitable manner, for example, by a variable speed motor (not shown) so that the speed of withdrawal of the blank 19 and the ingot can always be controlled at a rate so that the level of the molten metal in the pouring cavity 20 will remain approximately constant during the pour. It will thus be apparent that the pouring orifice 23 is of such a size that the metal will be delivered to the pouring cavity at a rate such that the necessary skin may form around the edges of the molten metal in contact with the molding tube, so that the forming ingot may be withdrawn without rupture of the skin wall thus formed. The rate of formation of the skin will depend upon the ability of the apparatus to carry away the heat transferred from the molten metal in the pouring cavity 20 through the molding tube 15.

The molding tube 15 is preferably formed of

copper or brass because of the high thermal conductivity of such metals and is made of such thickness that it will have a thermal conductivity sufficient to transfer the heat in the molten metal in the cavity to the chamber 17 at a rate substantially equal to the rate at which the heat is given up by the molten metal within the mold cavity. I have discovered that the mold tube should be made of a metal having a high thermal conductivity and as thin as is structurally possible. In this connection I have used and found satisfactory a copper tube having a thickness of approximately $\frac{1}{16}$ inch.

The length of the tube 15 depends upon the heat content of the metal being poured and the desired lineal speed of withdrawal of the solidifying metal from the discharge end of the tube. The tube should be of a length sufficient to allow the metal to be in contact therewith for such a period of time as will cause the shell or skin which solidifies around the metal to be of sufficient thickness and strength to maintain the still molten metal within its confines as it emerges from the end of the tube without the need of supporting walls. I have found that a round copper molding tube approximately 6 inches in diameter and having a length of approximately 30 inches is sufficient for the casting of steel.

It is absolutely essential that the heat be scoured away from the outer wall of the molding tube as fast as it is conducted through the molding tube from the molten metal. It is also essential that the water be maintained in intimate contact with the wall of the tube without the formation therebetween of steam or vapor, or the liberation of gases. I have discovered that this cooling chamber should be of a radial thickness as small as is structurally possible, and I have successfully used my apparatus with a water chamber of a thickness of about $\frac{1}{16}$ of an inch, which is approximately the thickness of the molding tube employed. However, it will be understood that this water chamber can be of a radial thickness less than $\frac{1}{16}$ of an inch and so also the thickness of the molding tube can be less than $\frac{1}{16}$ of an inch. Structural possibilities and operating conditions will determine the thickness of the tube and the radial thickness or depth of the cooling chamber. By means of the shallow cooling chamber the cooling fluid is forced at a relatively high velocity along and in intimate contact with the outer wall of the molding tube 15 and thus rapidly scours away the heat conducted from the poured metal.

I have found that it is not necessary to have the cooling chamber of a radial thickness of $\frac{1}{16}$ of an inch or less for the whole length of the molding tube, but it is essential that a very thin water-passage be maintained around the molding cavity and adjacent the top portion of the apparatus. Toward the bottom of the apparatus, however, the cooling chamber may have a greater radial thickness and this will serve somewhat to reduce the pressure necessary to force the water through the chamber.

Below the mold tube an auxiliary cooling means may be provided for completing the solidification of the ingot before it is cut to length. The auxiliary cooling means may be of any desired form such as an annular pipe 33 positioned at the discharge end of the tube 15 and having a series of nozzle orifices 34 therein for directing a cooling fluid such as water against the solidified surface of the ingot as it emerges from the discharge end of the tube. The pipe 34 is connected by means of a pipe 35 to a suitable source of water supply.

In Figure 3, I have illustrated a modification of my apparatus, in which means are provided for increasing the velocity of the cooling fluid in the cooling or jacket chamber 17 without increasing the quantity of flow. In this modification the outer surface of the molding wall 15' is grooved to form a series of spaced ribs 36 which extend longitudinally of the tube and bear against the inner surface of the casing 16', thus supporting the tube on the casing, reinforcing it longitudinally and increasing its external radiating surface. The ribs may be formed integral with the molding tube or may be attached thereto in any manner such as by brazing or welding. The spaces or grooves 37 between the ribs 36 form passageways extending lengthwise of the tube 15' and which are approximately equal in depth but may be less than the effective thickness of the molding wall. As a result of the shallowness of the grooves 37, the cooling fluid is conveyed therethrough from the inlet pipe 28 to the outlet or discharge pipe 31 at a high velocity due to the restricted area of the water passages. Such a high velocity is of great aid in carrying away or scouring the heat from the outer surfaces of the molding wall 15'. The mold tube may have this construction throughout the full length of the apparatus or this construction may extend for about one-half of the length of the molding tube, in which case the lower portion of the molding tube may be made of uniform cross section and the water passage thickness increased, similarly to the construction illustrated in Figure 1.

In Figure 4 I have shown a cross section of an apparatus similar to that shown in Figure 1 but of different cross section to enable slabs or rectangular shaped ingots to be poured. In this form of apparatus the thin walled molding tube 15a is maintained in spaced apart relation to the casing 16a to provide a shallow cooling chamber 17a therebetween. To reinforce the walls of the molding tube the wedge shaped ribs 38 are secured to tube 15a as by welding or brazing, or they may be formed integral therewith. The base of the wedges fit in slots 39 formed in the casing 17a. In other respects the arrangement may be as shown in Figure 1 hereinabove described.

The operation of my apparatus is as follows:

Molten metal is delivered to the pouring box 22 in a substantially constant stream and in such quantities as to maintain a constant flow of molten metal through the orifice 23 into the mold cavity 20. This flow through the orifice should be at such a rate as to occasion the introduction of an uninterrupted stream into the cavity, i. e. a continuous stream as distinguished from a drop by drop stream. Upon initially starting the apparatus, the cavity 20 above the stool 19 is filled to a predetermined level, it being understood that during this filling operation the refrigerating or cooling medium is within and is being delivered through the jacket chamber 17 in direct contact with the outer surface of the mold tube 15. When the metal within the mold cavity has reached the predetermined level, the blank is withdrawn at such a rate as to maintain the metal level substantially constant within the cavity.

The refrigerating medium is delivered at such a temperature and rate of flow that the differential of temperature between the inner and outer surfaces of the tube 15 is such as to not

only insure a substantially immediate solidification of molten metal directly contacting with it but also a substantially immediate shrinkage of the shell of solidified metal formed, so as to break the intimate engagement between the shell and tube and reduce the frictional contact between them. As the shell moves downwardly, it continuously gives up heat to the tube with the result that the shell formed by the initial solidification of the molten metal increases in thickness as it recedes from the metal admission end of the tube. It will thus be apparent that with relation to any transverse section of the ingot the mass of unsolidified metal gradually decreases as the ingot is withdrawn from the metal admission end of the tube and the molten metal which is maintained within the interior of the ingot prevents the formation of shrinkage cavities. The initial solidification of the metal in the mold cavity and along the top of the stool is shown at 41.

The pressure necessary to prevent vaporization of the cooling liquid varies with the ingot speed and the heat content of the molten metal being poured, and I have found that when pouring a low heat-content metal the apparatus will work perfectly when a cooling liquid, such as water, is introduced into the chamber 17 under a head pressure of about 35 to 45 pounds per square inch. With metals having a high heat content and where the casting is withdrawn from the tube 15 at a high lineal speed, the head pressure of the cooling liquid must be increased materially and may be as high as 150 pounds or more per square inch. For example, I have found in casting aluminum in a brass molding wall of circular shape 6 inches in diameter and having a wall thickness of approximately $\frac{1}{8}$ of an inch and a cooling chamber approximately $\frac{1}{8}$ of an inch in radial thickness that a solidified skin will be formed almost instantly adjacent the inner wall of the tube which is of sufficient thickness and strength to support the pool of still molten metal within its confines and will contract sufficiently to reduce its frictional engagement with the tube, so as to permit the ingot to be withdrawn, when the outer surface of the tube is continuously washed with water supplied at a rate of 30 to 35 gallons per minute under a head pressure of 30 to 40 pounds per square inch at water main temperature. Under such conditions, I have been able to withdraw the solidified metal from the molding tube 15 at commercial lineal speeds.

When steel and other metals having a high heat content are being cast in the apparatus above set forth with the volume of water passing through the cooling chamber 17 remaining the same, that is, 30 to 35 gallons per minute, I have found that the head pressure of the water must be increased materially and pressures of 75 to 150 pounds or more may be required to prevent the water from vaporizing and to secure sufficient cooling to form a solidified skin adjacent the mold wall with sufficient rapidity to permit the ingot to be continuously withdrawn from the tube at commercial lineal speeds.

In the apparatus illustrated and described, the pouring box 22 is shown as having an orifice 23 in the bottom thereof through which the molten metal issues in an open stream, but it will be understood that the orifice may be provided with a downwardly projecting nozzle (not shown) which extends into the interior of the mold cavity 20 below the normal level of the molten metal within the cavity blank. Such a nozzle may be beneficially employed when certain molten metals which oxidize rapidly are being cast, and it will also tend to decrease turbulence within the pool.

It is impossible to definitely designate the desirable liquid pressure and the velocity of liquid flow through the jacket for all the varying conditions which may be encountered in casting metals, but, as above stated, the pressure and the velocity of flow should be such that under the temperature conditions encountered, the water will neither vaporize within the jacket nor give off such gases as it may carry, when coming in contact with the hot surface of the molding tube. Where a cooling medium other than a liquid is employed in the jacket surrounding the molding tube, this medium should be introduced into the jacket space at such a temperature, in such quantities, and at such velocity as will not only insure a substantially instantaneous solidification of the molten metal contacting with the tube, but will also cause sufficient contraction or shrinkage of the metal thus solidified to break or materially lessen the frictional contact between it and the tube. It is also desirable to maintain a flow of the cooling medium through the jacket space in such a way that the coldest medium within that space contacts with the hottest portion of the molding tube.

While I have described one apparatus for carrying out my invention and while I have described the invention in connection with continuous casting, it will be apparent that other types of apparatus may be employed and that the procedure here outlined may also be effectively employed in connection with intermittent as well as continuous casting. It will be apparent from the foregoing that the present invention particularly contemplates a procedure for the rapid removal of heat during a casting operation, and this procedure in its broad application can be made use of either in continuous or intermittent casting. It will also be understood that various changes, omissions, and additions may be made to that procedure without departing from the spirit and scope of the invention as set forth in the appended claims.

I claim:

1. The method of continuously casting metal into ingot form which consists in continuously pouring metal into the top of a molding tube having high thermal conductivity and passing a shallow stream of cooling fluid at high velocity along the outer surface of said tube and in contact therewith whereby said surface is maintained at a temperature such that a layer of solidified metal is almost immediately formed around the outside of the metal so poured of sufficient strength to permit drawing the metal so molded downwardly through the tube.

2. The method of continuously casting metal into ingot form which consists in continuously pouring metal into the top of a molding tube having high thermal conductivity and passing a shallow stream of cooling fluid at high velocity along the outer surface of said tube and in contact therewith and at such pressure as to prevent a film of vapor from forming between the outer surface of the tube and the shallow stream, whereby said surface is maintained at a temperature such that a layer of solidified metal is almost immediately formed around the outside of the metal so poured of sufficient strength to permit drawing the metal so molded downwardly through the tube.

3. The method of continuously casting metal

into ingot form which consists in continuously pouring metal into the top of a molding tube having high thermal conductivity and passing a shallow stream of cooling fluid at high velocity along the outer surface of said tube and in contact therewith and at such pressure as to prevent a film of vapor from forming between the outer surface of the tube and the shallow stream, whereby said surface is maintained at a temperature such that a layer of solidified metal is almost immediately formed around the outside of the metal so poured of sufficient strength to permit drawing the metal so molded downwardly through the tube, and subjecting the molded metal adjacent the tube exit to the action of a cooling fluid.

4. The method of cooling the outer surface of a thin confining wall of a mold which consists in subjecting the outer surface of such wall to the scrubbing action of a shallow stream of cooling fluid forced at high velocity along said wall, maintaining said fluid under sufficient pressure to prevent vaporization thereof adjacent said wall and delivering such fluid in sufficient volume to preclude an appreciable temperature rise therein, whereby a temperature differential is produced between the inner and outer surfaces of said wall which will substantially instantaneously solidify a skin of metal adjacent the inner surface of said wall as rapidly as it comes in contact therewith.

5. The method of casting molten metal which consists in delivering molten metal in a substantially continuous stream to a stationary thin walled molding tube of high thermal conductivity, continuously subjecting the outer surface of said tube to the action of a shallow stream of cooling fluid delivered under such pressure as to cause the fluid to travel at a high velocity along the outer surface of the tube and to prevent vaporization of the fluid along the tube whereby the heat from the molten metal is rapidly transferred to and carried away by the fluid, thus causing the molten metal adjacent the said wall to congeal.

6. In apparatus for casting molten metal comprising a thin wall molding tube having a thin wall for at least a portion of its length, a casing surrounding said tube and spaced therefrom to form a cooling chamber therebetween of shallow radial depth for at least a portion of its length, means for circulating fluid along the outer surface of said tube at high velocity and at pressures sufficiently high to prevent vaporization of the fluid in contact with the outer surface of the molding tube, and means for supporting the molten metal delivered to said tube.

7. In apparatus for continuous casting of metal ingots comprising a thin wall molding tube, a casing surrounding said tube and spaced therefrom to form a relatively shallow cooling chamber therebetween, means for circulating fluid through said chamber at high velocity, and at a pressure to prevent vaporization of the fluid at the surface of the tube, and means adjacent the discharge end of the tube for spraying fluid on the formed ingot after it has emerged from the tube, and means beyond said tube for drawing the ingot out of and away from said tube.

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