US 20080163999A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2008/0163999 A1**

Hymas et al. (43) **Pub. Date: Jul. 10, 2008**

(54) **METHOD OF AND APPARATUS FOR CONVEYING MOLTEN METALS WHILE PROVIDING HEAT THERETO**

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(21) Appl. No.: **12/002,989**

(22) Filed: **Dec. 18, 2007**

Related U.S. Application Data

(60) Provisional application No. 60/876,045, filed on Dec. 19, 2006.

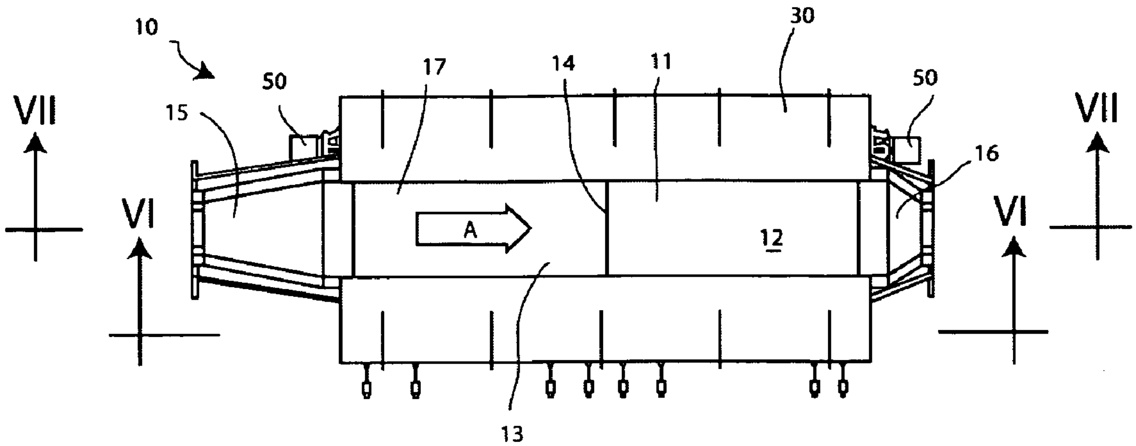
Publication Classification

(51) **Int. Cl.**
B22D 35/06 (2006.01)
F24D 5/02 (2006.01)

(52) **U.S. Cl.** **164/1**; 266/200; 237/81

(57) **ABSTRACT**

The invention relates to a method of and apparatus for providing heat to a molten metal flowing through metal-conveying apparatus. The apparatus includes a molten metal-conveying channel, an enclosure for receiving and circulating combustion gases while preventing entry of the gases into said channel, a heat-conductive body of material separating at least part of the channel from the enclosure; and a combustion device for generating combustion gases and delivering the gases to the enclosure. Heat from the combustion gases is used to heat molten metal held in the channel, while preventing contact between the combustion gases and the molten metal. The body of material may be a trough used to form the channel, a tube for conveying the molten metal, or a tube acting as the enclosure, or the like.



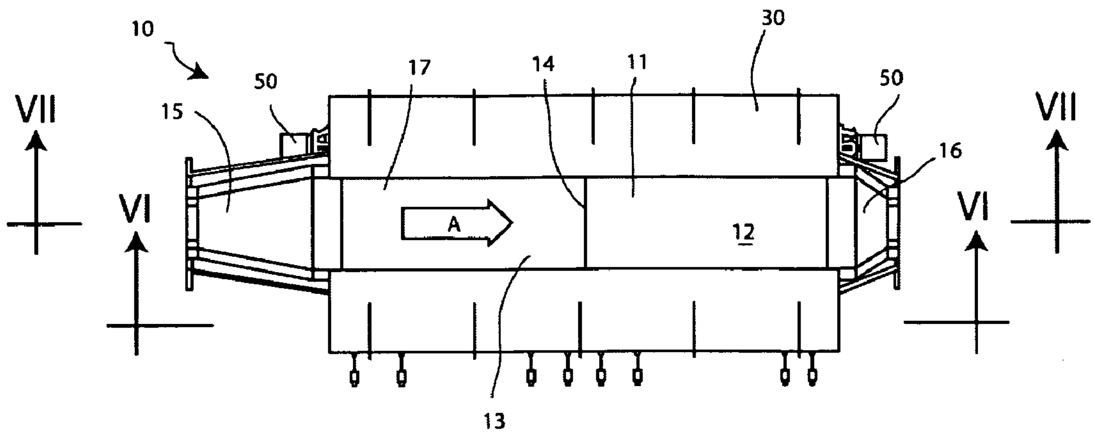


Fig. 1

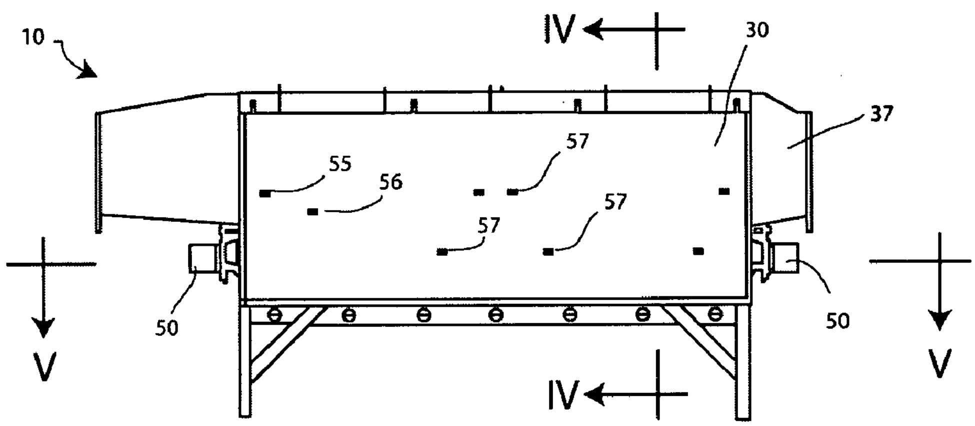


Fig. 2

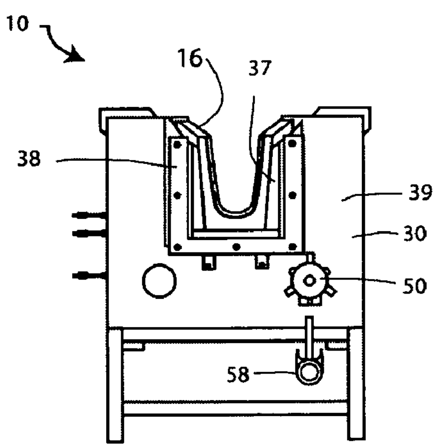


Fig. 3

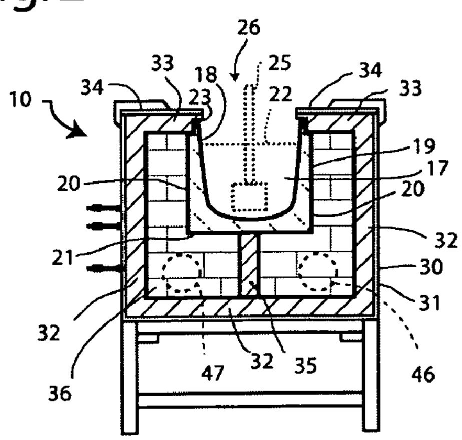


Fig. 4

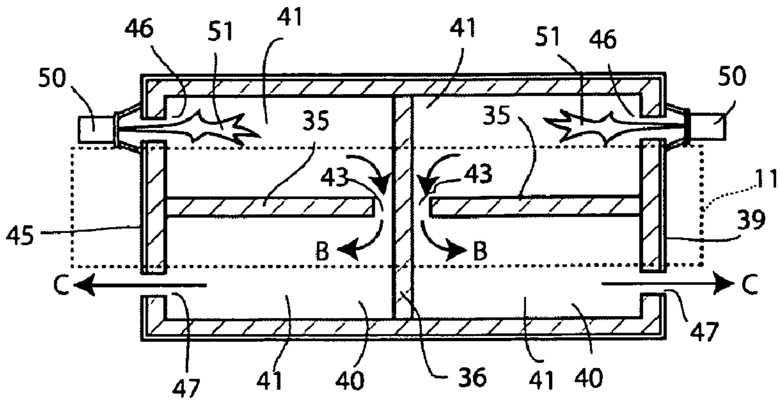


Fig. 5

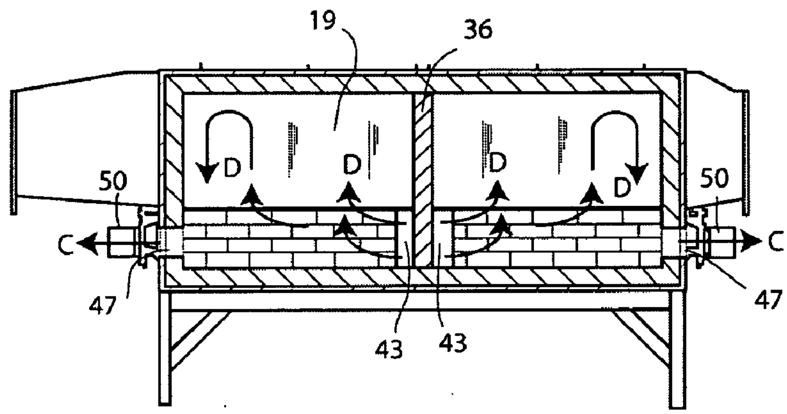


Fig. 6

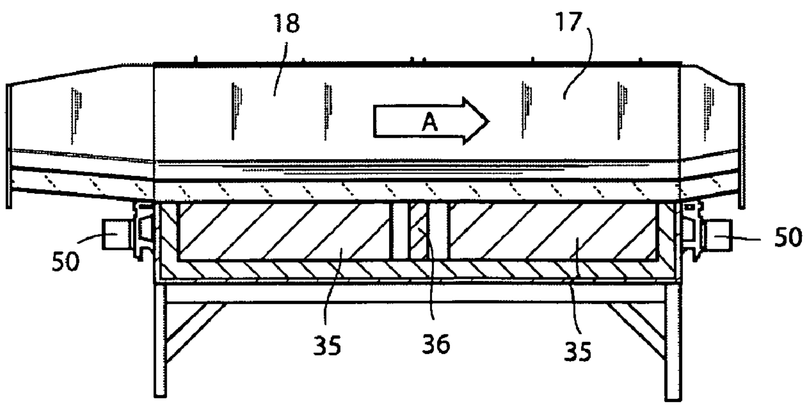
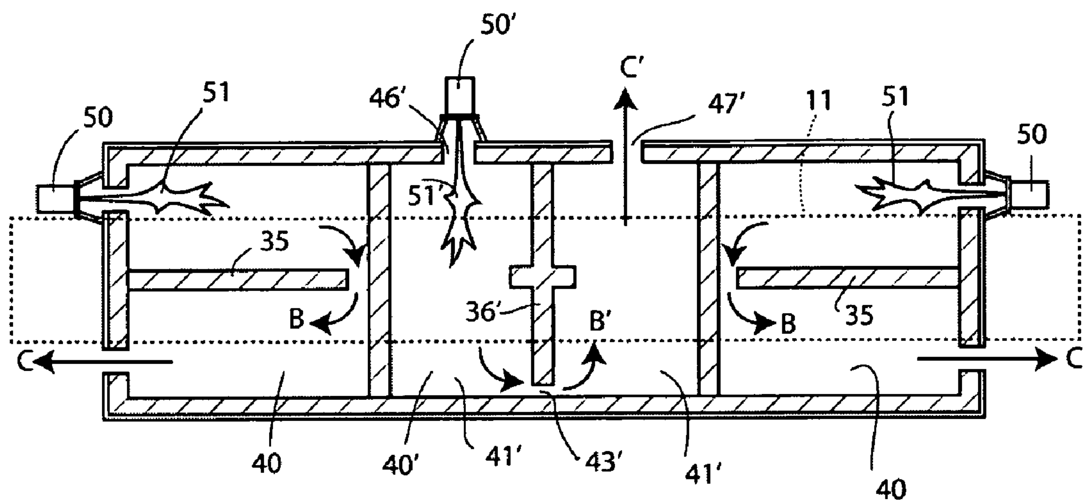


Fig. 7


50'
C'
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47'
11
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40'
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43'
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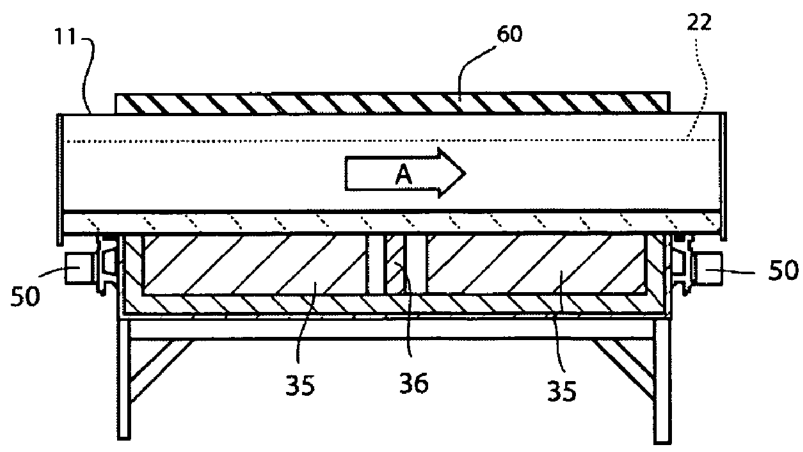
Fig. 8


11
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A
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Fig. 9

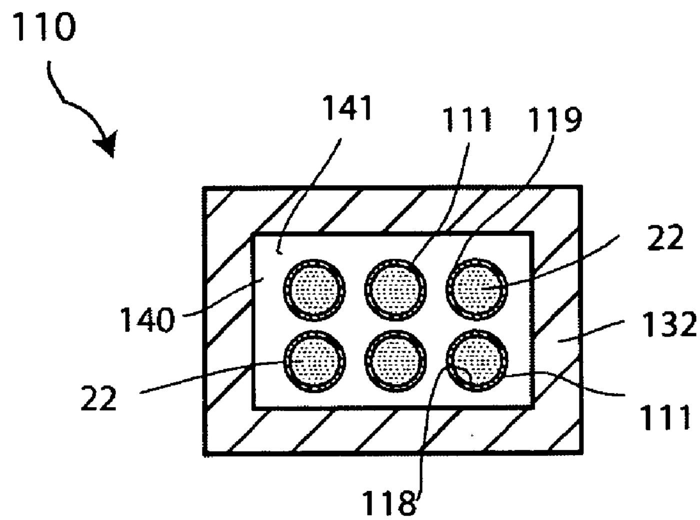
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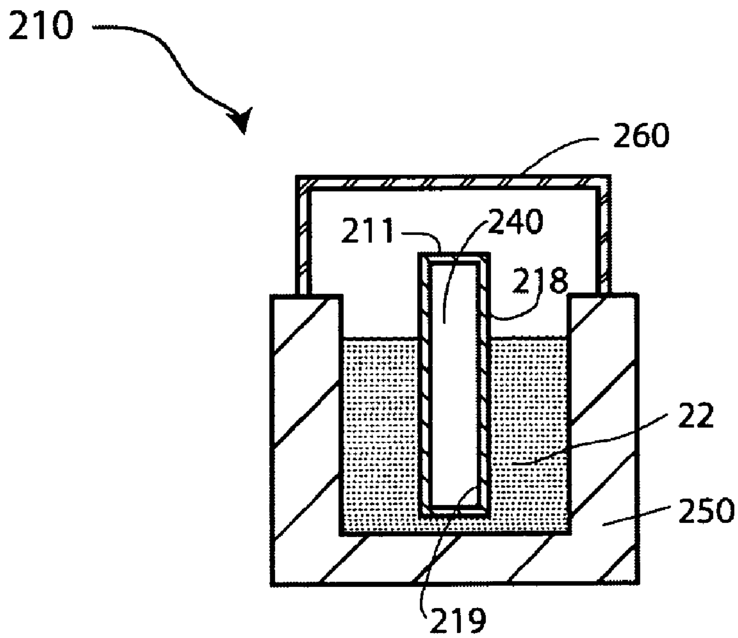
Fig. 10


210
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250
219

Fig. 11

METHOD OF AND APPARATUS FOR CONVEYING MOLTEN METALS WHILE PROVIDING HEAT THERETO

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority right of provisional U.S. patent application Ser. No. 60/876,045 filed Dec. 19, 2006 by applicants named herein.

BACKGROUND OF THE INVENTION

[0002] I. Field of the Invention

[0003] This invention relates to apparatus used for conveying molten metals during casting operations and the like. More particularly, the invention relates to apparatus for and methods of providing heat to molten metals conveyed in such apparatus to prevent metal freeze-up, undue cooling, or similar effects, during the passage through such apparatus.

[0004] II. Background Art

[0005] It is common practice during metal casting operations to cause a molten metal to flow through an elongated trough (sometimes called a launder), for example from a melting furnace to a casting mold. Such troughs are made of a material that can resist exposure to the molten metal for a reasonable period of time without undue damage, and the conditions must be such that the metal does not cool below its freezing temperature (solidus) before it reaches its destination. When troughs of this kind are fairly short, fast-flowing (e.g. relatively steeply inclined) or of relatively small metal-holding capacity, there is little risk of metal freezing. Recently, however, various new practices have made it necessary to provide troughs of greater capacity, greater length and/or slower flow, particularly in the aluminum treatment arts. For example, U.S. Pat. No. 5,527,381 to Peter D. Waite, et al., which issued on Jun. 18, 1996, discloses a method of treating a molten metal with a gas to remove dissolved hydrogen and other impurities as the metal flows through a trough or launder. The treatment can be made more thorough if the trough is of large metal-holding capacity and the metal is caused to flow at a slow rate of throughput. Similarly, it is now possible to co-cast different molten metals to form a single ingot by direct-chill casting, and the molten metal used for a cladding layer of such an ingot is generally cast in much smaller amounts than the molten metal used for a core layer, so that the metal for the cladding layer must flow more slowly to the casting apparatus than the metal for the core. Additionally, molten metal is sometimes filtered through ceramic foam filters to remove solid particles, and the use of such filters may slow the flow of molten metal through a trough. Consequently, in applications such as these and others, the risk of metal solidification (or undue cooling) in the trough is increased.

[0006] One way of eliminating the risk of metal solidification is to heat the metal in the trough or the trough itself. Metal in the trough can be heated by directing a flame onto the upper surface of the metal as it flows through the trough, but this has the disadvantage that oxidation of the metal at the surface is thereby accelerated, particularly if the metal is aluminum or an aluminum alloy. Heating of the trough can be carried out by providing electrical heaters on or adjacent to the inner surface of the trough, but generally such heaters are slow to transfer heat to the metal and are therefore not always very effective in applications of this kind.

[0007] Two patents illustrate the kind of approach taken in the past. U.S. Pat. No. 5,744,093 to John A. Davis, which issued on Apr. 28, 1988, discloses the provision of a covered trough to provide increased insulation. Gases emerging from the trough are drawn into a plenum, and heat may be introduced above the metal by means of a burner arrangement penetrating the trough cover. Combustion gases from the burner are then withdrawn from the space above the metal by being drawn into the plenum.

[0008] U.S. Pat. No. 3,942,473 which issued on Mar. 9, 1976 to Charles M. Chodash is concerned with the accretion of copper and provides an enclosed trough having a covered head space above the metal channel. The metal is kept at an elevated temperature either by providing radiant heaters in the head space or by directing gas flames onto the upper and lower surfaces of the trough.

[0009] There is a need for improvement of the heating of metal-conveying troughs, particularly for troughs of large capacity and/or slow throughput, and particularly for apparatus intended for use with aluminum and aluminum alloys.

SUMMARY OF THE INVENTION

[0010] In exemplary aspects, a method and apparatus are provided for providing heat to a molten metal flowing through a metal conveying apparatus. Hot combustion gases, generated by a burner or the like, are used to heat a heat-conductive material that comes into contact with the molten metal. However, the hot combustion gases are kept out of contact with the molten metal and are used to heat the metal solely by conduction through the refractory material. The heat-conductive material may be used to form a section of a trough, a channel element, or just a part of a trough or channel, or as an insert or body contacting the molten metal. The gases brought into contact with the heat-conductive material are confined within one or more enclosures that allow the gases to flow through the apparatus in the form of a stream while preventing contact of the combustion gases with isolated the molten metal (and preferably also the external atmosphere surrounding the apparatus).

[0011] One exemplary embodiment provides a molten metal-conveying apparatus, comprising a molten metal-conveying channel, an enclosure for receiving and circulating combustion gases while preventing entry of said gases into said channel, a heat-conductive body of material separating at least part of said channel from said enclosure, and a combustion device for generating combustion gases and delivering said gases to said enclosure. In use, heat from said combustion gases is transferred to molten metal held in said channel through said body of heat conductive material. Hence, the molten metal is heated by the combustion gases, but the gases are kept out of direct contact with the molten metal in the channel.

[0012] The heat-conductive body of material may form an elongated element (with a metal-contacting surface defining the channel and another surface contacting the combustion gases, e.g. an outside surface of the elongated element). In such a case, the elongated element may be an open-topped trough section or an enclosed tube or tubes. Alternatively, the heat-conductive body of material may be separate from an element defining the channel, e.g. it may be a tubular member extending into the channel formed in an elongated element.

[0013] In another exemplary embodiment, the invention provides a molten metal conveying trough apparatus. The apparatus includes a molten metal conveying trough section having an upper end and an outer surface extending around the trough section from the upper end. An enclosure at least partially encloses the outer surface of the trough section, and the enclosure contains at least one chamber adjacent to the outer surface. An entrance into the chamber, or an entrance into each chamber when there is more than one, is provided through which hot combustion gases are introduced into the or each chamber. An exit from the or each chamber is also provided through which the hot combustion gases are removed after flowing as a stream through the chamber(s), thereby transferring heat into the trough section through the outer surface thereof. The apparatus preferably additionally comprises at least one generator of hot combustion gases, such as a fuel burner, positioned at the entrance of the or each chamber.

[0014] Another exemplary embodiment provides a method of providing heat to a molten metal flowing through metal-conveying apparatus provided with at least one channel for conveying said molten metal, an enclosure for receiving and circulating combustion gases and a body of heat-conductive material separating at least part of said channel from said enclosure, said method comprising conveying molten metal through the channel, generating combustion gases, causing the combustion gases to enter and circulate through the enclosure while confining said combustion gases to prevent said gases entering said channel.

[0015] Yet another exemplary embodiment provides a method of heating a section of a molten metal conveying trough having an upper end and an outer surface extending around the trough section from the upper end. The method comprises generating at least one stream of hot combustion gases, and directing the at least one stream to flow through an enclosed volume surrounding at least part of the outer surface of the molten metal conveying trough section. The outer surface of the trough is thereby exposed to the stream of hot combustion gases, thereby causing heat to transfer to the trough section and its contents through the outer surface.

[0016] Preferably, the hot combustion gases are generated by a burner that creates a stream of hot gases and a flame introduced into the enclosure. The combustion gases are normally used directly, i.e. without having an opportunity to cool down to any significant extent. Ideally, the hot combustion gases are preferably confined to follow a winding path while in contact with the heat conductive refractory material and, ideally, substantially all of the surface of the heat conductive material opposite to the metal-contacting surface is exposed to the hot gases.

[0017] The heat-conductive body may be made of any material that has sufficient heat conductivity to allow heat to pass at an effective rate from the hot combustion gases to the molten metal in the channel when used in thicknesses appropriate to provide good support for the molten metal and a robust apparatus. An "effective rate" of heat passage is, of course, a rate sufficient to achieve the desired effect (e.g. molten metal heating, metal temperature retention, or slowed cooling of the metal as it passes through the channel). While any effective thickness of material may be used, thinner cross-sections are better because they are less resistant to the passage of heat, provided adequate strength is retained. The thickness selected is generally no greater than that required for adequate strength of the trough section and good support of the molten metals. Normally, effective materials are used in thicknesses that range from 0.25 inch to 12 inches or 0.5 inch to 6 inches, more preferably 1 to 8 inches, and even more preferably 2 to 6 inches, depending on the type of material employed, although thinner or thicker sections are not excluded. Of course, the thickness does not have to be constant at all points in the material and thicknesses may vary from point to point, as required, as may the composition of the material.

[0018] Suitable heat conductive materials include, for example, refractory metal compounds or solid metals. Many solid metals are attacked by flowing molten metal of the same or a different kind and are therefore not suitable, unless the metal-contacting surface is protected in some way. Cast iron has been found to have a good resistance to attack by molten metal (e.g. aluminum alloys) and the metal-contacting surface may be further protected by applying a thin coating of a refractory metal compound, e.g. boron nitride. Refractory metal compounds may be used instead of metal, provided they have good thermal conductivity or can be used in thin sections. Such materials are generally strong at high temperatures, resistant to thermal shock, unreactive with molten metal, and have low coefficients of expansion. However, refractory metal oxides, e.g. alumina, silica and calcium oxide, are generally regarded as heat insulators may not be suitable (unless mixed with more conductive materials or used in very thin sections) because they have low thermal conductivity (e.g. usually less than about 2 Watts/meter-Kelvin (W/mK). On the other hand, silicon carbide, boron nitride and silicon nitride are suitable materials (although boron nitride is extremely expensive, and is therefore unlikely to be used in practice while its price remains so high).

[0019] It has been found that heat-conductive refractories containing silicon carbide are particularly preferred, sometimes protected with a layer of silica to prevent oxidation at high temperatures. Although silicon carbide may be used in its pure form, it is generally mixed in granular form with binders and other refractory compounds in water, cast, dried and cured to form a dense solid. The larger the proportion of silicon carbide, the higher is the heat conductivity of the resulting refractory.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIG. **1** is a top plan view of an apparatus according to one embodiment of the present invention;

[0021] FIG. **2** is a side view of the apparatus of FIG. **1**;

[0022] FIG. **3** is an end view of the apparatus of FIG. **1**;

[0023] FIG. **4** is a vertical transverse cross section of the apparatus of FIG. **1** taken on the line IV-IV shown in FIG. **2**;

[0024] FIG. **5** is a horizontal cross section of the apparatus of FIG. **1** taken on the line V-V shown in FIG. **2**;

[0025] FIG. **6** is a vertical longitudinal cross section of the apparatus of FIG. **1** taken on the line VI-VI shown in FIG. **1**;

[0026] FIG. **7** is a central vertical longitudinal cross section of the apparatus of FIG. **1** taken on the line VII-VII shown in FIG. **1**;

[0027] FIG. **8** is a cross-section similar to FIG. **5** of an alternative embodiment of the present invention;

[0028] FIG. **9** is a cross-section similar to that of FIG. **7**, but showing a modified embodiment in which the trough has a constant depth throughout its length, and an insulating cover over the open top;

[0029] FIG. **10** is a cross-section of an alternative exemplary embodiment; and

[0030] FIG. **11** is a cross-section of yet another alternative embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0031] A first exemplary embodiment of a molten metal conveying apparatus is shown in FIGS. **1** to **7** of the accompanying drawings. This particular embodiment is intended for use with metal degasser nozzles intended for use with molten aluminum or aluminum alloys, thereby forming a compact in-line metal degasser unit which may, for example, be incorporated into a conventional trough or launder leading from a metal melting furnace to a casting apparatus. Other exemplary embodiments may be intended for use with other molten metals.

[0032] The apparatus is indicated generally by reference numeral **10** and includes a section **11** of metal-conveying trough made up of two trough parts **12** and **13** abutting each other at a junction **14**. The trough section **11** acts as an elongated channel-forming element that conveys molten metal through the apparatus. Butting up to the trough section **11** at an upstream end is a trough inlet member **15**, and butting up to the trough section **11** at a downstream end is a trough outlet member **16**. All of these parts are of generally U-shaped cross-section and are made of a body of heat-conductive refractory ceramic material, the same material preferably being used for all these parts. While most molten metal-conveying troughs are made of insulating refractories, e.g. metal oxides, designed to prevent undue cooling of the molten metal as it is conveyed through the trough, the trough section **11** is instead heat conductive. The preferred refractory material used for this purpose is a dense cast ceramic having a high thermal conductivity made of or containing silicon carbide (SiC). This material is resistant to high temperature and attack by aluminum and most aluminum alloys at their normal casting temperatures. The heat conductivity of such ceramics increases as the content of SiC increases and therefore it is desirable to use at least 25%, more preferably at least 50%, and even more preferably at least 65% of SiC in the composition. Pure cast SiC may be used, but is expensive and somewhat brittle. A particularly preferred material has the following composition:

SiC	80 wt. %
Al_2O_3	15 wt. %
SiO_2	3 wt. %
Balance	miscellaneous refractory components.

[0033] This material has a density of about 2.4 grams per cc and a heat conductivity in the range of 9.4 to 10.8 W/mK.

[0034] Arranged in the manner shown, inlet member **15**, trough section **11** and outlet member **16** are firmly held together, possibly under resilient longitudinal compression provided by spring-loaded end plates (not shown), usually without any jointing or sealing compound, to form a continuous elongated open-topped channel **17** for conveying molten metal in the direction of arrow A from one side of the apparatus to the other. Although not shown in the drawings, the inlet and outlet members are, in use, joined to other metal-conveying apparatus or trough parts using standard means of attachment. In the illustrated embodiment, the inlet member **15** and outlet member **16** incorporate slight downward slopes from their respective outer ends to their inner ends, thereby making the channel **17** somewhat deeper within the trough section **11** than at the extreme inlet and outlet ends (see FIG. **7**). However, it should be noted that a deep section of this kind in a trough may make it difficult to remove all of the metal between metal-conveying operations, so the trough section **11** and members **15** and **16** may alternatively be made of constant depth, if preferred.

[0035] As shown most clearly in FIG. **4**, the trough section **11** has an upper end **23**, an inner surface **18** defining part of the channel **17** and an outer surface **19** forming flat side walls **20** and flat bottom wall **21** delimiting the physical outer dimension of the trough section. Since the open channel **17** occupies most of the upper end **23**, there is virtually no trough outer surface at the upper end of the trough. The thickness of the channel section between the inner surface **18** and the outer surface **19** is sufficient to confine and support the molten metal without yielding. It can be seen that the channel **17** formed within the trough section **11** is relatively broad and deep so that it can hold quite a large quantity of molten metal when sufficiently filled (e.g. up to the level **22** shown by broken line in FIG. **4**). Of course, in other embodiments, the channel section may be shaped and dimensioned differently to suit particular applications, and may be, for example, rectangular, V-shaped or semi-cylindrical. As already mentioned, the apparatus of this exemplary embodiment is intended to be used with metal degassers (e.g. spinning gas injectors, one of which **25** is represented in broken lines in FIG. **4**), and the deep and broad shape and dimension of the channel **17** allows sufficient room for the immersion and use of such degassers, a good head of metal above the gas insertion points (which improves metal degassing and cleaning operations), and optionally a relative slow rate of metal flow through the channel of about 3 meters/minute or less (in other applications where the channel section is used primarily for metal delivery, a higher flow rate of 4 to 9 meters/minute is more common and preferred). The particular cross-sectional shape and size of the channel **17** also means that the ratio of the molten metal surface **22** exposed to the atmosphere relative to the volume of contained molten metal is quite small, so surface oxidation does not present as much of a problem as would be the case for a shallower or wider trough. A cover (not shown in this embodiment, but see element **60** of FIG. **9**) may be positioned over the channel **17** to reduce heat loss from the molten metal, although, in this embodiment, such a cover (if used) requires holes to allow the gas injectors **25** to pass through.

[0036] As can be seen from the drawings, the trough section **11** is surrounded on all sides, except at the open top **26** of the channel **17**, by an enclosure in the form of a housing **30** comprising a metal-sided tank **31** lined with heat insulating refractory material **32** made, for example, of fire bricks stacked side-by-side or one on top of another, optionally without any jointing or sealing compounds, although a refractory mortar may be used between the bricks, if desired. The open top of the tank is wider than the trough section **11** and the gaps between the sides of the tank and the upper edges of the trough section are also bridged and closed off by refractory blocks **33**, e.g. ceramic bricks laid transversely relative to the long dimension of the trough section and supported at their inner edges by notched corners of the trough section itself at the upper end **23**, as shown in FIG. **4**. Removable insulating covers **34** are positioned over the refractory lining material **33** to provide a relatively cool upper surface for the safety of operators. Within the housing **30**, the trough section **11** is supported by a short vertical wall **35** rising upwardly from the floor of the tank along the longitudinal centerline, and also by a vertical wall **36** extending transversely of the trough section (see FIG. **5** in particular). The junction **14** of the two parts **12** and **13** of the trough section is aligned with wall **36** to prevent slippage between the parts. Any tendency of the trough section **11** to sag or slip under the weight of the metal at the operating temperature is thus avoided by the underlying rigid and effective support provided by walls **35** and **36**.

[0037] As shown in FIG. **3**, the outlet member **16** of the trough is retained within an open-topped metal shell **37** held in place by an open-topped rectangular bracket **38** bolted to end wall **39** of the tank. A similar arrangement is provided for the inlet member **15** of the trough at the other end of the apparatus.

[0038] As can be seen best from the horizontal cross-section of FIG. **5**, the interior of the housing **30** incorporates two hollow chambers **40** forming enclosed spaces isolated from the outside atmosphere and mutually aligned with one following the other in the longitudinal direction of the apparatus. The chambers **40** are separated by transverse wall **36** which extends closely around the outer surface **19** of the trough section **11** (see FIG. **6**) and thereby isolates the atmospheres within the two chambers from each other. Each chamber **40** is divided down the center by longitudinal wall **35** to form two hollow compartments **41**, but these compartments communicate with each other by virtue of the fact that the longitudinal walls **35** do not extend fully up to the transverse wall **36**, leaving gaps **43** on each side.

[0039] It is preferable that substantially all of the outer surface **19** of the trough section **11** should be encircled by the housing and chambers, i.e. at least those parts of the trough between end walls **39** and **45** of the housing. In some embodiments, however, it may be possible to enclose less of the outer surface of the trough, i.e. the upper end of the trough may stand clear of the housing, or the bottom wall of the trough may rest on the bottom of the tank and may not be exposed to the internal chambers **40**. Generally, however, at least 50%, and more preferably at least 75%, and optionally at least 95% of the outer surface of the trough section is enclosed and encircled by the internal compartments and chambers, thereby ensuring (as will be explained) good and even heat delivery to the trough section and molten metal contained therein. Any parts of the trough that are not enclosed in this way may, if desired, be covered by a layer of heat insulating material to prevent undue heat loss from these parts.

[0040] As already noted, in the illustrated embodiment, substantially the entire outer surface **19** of the trough section **11** is surrounded by and directly exposed to the internal compartments **41** of each chamber **40**, i.e. not only at the sides **20** but also along the bottom **21**. The only parts of the trough section not directly exposed to these hollow compartments are the parts supported by the walls **35** and **36**, and the parts in contact with the refractory material **33** at the top edges. These parts of the trough section add up to only a small percentage of the outer wall of the trough section. Two openings **46** and **47** are formed in each of the end walls **39** and **45** of the tank **31** and pass through the adjacent refractory lining. Openings **46** are intended as inlets for hot combustion gases into the respective chambers **40**, and openings **47** are intended as outlets for such gases (and are normally each connected to gas exhaust piping, not shown). Fuel burners **50** are positioned in or adjacent to the inlet openings **46** to generate streams of hot combustion gases, and optionally flames **51**, and to introduce them into the compartments **41**, as shown in FIG. **5**. The hot gases circulate between the compartments **41** in each of the chambers **40** by virtue of the gaps **43** positioned at a distance from each of the inlets and outlets. This circulation of hot gases is represented by arrows B. The gases eventually leave the apparatus via the outlets **47**, as represented by arrows C. As shown in FIG. **6**, the hot gases are free to ascend along the sides of the trough section **11**, as shown by arrows D, so that the substantially the entire outer surface **19** of the trough section **11** is exposed to and bathed in the hot circulating combustion gases during operation of the burners. Collectively, the movements represented by arrows B, C and D form a steady stream of hot gases flowing through the chambers **40**. It will be noted that the chambers are completely enclosed within the housing **30** and are sealed against loss of gases, except at inlets and outlets **46** and **47**, so the streams of hot combustion gases are constrained to follow a winding or sinuous or serpentine path through each chamber, i.e. from compartment to compartment **41** via the distant gap **43** with the gases flowing in opposite directions in each compartment. It will be understood that the combustion gases are channeled and constrained in such a way that they are prevented from entering the channel **17** and coming into contact with the molten metal conveyed through the apparatus.

[0041] In practice, trough section **11** is heated at its outer surface **19** by both radiant heat from the flames **51** and conduction/convection from direct contact with the hot combustion gases. The relatively good heat conductivity of the material of the trough section **11** allows the heat to penetrate through the trough section and into the channel **17** and molten metal held therein. The openings **46** and **47**, and the burners **50**, are preferably positioned and angled such that flames **51** and the stream of hot gases are not initially directed onto the outer surface **19** of the trough section **11**, nor onto the refractory lining **32**, **33**, thereby avoiding the formation of hot-spots and possible damage to the refractory surfaces. The flame and hot gases from the burners **50** are generally oriented horizontally in the longitudinal direction of the trough section into an open area of each chamber **40** beneath the level of the bottom wall of the trough section. This arrangement also ensures good heat distribution across the entire outer surface **19** of the trough section and thus prevents the formation of cool spots within the metal channel **17**. It will be noted that the hot gases passing through the chambers **40** encounter only the refractory of the tank lining or the refractory of the trough section so that the high temperatures are accommodated without damage to the apparatus or undue heat loss.

[0042] The burners **50**, which may for example be gas-fired or oil-fired, are provided with suitable heating capacity to raise the temperature in the chambers quickly and to introduce sufficient heat into the trough section **11** to raise the temperature of the molten metal in channel **17**, to keep the temperature of the molten metal constant, or to allow the molten metal to cool in a controlled manner, depending on the plans for the metal. Examples of suitable burners are so-called premix burners that are aspirated at the spud and the burner throat created by the velocity of gas moving through a nozzle. The mix of fuel and air and may be controlled by a manual valve, or may be controlled automatically, e.g. by a computer following a pre-determined program. Examples of such burners are disclosed in the North American Combustion Handbook (1978), North American Mfg. Co., Second Edition, 1978 (ISBN: 0960159614), page 243, FIGS. 6.7

(inspirator design) and 6.8 (aspirator design). The disclosure of this handbook is specifically incorporated herein by this reference. As an alternative, compressed air may be used to jet the combustion gases into the chambers **40**, or a nozzle-mix burner may be used in which the burner mixes air and gas but requires a blower to provide the air. In all cases, there is a necessary fuel supply with appropriate safety equipment to control purging, pressure, flame monitor, etc. Generally, the combustion gases have a temperature in the range of 500 to 2000° C. or more when introduced into the apparatus, and are thus capable of delivering heat rapidly and in unlimited quantities.

[0043] In operation, if desired, the ceramic material of the trough section may be raised quickly to a suitable high temperature by the burners when the apparatus is first put into operation, and such temperature can be maintained indefinitely during normal metal flow. Alternatively, the apparatus may be heated by the combustion gases before metal is caused to flow through the trough, thereby avoiding rapid cooling of the metal as the first flow of the hot metal pours into the apparatus. Once a steady temperature has been reached, the output of the fuel burners **50** may be scaled back or cycled on and off to maintain an equilibrium temperature under the control of thermocouples or similar temperature-sensing devices, ideally monitored by computer numerical equipment. For this purpose, two thermocouples **55**, **56** are provided to control the temperature of each chamber, one (**55**) for the control of the temperature of the trough and/or the metal within the trough, and the other (**56**) for control of over-temperature within the chamber. Trough temperature is taken outside the fire box near to the burner via thermocouple **55** positioned in direct contact with the trough. Alternatively, a thermocouple may be provided in contact with the molten metal and extending into the trough from the open upper end. The second thermocouple **56** is positioned in contact with the refractory **32** in the coolest part of the chamber. The burner **50** is then cycled between two control points, i.e. low metal temperature cycles the burner on, and high chamber temperature cycles the burner off. Backup thermocouples **57** are also provided in case of failure of the primary thermocouples.

[0044] Thermocouples may be provided only on one long side of the housing **30**, but may alternatively be positioned on both sides. In general, the thermocouples are provided on the burner side of a chamber, but the burner of each chamber may be positioned differently in different installations due to such considerations as available space and exhaust facilities, etc., so it is prudent to provide thermocouples on each side during the production of the apparatus. Also, it should be kept in mind that in a two-chamber housing of the kind shown in the FIGS. **1** to **7**, the burners of one chamber may be positioned on the opposite transverse side from the burner of the other in contrast to the same-sided arrangement shown in the drawings. Indeed, this may be preferred for even distribution of heat along the trough section.

[0045] It will be noted from the drawings that there is no barrier or layer of material of any kind between the outer surface **19** of the trough section **11** and the inside of the chambers **40**, because any such barrier or layer would add a measure of insulation between the trough section and the hot combustion gases, thereby slowing the temperature response of the apparatus or reducing the maximum temperature that may be imparted to the molten metal. However, a thin covering or shell of material, such as metal or protective ceramic layer, may be provided to support and protect the material of the trough section, if this is considered desirable. Such a layer should preferably be thin enough (or conductive enough) to provide little or no heat-insulation value.

[0046] The burners **50** are fed with fuel through conventional oil or gas lines (not shown in the drawings) and the lines may be secured by a hose clamp **58** as shown in FIG. **3**. In FIG. **4**, the position of inlet **46** and outlet **47** are shown in broken lines to indicate their positions relative to the interior, although it will be realized that these elements are formed in the exterior wall (not shown in FIG. **4**).

[0047] FIGS. **1** to **7** represent an exemplary embodiment in which there are two longitudinal heating chambers **40** within the housing, each divided into two lateral compartments **41**, which is an arrangement that is normally preferred. However, for a relatively short trough section, there may be just a single chamber with two compartments, one inlet, one outlet and one fuel burner (the inlet and outlet being positioned in the same side wall, and the chamber extending for the full length of the trough section). For a longer trough section, more than two chambers may be provided. For example, FIG. **8** is a view similar to FIG. **5**, but showing a three-chamber apparatus. In this case, an additional chamber **40'** is positioned between two end chambers **40**. The additional chamber has a divider wall **36'** that divides the chamber into two compartments **41'** and forces the hot combustion gases entering the chamber **40'** through side inlet **46'** from burner **50'** to extend around the end of the divider wall as shown by arrows B' before emerging from the compartment at side outlet **47'**. Additional similar chambers may be provided, if required. It is to be noted that the provision of more burners and chambers makes it possible to introduce greater amounts of heat into the apparatus and offers a more precise control of temperature or temperature profile along the channel.

[0048] As noted earlier, the apparatus of FIGS. **1**-**7** (and also FIG. **8**) is intended to provide a trough section suitable for use with metal degasser nozzles and is therefore quite deep. FIG. **9** shows an alternative embodiment having a shallower trough section **11** intended for more general use for conveying molten metal from one location to another. In this case, the floor of the trough section **11** is flat throughout its length and there are no trough inlet and outlet members as in the earlier apparatus. The overall height of the trough section **11** should preferably be approximately 100 mm above the metal level **22** for safety. As there is no intention to introduce devices such as gas nozzles into the metal in this form of the apparatus, an insulating cover **60** (either removable or fixed) may be positioned over the open upper end of the trough section to provide heat insulation for the molten metal.

[0049] In the case of a two-chamber apparatus of FIGS. **1** to **7**, the length of the trough section is normally about 6.5 ft. and the two burners combined are capable of generating a maximum of at least 600,000 Btu/hr, or 92,000 Btu/hr/ft during apparatus heat-up (for a total of 600,000 Btu/hr). In steady-state operation, the output of the burners may be scaled back to about 360,000 Btu/hr, or 55,000 Btu/hr/ft. When gas fired, the burners may consume 12,000 liters per minute of gas at maximum output. The amount of air supplied to the burners should be an amount suitable for complete combustion of the gas to carbon dioxide (usually an excess of 3% over the stoichiometrical amount required for complete combustion), e.g. 120,000 liters per minute. This degree of heating ideally keeps the metal within a suitable temperature range, e.g. 20° C. above the liquidus (or a minimum of 350° C.) up to 1300° C. (for aluminum and aluminum alloys), and up to about 850°

C., or even up to about 1000° C. A particularly preferred range is 650-725° C. It is to be noted that a large amount of the heating effect may be brought about by radiant heating as well as convection heating.

[0050] The metal movement through the trough section is generally expressed in terms of mass flow. The preferred rate is 86-550 lbs/minute, or about 2-5 cm/sec, although there is really no lower limit as the metal may be kept molten even when it is stationary. Generally, the flow should not be so fast that it becomes turbulent, which often occurs within the range of 15-20 cm/sec.

[0051] If necessary, when the apparatus of the illustrated embodiments is attached to other trough sections, those sections (particularly if shallower) may also be heated, but by other means, e.g. by electrical heaters embedded in the trough walls or used to produce radiant heat from above.

[0052] While the previous exemplary embodiments incorporate open-topped trough sections made of heat conductive refractory material, other arrangements may be provided. For example, further alternative exemplary embodiments of the invention are shown in FIGS. **10** and **11**. In the embodiment of FIG. **10**, molten metal **22** is conveyed through six parallel tubes **111** made of a heat conductive material, preferably containing silicon carbide. The tubes have inner, metal-contacting, surfaces **118** and outer surfaces **119** that remain out of contact with the molten metal. The tubes are surrounded by an enclosure **132** made of an insulating refractory material, e.g. a material made of refractory metal oxides. The enclosed space between the exterior of the tubes **111** and the interior of the enclosure **132** forms a passage **141** through which hot combustion gases are caused to flow and circulate (e.g. a burner is provided at an inlet at one longitudinal end of the enclosure **132** and a vent for the gases is proved at an opposite longitudinal end). The metal within the tubes **111** is kept hot by heat from the combustion gases passing through the walls of the tubes **111**, whereas heat is retaining within the apparatus **110** by the insulation provided by the enclosure **132**. The hot combustion gases in the channels formed by the tubes do not contact the molten metal as the gases are confined to follow a separate path and are vented before the molten metal exits the apparatus.

[0053] In the embodiment of FIG. **11**, molten metal **22** is conveyed through an elongated trough **250** made of a heat insulating material, e.g. a material made of refractory metal oxides. Suspended within the molten metal **22** is a body **211** of heat conductive material, preferably a refractory substance made of or containing silicon carbide. The body is fabricated in the form of a hollow tubular element encircling an enclosed space **240**. The body **211** has an outer surface **218** that contact the molten metal in the trough, and an inner surface **219** that is out of contact with the metal. Hot combustion gases are caused to flow through the enclosed space **240**, e.g. by providing a burner at an inlet at one longitudinal end of the body **211** and a vent at an opposite longitudinal end. The body **211** consequently confines and circulates the hot gases and keeps the gases out of contact with the molten metal in the trough **250**. The molten metal is kept hot by heat from the combustion gases that passes through the conductive walls of the body **211**. A removable cover **260** is provided to reduce heat losses from the surface of the molten metal.

COMPARATIVE INFORMATION

[0054] Potential materials for the heated trough were investigated for thermal conductivity and resistance to attack by molten aluminum. The results are shown in the Table 1 below.

TABLE 1

Supplier	Product	Composition	Density g/cc	Thermal Conductivity W/mK	Resistance to Molten Al	Notes
Pyrotek	O'Sialon	65% SiC	2.6	9	OK	
Andeman	EC70P	70% SiC, Al silicate	2.1	7	OK	
Pyrotek	Pyrocast SCM2600	77% SiC, Al silicate	2.6	7	OK	
Pyrotek	Pyrocast SC2600	83% SiC, alumina	2.4	10	OK	
Andeman	EC90P	90% SiC, Al silicate	2.2	25	OK	
Aremco	Bisque Fired Alumina	Alumina	2.8	4	Cracks	Machinable
Pyrotek	Pyrocast ZA	Alumina - Metal	2.7	6	OK	Contains metal fibers for strength
St. Gobain	AX05	BN	1.8	78	OK	Very expensive
GE	BNC1	BN Composite	2.2	10	OK	Machinable
Pyrotek	Pyrocast ZR	Fused SiO, Al silicate	2.3	1-2	OK	
SGL Carbon	EK10	Graphite	1.7	10	OK	Burns in air
Morgan	Frequentite 1000	Mg Silicate	2.8	3	No data	
Ceradyne	147-1B	Si_3N_4	2.3	14	OK	Machinable before filing
	EKatherm	Si_3N_4	3.2	22	OK	Machinable before filing
	Plain C steel		7.9	50	Dissolves	

TABLE 1-continued

Supplier	Product	Composition	Density g/cc	Thermal Conductivity W/mK	Resistance to Molten Al	Notes
	Alloy steel		7.8	40	Dissolves	
	Stainless steel		7.9	15	Dissolves	
	Hi-Ni ductile iron		7.4	13	Dissolves	
	Cast Iron			80	Erodes	Can be coated with a wash (e.g. BN) to extend service life

[0055] A review of the published properties of various forms of SiC revealed the information shown in Table 2 below (from MatWeb website).

TABLE 2

Material	Thermal Conductivity W/mK
SiC, sintered alpha	126
SiC, sublimed	110
SiC, 99.9995%	200
SiC, hot pressed	70
SiC, zero porosity	100-160
SiC, reaction bonded	125
SiC, sintered	150
SiC, Chemical Vapor Deposition 99.9995%	115
SiC, fibers	150
SiC, synthetic	90
SiC, beta	42

[0056] It appears that all these forms of SiC are of very high thermal conductivity, and may thus be used in the illustrated embodiments when sufficiently strong and durable.

[0057] From these tables, it can be seen that a preferred range of thermal conductivity is at least about 2.5 W/mK, e.g. in the range of about 2.5 to 200 W/mK, with more preferred ranges being 5 to 80 W/mK and 7 to 25 W/mK.

1. A molten metal-conveying apparatus, comprising:

a molten metal-conveying channel;

an enclosure for receiving and circulating combustion gases while preventing entry of said gases into said channel;

a heat-conductive body of material separating at least part of said channel from said enclosure; and

a combustion device for generating combustion gases and delivering said gases to said enclosure;

whereby, in use, heat from said combustion gases is transferred to molten metal in said channel through said body of heat conductive material.

2. The apparatus of claim **1**, wherein said material has a thermal conductivity in a range of 2.5 to 200 W/mK.

3. The apparatus of claim **1**, wherein said material has a thermal conductivity in a range of 5 to 80 W/mK.

4. The apparatus of claim **1**, wherein said material has a thermal conductivity of 7 to 25 W/mK.

5. The apparatus of claim **1**, wherein said material comprises a refractory metal compound.

6. The apparatus of claim **5**, wherein said refractory metal compound is selected from the group consisting of silicon carbide, boron nitride and silicon nitride.

7. The apparatus of claim **5**, wherein said material comprises at least 65% by weight of silicon carbide.

8. The apparatus of claim **1**, wherein said material is a metal having a coating of a substance, at least on a metal-contacting surface of the material, that is resistant to attack by said molten metal.

9. The apparatus of claim **8**, wherein said metal is cast iron.

10. The apparatus of claim **8**, wherein the substance is boron nitride.

11. The apparatus of claim **1**, wherein said channel is defined by an open-topped trough section and said enclosure encircles an outer surface of said trough section.

12. The apparatus of claim **1**, wherein channel is defined by at least one tube adapted to convey molten metal therethrough, said body of material forms walls of said at least one tube, and said enclosure fully surrounding said at least one tube.

13. The apparatus of claim **1**, wherein said body of material forms a hollow tubular element suspended in said channel, and said hollow tubular element acts as said enclosure defining said enclosed space within said element.

14. A molten metal-conveying trough apparatus, comprising:

a molten metal conveying trough section having an upper end and an outer surface extending around the trough section from said upper end;

an enclosure at least partially enclosing said outer surface of the trough section, said enclosure containing at least one enclosed chamber adjacent to said outer surface;

an entrance into the chamber, or an entrance into each chamber when more than one, through which hot combustion gases can be introduced into the or each chamber; and

an exit from the chamber, or each chamber when more than one, through which said hot combustion gases can be removed from the chamber, or each chamber when more than one, after flowing through the or each chamber, thereby transferring heat to the trough section through said outer surface.

15. The apparatus of claim **14**, wherein said enclosure encloses substantially all of said outer surface of the trough section.

16. The apparatus of claim **14**, further comprising at least one generator of a stream of hot combustion gases, one said generator being positioned at said entrance of the or each chamber.

17. The apparatus of claim **16**, wherein said at least one generator introduces said stream of hot combustion gases into the or each chamber generally horizontally beneath said trough section.

18. The apparatus of claim **14**, wherein said trough section is made of a heat-conductive refractory material.

19. The apparatus of claim **14**, wherein the heat-conductive refractory material comprise silicon carbide.

20. The apparatus of claim **14**, having at least two said chambers arranged one following another in a longitudinal direction of said trough section.

21. The apparatus of claim **14**, wherein the or each chamber comprises at least two compartments interconnected together at a distance from said inlet and said outlet and positioned to confine said stream of hot combustion gases to flow along an extended path adjacent to said outer wall of said trough section.

22. The apparatus of claim **14**, wherein the chamber, or each chamber when more than one, has an inner volume in use receiving said hot combustion gases, and said outer surface of said trough section is directly exposed to said inner volume.

23. The apparatus of claim **14**, further comprising at least two thermocouples, one positioned to measure temperatures of molten metal when present in said trough section, and another positioned to measure temperatures in said chamber, or at least one of said chambers when more than one.

24. The apparatus of claim **14**, further comprising a heat-insulating cover positioned over said upper end of said trough section.

25. A method of providing heat to a molten metal flowing through metal-conveying apparatus provided with at least one channel for conveying said molten metal, an enclosure for receiving and circulating combustion gases and a heat-conductive body of material separating at least part of said channel from said enclosure, said method comprising:

conveying molten metal through said channel;

generating combustion gases;

causing said combustion gases to enter and circulate through said enclosure while confining said combustion gases to prevent said gases entering said channel.

26. A method of heating a section of a molten metal conveying trough having an upper end and an outer surface extending around the trough section from said upper end, which comprises:

generating at least one moving stream of hot combustion gases; and

directing said at least one stream of hot combustion gases to flow through at least one enclosed volume surrounding at least part of said outer surface of said molten metal conveying trough section, thereby exposing said at least a part of said outer surface of said trough section to said hot combustion gases and enabling heat to transfer into said trough section through said outer surface.

27. The method of claim **26**, wherein said at least one enclosed volume surrounds substantially all of said outer surface of said trough section.

28. The method of claim **27**, wherein said at least one stream is directed to flow in an extended path adjacent to said outer surface of said trough section.

29. The method of claim **28**, wherein said at least one stream is directed to flow in an extended winding path.

30. The method of claim **26**, wherein said stream of hot combustion gases is generated by burning fuel in a stream of combustion air.

31. The method of claim **26**, wherein said at least one stream of gases is directed to flow initially beneath said trough section.

32. The method of claim **26**, wherein at least two streams of said hot combustion gases are generated and each is directed to flow through a different enclosed volume, each volume being arranged one after another in a longitudinal direction of said trough section.

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