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TEMPERATURE CONTROL DURING METAL CASTING

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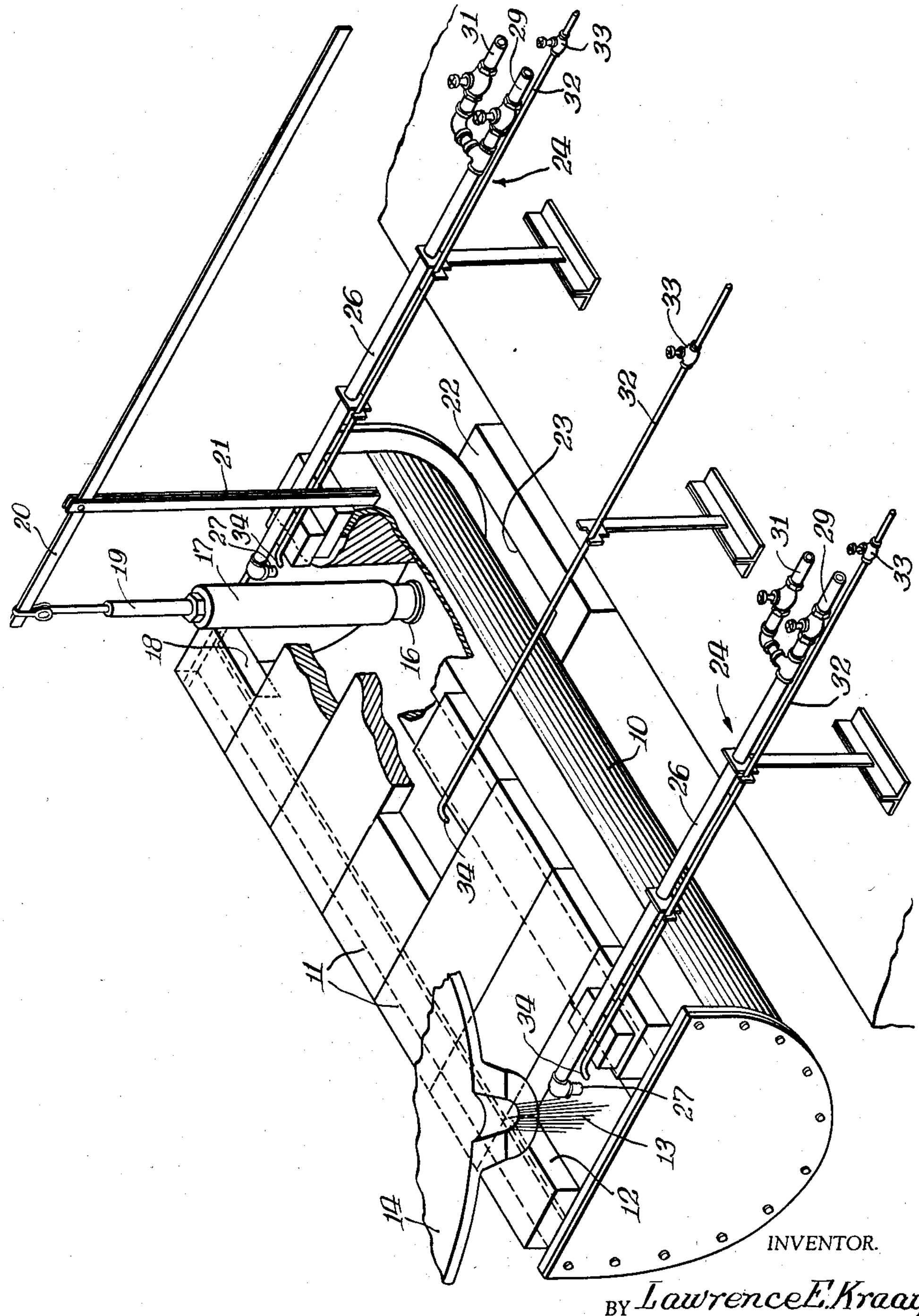

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TEMPERATURE CONTROL DURING METAL CASTING

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This invention relates to the improvements in the casting of ferrous metals. More particularly, the invention relates to novel and improved means for controlling or maintaining the temperature of molten ferrous metal during pouring thereof into a mold.

In steelmaking it is common practice to pour the molten metal directly from a ladle into ingot molds. However, as an alternative procedure, the technique known as tundish or basket pouring affords distinct advantages under some circumstances. According to the latter procedure, an intermediate pouring vessel or tundish is employed which receives the molten metal from the ladle and discharges the same into the molds.

Also, various schemes for the continuous casting of metals have been proposed in which a tundish or pouring box is interposed between the ladle and the mold. According to one such arrangement, the molten metal is poured from a ladle into a tundish which is disposed over a vertical water-cooled mold having the desired configuration and mounted for vertical oscillation. The molten metal flows at a controlled rate from the tundish into the upper end of the mold and provision is made for continuously withdrawing the cast shape at a controlled rate from the lower end of the mold.

During such transfer of molten metal from a ladle to a tundish and from the tundish to a mold, it is usually quite important to prevent excessive cooling of the molten metal. This problem of heat loss is a difficult one when casting ferrous metals, particularly during a continuous casting operation. Various expedients such as preheating the tundish and the use of burners in the ladle or the tundish have been resorted to in an effort to overcome the tendency for the metal to cool to a detrimental degree in the tundish, but no entirely satisfactory solution to the problem has been devised heretofore.

Accordingly, a primary object of the present invention is to provide novel means for controlling the pouring temperature of molten metal in a casting operation.

Another object of the invention is to provide novel means for avoiding excessive cooling of molten ferrous metal in the tundish or pouring box of a casting apparatus.

A further object of the invention is to provide a novel method for imparting heat to molten ferrous metal in the tundish of a continuous casting apparatus in order to combat heat loss and insure proper flow of the metal to the mold.

An additional object of the invention is to provide a novel apparatus for carrying out the foregoing objects.

Further objects and advantages of the invention will become apparent from the subsequent detailed description taken in conjunction with the accompanying drawing which is a perspective view of one form of apparatus suitable for carrying out the present invention in conjunction with a continuous casting device, portions of the structure being broken away in order to reveal the interior construction.

Although, for the sake of illustration, the invention is described hereinafter with particular reference to a continuous casting operation, it will be understood that the invention has utility in connection with other casting procedures, as mentioned above, and in other circumstances wherein heat loss must be combated during transfer of molten ferrous metal.

In the continuous casting of medium or low carbon steels, the temperature of the metal from the ladle is ordinarily in the range of from about 2800° F. to about 3000° F. For acceptable casting results, it is essential that the temperature of the molten metal at the outlet of the tundish, i.e. as the metal is introduced into the inlet end of the casting mold, be not less than about 2750° F. and preferably at least about 2800° F. The provision of burners and an insulating cover at the tundish assists in retarding heat loss from the tundish, but at the relatively low or moderate casting rates presently attainable in the continuous casting of plain carbon steels in shapes of large cross sectional area, a serious heat loss problem still confronts the operator.

Broadly speaking, the present invention solves this problem by effecting limited oxidation of the metal in the tundish with free oxygen so as to take advantage of exothermic heat of oxidation to maintain the metal at a proper casting temperature. Instead of the usual box-type tundish, the invention preferably employs an elongated trough-type tundish which affords more exposed metal surface for reaction with oxygen. The tundish is disposed at a slight incline so that the molten metal can be introduced at one end from the ladle and then flows to the other end of the tundish and is discharged through a nozzle or spout into an underlying mold. During the flow of the molten metal through the tundish a certain amount of heat is preferably supplied to the metal by directing burner flames on the metal surface. However, additional heat is also supplied by introducing concentrated free oxygen gas into the space in the tundish above the metal surface and directing the gas against the metal surface so as to effect limited oxidation of the metal, the exothermic heat of reaction being sufficient, especially in combination with the heat supplied by the burner flames, to prevent excessive temperature drop of the molten metal and thereby maintain the effluent metal from the tundish outlet at a suitable casting temperature. As will hereinafter appear, the surprising and unexpected aspect of the invention is that sufficient oxidation of the metal can be realized to obtain the desired temperature control without any detrimental departure from the desired final analysis of the metal.

Referring to the drawing, one type of apparatus suitable for carrying out the present invention comprises an elongated open top vessel **10** which may be referred to as a trough-type tundish. For purposes of heat conservation, the open top of the tundish **10** is covered by insulating brick or tile **11**. At the left-hand end of the tundish **10**, as viewed in the drawing, an opening **12** is provided in the tile covering through which a stream of molten steel **13** may be poured from a ladle indicated fragmentarily at **14**. Although a tiltable ladle is shown, it will frequently be more convenient to employ a ladle of the bottom pour type. At the opposite or right-hand end of the tundish **10** a bottom discharge opening or outlet nozzle **16** is provided, it being understood that the tundish **10** is disposed at a slight incline downwardly from left to right as viewed in the drawing so that the molten metal introduced at **13** will flow by gravity to the outlet **16**. An adjustable stopper **17** disposed at the discharge opening **16** extends upwardly through an opening **18** in the tile cover and is arranged for reciprocable up-and-down movement by means of a stopper rod **19** which is swingably connected to a control lever **20** having a pivotal mounting on an upright support 21. Obviously, by manipulation of the outer end of the lever 20, either manually or automatically, the discharge of molten metal through the outlet opening 16 can be controlled in a manner well known in the steelmaking art. Immediately below the tundish outlet 16 is shown the upper open end of an elongated vertical continuous casting mold 22 having a mold cavity 23 of the desired cross-sectional configuration.

As a source of heat for maintaining the temperature of the molten metal during passage thereof through the tundish 10, a plurality of burner devices 24 are provided. In this particular instance, two such burners 24 are shown at opposite ends of the elongated tundish 10 but it will be understood that any suitable number of burners may be used as necessary to meet the requirements of a particular installation. As herein illustrated, each burner 24 consists of an elongated pipe or conduit 26 having a downturned tip or nozzle 27 extending into the tundish at the openings 12 and 18 so that the flames are directed onto the surface of the metal in the tundish. Combustion air is fed to the burner pipe 26 through a valve controlled connecting line 29 and a suitable fuel is supplied through a valve controlled branch line 31. A gaseous fuel such as coke oven gas or a commercially available hydrocarbon gas such as propane are most suitable but under some circumstances it is also possible to utilize a normally liquid fuel.

As the molten metal 13 is introduced from the ladle 14 into the tundish 10 at a temperature on the order of 2800–3000° F., the body of metal in the tundish flows in a relatively elongated stream toward the discharge outlet 16 of the tundish and is there discharged into the casting mold 22. Although the pouring of metal from the ladle 14 into the tundish may be carried out on a continuous or intermittent basis in accordance with available facilities, it is highly important that the flow of metal from the tundish 10 to the mold 22 be continuous and at a substantially constant flow rate. Preferably, the operation is controlled so as to maintain a substantially constant fluid head of metal above the discharge opening 16 of the tundish.

However, in order to maintain a substantially constant flow rate from the tundish outlet, it is vital that the temperature of the effluent molten metal from the tundish be maintained above a certain predetermined minimum temperature which for low and medium carbon steels is at least about 2750° F. and preferably at least about 2800° F. Although the burner devices 24 and the insulating cover 11 are valuable in combating heat loss in the tundish 10, nevertheless, it has been found that there are definite limits to the effectiveness of these means for avoiding heat loss. Accordingly, one or more streams of free gaseous oxygen, preferably commercial grade 98–99% purity oxygen, are directed downwardly against the surface of the flowing metal in the tundish 10. In the illustrated embodiment of the invention, three such oxygen streams are used, the oxygen being supplied in each case by means of a pipe 32 having a control valve 33 and a generally downturned outlet 34. At the ends of the tundish in this instance the oxygen is directed against the surface of the metal in the same general area of impingement as the burner flames from the nozzles 27.

Although there is, of course, some degree of enrichment of the burner flames by reason of the introduction of oxygen from the adjacent supply pipes 32, nevertheless, the effect of the oxygen on the combustion of the fuel is by no means primarily responsible for the increased heating effect on the metal in the tundish. On the contrary, the required extra heat comes from the exothermic oxidation reactions which take place by reason of the contact of free oxygen with the surface of the metal in the tundish, the free oxygen being present in the tundish in excess of fuel combustion requirements in all cases. By means of the present invention it has been found that the temperature of the metal from the tundish may be as much as 50 to 100° F. higher than can otherwise be obtained by the use of burner flames alone.

Contrary to what might have been expected, it has also been found that sufficient oxidation of metal can be obtained for temperature control without causing any major or intolerable departure from the desired final metal analysis in the cast product. The oxidation reactions involved include the oxidation of iron, manganese, carbon, and possibly other elements such as silicon and aluminum if present. However, it has been found that the desired introduction of oxygen into the tundish can be carried out successfully with an average drop in manganese content of only about .02% and not in excess of about .06% in any given heat. Although there is not always a consistent drop in carbon content as a result of using oxygen in the tundish, the observed carbon loss may range from about .01% to about .04%. However, in the case of low and medium carbon steels this is usually an unobjectionable feature and may be decidedly advantageous, e.g. when making a low carbon steel.

In carrying out the process of the present invention it is preferred to direct each oxygen stream against the surface of the metal in the tundish as a separate entity from the burner flame, i.e. without prior commingling of the oxygen with the fuel in the burner supply pipe. Although under some circumstances by using an excess of oxygen over fuel the oxygen may be introduced directly into the burner pipe so as to provide an oxidizing flame with excess free oxygen present, it is generally preferred to introduce the oxygen as an independent stream because the temperature of an oxygen enriched flame may be sufficiently high to cause excessive manganese and carbon loss and excessive slag formation in the tundish. Moreover, by utilizing separate burner flames and oxygen streams, advantage may be taken of the temperature and mechanical effects of the flames in preventing "crusting" at the metal surface in the tundish and thereby providing a fluid metal surface to be contacted by and reacted with the free oxygen streams. Also, with such an arrangement the independent control of fuel and oxygen supply rates is greatly simplified. In any event, whether the oxygen is supplied through the fuel burner pipes or as independent streams, it is essential to provide an excess of free oxygen over fuel combustion requirements and to direct the excess oxygen against the metal surface to facilitate oxidation of the metal.

A commercial grade of straight oxygen having a purity on the order of 98–99% is preferred for introduction to the oxygen pipes 32, but it is also within the scope of the invention to employ a high oxygen content or oxygen-enriched gas containing, for example, 80% oxygen or more. Dependent upon the size of the installation, the geometry of the tundish, and other factors which will be evident to those skilled in the art, the quantity of oxygen supplied to the tundish is regulated to obtain the desired degree of temperature control without excessive losses or slag formation and without interfering to any serious extent with the action of the metal in the mold. For casting rates for low and medium carbon steels ranging from about 1000 to about 1700 lbs. per minute, it has been found that straight oxygen may be supplied to the tundish in an amount of from about 40 to about 75 cubic feet per minute with effective results. The pressure and velocity of the oxygen stream directed against the metal surface should be sufficient to blow aside or displace any supernatant slag that may be present.

By comparison of optical pyrometer readings taken on the metal stream from the pouring ladle and also from the tundish outlet it is found that the temperature drop from the ladle to the tundish may readily be held to a maximum of about 100° F. and in some cases even as low as 20° F. by using oxygen in the tundish. However, the burner flames and the introduction of oxygen must be controlled to prevent excessive slagging which tends to clog the nozzle or discharge outlet 16 of the tundish. It is desirable to employ magnesite, zirconia, or magnesia for the tundish nozzle 16 since these materials are most resistant to deterioration by slagging.

In addition to the temperature control features discussed above, the use of free oxygen in the tundish as herein described also has another important advantage in that it facilitates and simplifies the making of various metallurgical alterations at this point. For example, it is frequently desirable to add alloying ingredients or make other metallurgical additions just prior to the introduction of the metal into the mold. Such additions may have an undesirable cooling effect in the tundish, but the use of oxygen as herein described tends to overcome any such cooling. In other instances, the substance being added to the metal in the tundish may be difficultly or only slightly soluble in the metal, but the increased temperature effect resulting from the use of oxygen tends to promote rapid solution of the added ingredient.

Although the use of oxygen in accordance with the present invention lends itself most readily to rimmed steels which are characterized by a relatively low deoxidation level and a high degree of gas evolution in the mold, nevertheless, it is a particularly significant advantage of the invention that it can also be utilized with satisfactory results even in the case of semi-killed and killed steels which are more highly deoxidized.

The following specific examples are presented by way of illustration and further explanation of the invention but should not be construed as limiting.

Example I

Using an apparatus of the same type shown in the drawing, a rimmed steel having a ladle analysis of .08% carbon and .35% manganese was successfully cast according to the above described technique utilizing both gas flames and oxygen streams in the tundish. At the burners, coke oven gas at 30 ounces per square inch was burned with air at 85–90 lbs. per square inch. From time to time the oxygen supplied to the oxygen pipes was cut in and out in order to evaluate the effect of oxygen on the metal temperature in the tundish, the supply pressure of the oxygen being about 120 lbs. per square inch.

By optical pyrometer readings, a typical pouring ladle temperature of 2950–2960° F. and a tundish outlet temperature of 2940° F. were observed when oxygen was being supplied. However, as soon as the oxygen supply was cut off, the tundish outlet temperature dropped to 2910° F. Shortly thereafter oxygen was again introduced to the tundish and the metal temperature at the tundish outlet immediately increased to 2930° F.

Example II

The data in the following table illustrate the results obtained in the casting of rimmed steel on a commercial scale using 30 ton heats. A tundish of the same general type shown in the drawing was employed and commercial grade high purity oxygen was supplied to the tundish at a rate of about 60 cubic feet per minute while casting the steel at a rate of from about 1000 to about 1700 lbs. per minute.

Heat	Metal Into Trough	Temp., ° F., Into Mold	Ladle Analysis, Wt. percent				Product Analysis, Wt. percent			
			C	Mn	P	S	C	Mn	P	S.
A	2,890	2,800	.08	.34	.010	.030	.09	.32	.008	.031
B	2,910	2,835	.09	.42	.009	.025	.09	.39	.008	.024
C	2,905	2,840	.12	.33	.008	------	.08	.33	.007	.029
D	2,920	2,860	.10	.37	.010	.031	.08	.34	.009	.031
E	2,880	2,810	.06	.37	.006	.027	.10	.37	.008	.028
F	2,865	2,820	.09	.42	.008	.040	.09	.40	.012	.041

In each heat the flow characteristics were quite satisfactory and, as will be evident from the table, the temperature drop in the tundish was held below 100° F. in every case. Morever, the reduction in manganese content did not exceed .03% while the carbon loss if any was not more than .04%.

Example III

Using the same commercial size equipment referred to in Example II, several heats of low carbon killed steel were cast in a 24 x 6½ inch section slab mold. Oxygen was used for temperature control in the tundish as previously described. In some heats aluminum in an average amount of about 2.5 lbs. per ton was used for deoxidation, the aluminum being added partly in the ladle and partly at the mold in order to obtain proper flow of the metal through the nozzles of the ladle and tundish and to avoid crusting of the surface of the metal in the mold. In one heat deoxidation was effected by the addition of 1.75% silicon to the ladle. The analyses and temperature data were as follows:

Steel	Metal Into trough	Temp., ° F., Into mold	Ladle Analysis, Wt. percent					Product Analysis, Wt. percent					
			C	Mn	P	S	Si	C	Mn	P	S	Si	Al
Al killed	2,900	----------	.07	.35	.008	.055	.002	.06	.35	.007	.058	.002	.004
Al killed	2,930	2,865	.08	.39	.008	.039	.02	.07	.38	.007	.038	------	.012
Al killed	2,910	2,840	.09	.45	.010	.029	.02	.07	.43	.012	.029	------	.033
Si killed	2,980	2,870	.07	.27	.010	.036	1.76	.06	.27	.012	.038	1.70	------

As will be evident from the above table, the use of oxygen and gas heating was effective in holding the temperature of the molten metal passing through the trough nozzle well above the critical value. Moreover, the change in manganese and carbon content was practically insignificant.

Example IV

Using the same commercial size equipment and oxygen technique described in Examples II and III, several heats of semi-killed steel were also cast. In one instance the deoxidation was accomplished by using a controlled quantity of aluminum only in the ladle, but in the other heats deoxidation in the ladle was effected by the addition of ferrosilicon followed by further deoxidation with controlled amounts of aluminum in the mold. The temperature and analysis data were as follows:

Ladle Deoxidizer	Metal Into trough	Temp., ° F., Into mold	Ladle Analysis, Wt. percent					Product Analysis, Wt. percent				
			C	Mn	P	S	Si	C	Mn	P	S	Si
Al	2,960	2,860	.07	.42	.011	.036	-----	.07	.38	.011	.035	-----
FeSi	2,910	2,860	.08	.33	.011	.040	.05	.05	.36	.012	.042	.05
FeSi	2,910	2,830	.08	.38	.012	.036	.07	.08	.37	.011	.030	.07
FeSi	2,875	2,820	.09	.40	.007	.027	.07	.08	.39	.007	.027	.06

The temperature control was quite effective and the final silicon content was in the same range as is expected in conventionally cast semi-killed steels. Likewise, the carbon and manganese loss was quite tolerable. Also, it is interesting to note that there was little change in silicon content between the metal coming from the ladle and the final product.

From the foregoing it will be seen that the invention provides novel means for combating heat loss and controlling metal temperature in a tundish while at the same time affording an opportunity for making metallurgical additions and alterations under most favorable conditions and also for obtaining a controlled increment of oxidation and loss of metal constituents which may be advantageous and desirable in certain cases, e.g. loss of carbon in the case of low carbon steel.

Although the invention has been described with particular reference to certain specific embodiments and examples, it is to be understood that various modifications and equivalents may be resorted to without departing from the scope of the invention as defined in the appended claims.

I claim:

1. In the casting of molten medium and low carbon rimmed steels and more highly deoxidized steels wherein the molten metal is passed through a tundish into a mold, the improvement which comprises introducing a gas containing at least about 80% oxygen into the space above the metal surface in the tundish for effecting controlled oxidation of the metal whereby the exothermic heat of oxidation supplies at least part of the heat required to maintain the effluent metal from the tundish at a satisfactory casting temperature not less than about 2750° F., said controlled oxidation resulting in the removal from the metal of not more than about .04% carbon, not more than about .06% manganese, and not more than about .06% silicon, and in any case said controlled oxidation resulting in no substantial interference with the action of the metal in the mold.

2. The method of claim 1 further characterized in that said gas consists essentially of free oxygen.

3. The method of claim 1 further characterized in that the casting rate is from about 1000 to about 1700 lbs. of metal per minute.

4. In the casting of molten medium and low carbon rimmed steels and more highly deoxidized steels wherein the molten metal is passed through a tundish into a mold, the improvement which comprises flowing the metal through the tundish in an elongated path whereby to expose a substantial metal surface, and introducing a gas containing at least about 80% oxygen into the space above the metal surface in the tundish for effecting controlled oxidation of the metal whereby the exothermic heat of oxidation supplies at least part of the heat required to maintain the effluent metal from the tundish at a satisfactory casting temperature not less than about 2750° F., said controlled oxidation resulting in the removal from the metal of not more than about .04% carbon, not more than about .06% manganese, and not more than about .06% silicon, and in any case said controlled oxidation resulting in no substantial interference with the action of the metal in the mold.

5. The method of claim 4 further characterized in that said gas consists essentially of free oxygen.

6. The method of claim 4 further characterized in that the casting rate is from about 1000 to about 1700 lbs. of metal per minute.

7. In the casting of molten medium and low carbon rimmed steels and more highly deoxidized steels wherein the molten metal is passed through a tundish into a mold, the improved method of maintaining the effluent metal from the tundish at a satisfactory casting temperature which comprises supplying heat to the metal by means of an open flame directed against the surface of the metal in the tundish, and introducing a gas containing at least about 80% oxygen into the space above the metal surface in the tundish for effecting controlled oxidation of the metal whereby the exothermic heat of oxidation in combination with the heat from the flame is sufficient to maintain the effluent metal from the tundish at a temperature of not less than about 2750° F., said controlled oxidation resulting in the removal from the metal of not more than about .04% carbon, not more than about .06% manganese, and not more than about .06% silicon, and in any case said controlled oxidation resulting in no substantial interference with the action of the metal in the mold.

8. The method of claim 7 further characterized in that said gas consists essentially of free oxygen.

9. The method of claim 7 further characterized in that the casting rate is from about 1000 to about 1700 lbs. of metal per minute.

10. In the casting of molten medium and low carbon rimmed steels and more highly deoxidized steels wherein the molten metal is passed through a tundish into a mold, the improved method of maintaining the effluent metal from the tundish at a satisfactory casting temperature which comprises flowing the metal through the tundish in an elongated path whereby to expose a substantial metal surface, supplying heat to the metal by means of a plurality of flames directed against the surface of the metal at spaced points along said path, and directing a plurality of gas streams containing at least about 80% oxygen against the metal surface at spaced points along said path for effecting controlled oxidation of the metal whereby the exothermic heat of oxidation in combinaion with the heat from the flames is sufficient to maintain the effluent metal from the tundish at a temperature of not less than about 2750° F., said controlled oxidation resulting in the removal from the metal of not more than about .04% carbon, not more than about .06% manganese, and not more than about .06% silicon, and in any case said controlled oxidation resulting in no substantial interference with the action of the metal in the mold.

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