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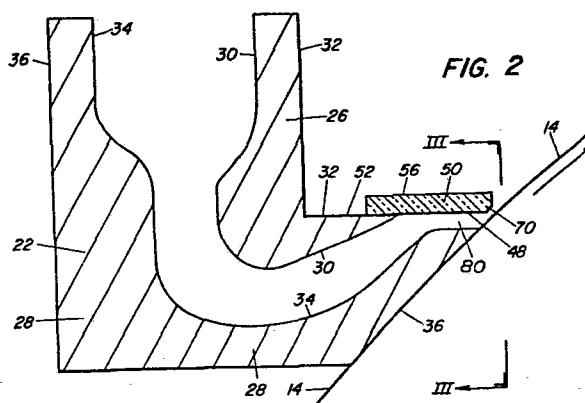
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Apparatus for strip casting.

Apparatus for continuously casting strip material onto a casting surface (14) is disclosed, comprising a tundish (22) for receiving and holding molten metal (20) having a nozzle therein. The nozzle comprises an orifice passage (80) defined between a first inside surface (30) and a second inside surface (34), wherein at least a portion of at least one inside surface (30) comprises an insert (50) disposed against the tundish (22). A nozzle gap of at least 0.254mm (0.010 inch) is maintained, an outer portion of the insert (50) is able to be disposed to within 3.048mm (0.120 inch) of the casting surface (14), and at least a portion of the outside surface (36) of the tundish (22) at the orifice of the nozzle (24) is able to be disposed to within at least 0.508mm (.020 inch) of the casting surface.



APPARATUS FOR STRIP CASTING

The present invention relates to apparatus for continuously casting strip material. More particularly, the present invention is directed to apparatus for casting thin metallic strip material.

Incorporated herein, by reference, is the subject matter of our co-filed European Patent Applications entitled "Strip Casting Apparatus", "Method and Apparatus For Strip Casting", "Method of Repetitiously Marking Continuously Cast Metallic Strip Material", "Apparatus For Strip Casting" and "Strip Casting Nozzle".

The apparent advantages and economic significance of producing thin metallic strip material by a casting process, as compared to the conventional rolling or reducing operations, are numerous. The fact that strip casting may be performed at such high quench rates as to produce amorphous material is even more meaningful. However, it is equally apparent that there are a multitude of strip casting parameters which must be controlled or monitored to assure that the cast strip is of acceptable quality and of uniform composition and

structure. For these reasons, those skilled in the art appreciate that the development of a commercially successful strip casting apparatus is difficult.

The general concept of casting thin metallic materials such as sheet, foil, strip and ribbon was disclosed in the early 1900's. For example United States Patents Nos. 905,758 and 993,904 teach processes wherein molten material flows onto a moving cool surface and the material is drawn and hardened thereon into a continuous thin strip. These references teach that molten metal may be poured onto the smooth peripheral surface of a rotating liquid-cooled copper drum or disc to form strip materials. Despite early disclosure of such concept, there is no evidence of commercial success of strip casting during the early part of the 20th century.

Recently, in United States Patents Nos. 3,522,836 and 3,605,863 a method for manufacturing a continuous product such as metallic wire or strip from molten metal has been disclosed. These references teach that a convex meniscus of molten material should project from a nozzle. A heat extracting surface, such as a water-cooled drum, is moved in a path substantially parallel to the outlet orifice and into contact with the meniscus of molten metal to continuously draw material from the meniscus to form a uniform continuous product. The above-described method is commonly called the "melt drag" process as the heat extracting surface moving past the meniscus of molten

metal at the nozzle orifice actually has an effect on the rate of molten metal flow, or drag, through the nozzle.

Even more recent strip casting developments focus on relatively narrow refinements in the metallic strip casting art. For example, United States Patent No. 4,142,571 is particularly directed to a slot construction in a metal strip casting nozzle having stringent dimensional requirements. Also, United States Patent No. 4,077,462 pertains to the provision of a specific construction for a stationary housing above the peripheral surface of a chill roll used for strip casting.

There are a number of other rapid quenching techniques known in the art. For example, melt spinning processes of producing metallic filament by cooling a fine molten stream either in free flight or against a chill block have been practiced. Also known are melt extraction techniques, such as crucible melt extraction disclosed in United States Patent No. 3,838,185 and pendant drop melt extraction techniques taught in United States Patent No. 3,896,203. It has been found difficult to produce uniform sheet or strip by such alternative techniques of rapid casting. There are many factors, such as auxiliary surface cooling, surface coatings and the like which appear to affect product thickness and quality of rapidly cast strip material.

Despite the relatively long history of the art of strip casting, and the recent developments in this area, strip casting is not a widely accepted and commercially

significant operation at the present time. It appears that various improvements, modifications, and innovations are required in the art to effect a significant commercial impact in the art of strip casting. In particular, proper relationships among such variables as molten metal tundish construction, nozzle orifice size and dimensions, spacing from a casting surface, speed at which such surface is moved, quench rates, metal temperature and feed rates, and the like may require more accurate identification in order to accomplish the uniformity and consistency required for successful, commercial production of cast strip. In particular, certain nozzle and slot structures and their dimensional relationship to the casting surface onto which strip material is cast, have been found to be desirable to yield uniform strip casting results.

Since it is apparent that dimensional relationships between the casting nozzle and the casting surface are critical, prior strip casting apparatus has been constructed with the nozzle forming an integral part of a molten metal holding tundish or with the nozzle integrally mounted therein. Thus, when it becomes necessary to move, align or change the nozzle, the tundish is also affected. Therefore, the requirement of maintaining rigid dimensional relationships has prevented flexibility in design and operation of the strip casting apparatus.

Accordingly, a new and improved apparatus for casting relatively wide, thin strip material is desired which

overcomes the disadvantages of the prior art structures. Such desired apparatus should be more efficient, more effective and more flexible than the structures disclosed in the prior art, and should lead to uniformity and consistency in strip casting.

Among the objects of the present invention is the provision of a strip casting apparatus which is capable of continuously casting metal strip material of substantially uniform dimension and substantially uniform quality throughout its length.

Another object of the present invention is the provision of a strip casting apparatus having a nozzle construction which promotes rapid casting of metals with a minimum of metal turbulence during casting.

Another object of the present invention is to provide a strip casting apparatus capable of reproducing successful strip casting operations.

another object of this invention is to provide a strip casting apparatus which can effect sufficiently rapid quenching of the produced strip to result in the production of amorphous strip. However, it should be understood that the production of continuously cast crystalline material is also comprehended by the present invention.

A further object of this invention is to identify certain design and dimensional requirements, particularly with regard to nozzle structure, which permits continuous and repetitive rapid casting of metallic strip material of uniform dimension and uniform quality.

Another object of the present invention is to utilize

at least one, separate insert to form a part of the nozzle. Such insert may be moved, aligned or changed without substantially affecting the remainder of the apparatus. Such insert may be generally unobstructed which facilitates the physical adjustment thereof, permits direct heating thereof and allows virtually unrestricted visual observation of the casting operation.

The present invention provides apparatus for continuously casting strip material comprising:

a tundish for receiving and holding molten metal having a nozzle therein through which molten metal is delivered to a casting surface movable past the nozzle at a speed of from 61 to 3048 linear surface metres per minute (200 to 10,000 linear surface feet per minute),

said nozzle comprising an orifice passage having substantially uniform cross-sectional dimensions throughout the longitudinal extent thereof, defined between a first inside surface and a second inside surface, wherein at least a portion of at least one of said inside surfaces forms part of an insert disposed in the tundish, and a minimum gap of at least 0.254mm (.010 inch) is maintained between said inside surfaces, and

said insert having a front edge surface capable of being disposed to within 3.048mm (0.120 inch) of the casting surface.

The invention will be more fully described with reference to the accompanying drawings in which:-

Figure 1 is a side elevation view, partially

in cross-section, illustrating a typical apparatus for continuously casting strip material according to the present invention,

Figure 2 is a cross sectional view on a larger scale of a tundish and nozzle for use in apparatus of the present invention.

Figure 3 is a front elevation view through III -III of the tundish and nozzle shown in Figure 2.

Figure 4 is a cross-sectional view on a smaller scale than Figs. 2 and 3 of an alternative tundish and nozzle for use in apparatus of the present invention.

Figure 5 is a cross-sectional view of another alternative tundish and nozzle for use in apparatus of the present invention.

Figure 6 is a cross-sectional view of yet another alternative tundish and nozzle for use in apparatus of the present invention.

Figure 7 is a cross-sectional view of a further alternative tundish and nozzle for use in apparatus of the present invention.

Figure 8 is a cross-sectional view of yet a further alternative tundish and nozzle for use in apparatus of the present invention.

Figures 9, 10 and 11 are enlarged cross-sectional views of the nozzle area of a tundish for use in apparatus of the present invention illustrating sequentially the disposition of the nozzle with respect to a casting surface.

Figure 12 is a cross-sectional view of an alternative tundish and nozzle for use in apparatus of the present

invention.

Figure 13 is a top elevation view of an insert on a tundish forming part of apparatus of the present invention.

Figure 14 is an enlarged cross-sectional view of the nozzle area of a tundish forming part of apparatus of the present invention.

Referring particularly to the drawings, Figure 1 generally illustrates apparatus in accordance with the present invention for casting metallic strip material 10. This apparatus includes an element 12 upon which the strip 10 is cast. In a preferred embodiment a continuous strip 10 is cast onto a smooth, outer peripheral surface 14 of a circular drum or wheel as shown in Figure 1. It should be understood that configurations other than circular may be employed. For example, a wheel with a smooth, frustoconical outer peripheral surface (not shown) may be employed. Also, a belt capable of rotating through a generally ovular path may also be employed as the casting element. Regardless of the configuration employed, the cooled casting surface should be at least as wide as the strip to be cast.

In a preferred embodiment, the casting element 12 comprises a water cooled, precipitation hardened copper alloy wheel containing about 90% copper. Copper and copper alloys are chosen for their high thermal conductivity and wear resistance. However, steel, brass, aluminum,

alloys or other materials may be utilized alone or in combination, or multipiece wheels having sleeves of molybdenum or other material may also be employed.

Likewise, cooling may be accomplished with the use of a medium other than water. Water is chosen for its low cost and its ready availability.

In the operation of the strip casting apparatus of the present invention, the surface 14 of the casting wheel element 12 must be able to absorb heat generated by contact with molten metal at the initial casting point 16, and such heat must diffuse substantially into the copper wheel during each rotation of the wheel. Heat diffusion, cooling, may be accomplished by delivering a sufficient quantity of water through internal passageways located near the periphery of the casting wheel 12. Alternatively, the cooling medium may be delivered to the underside of the casting surface. Understandably, refrigeration techniques and the like may be employed to accelerate or decelerate cooling rates, and/or to effect wheel expansion or contraction during strip casting.

Whether a drum, wheel or belt is employed for casting, the casting surface should be generally smooth and symmetrical to maximize uniformity in strip casting. For example, in certain strip casting operations wherein it is desired to cast uniform gauge strip, the distance between the outer peripheral casting surface 14 and the surfaces defining the orifice of the nozzle which is feeding the molten material onto the casting surface

should not substantially deviate from a desired or set distance. This distance shall hereinafter be called standoff distance or gap. It is understandable that the gap must be substantially maintained throughout the casting operation when it is the intention of the operator to cast uniform strip material.

It should also be understood that if the casting element is a drum or wheel, the element should be carefully constructed so as not to be out-of-round during operation to ensure uniformity in strip casting. Along these lines, it has been found that a drum or wheel which is out-of-round by about 0.508mm (0.020 inch), or more, may have a magnitude of dimensional instability which, unless corrected or compensated during operation, may be unacceptable for certain strip casting operations. It has been found that acceptable dimensional symmetry, as well as elimination of problems associated with weld porosity may be more readily accomplished by fabricating a wheel or drum from a single, integral slab of cold rolled or forged copper. However, as mentioned above alternative materials may be employed.

The molten material 20 to be cast in the apparatus described herein is preferably retained in a crucible or tundish 22, which is provided with a pouring orifice or nozzle 24. The nozzle 24 is typically, though not necessarily, located at a lower portion of the tundish 22 as shown in Figure 1.

The tundish 22 is constructed for receiving and holding

molten metal therein. It will be appreciated that appropriate materials must be utilized for the tundish 22 to withstand the molten metal conditions, and where the tundish 22 is not a monolithic structure, the joints and seams between separate pieces of the tundish must be assembled to prevent molten metal leakage during sustained operation.

The tundish 22 has a front wall 26 and a rear wall 28 (Fig. 2), with respect to the casting direction, which casting direction is indicated by an arrow adjacent the casting surface 14 in Figure 2. The front wall 26 has an inside surface 30 and an outside surface 32 with respect to the molten metal holding portion of the tundish 22. Likewise, the rear wall 28 has an inside surface 34 and an outside surface 36 with respect to the molten metal holding portion of the tundish 22. The inside surfaces 30 and 34 extend toward the nozzle area of the tundish 22. It should be understood that the molten metal holding portion of the tundish 22, which is formed between the inside surfaces 30 and 34, may take a variety of forms or shapes. However, it is preferable that the upper portion of the tundish 22 have a significantly larger cross-sectional volume than that of the nozzle area of the tundish 22 in order that the molten metal head height, above the nozzle, is substantially unaffected by minor variations in molten metal volumes in the tundish 22. Such structure contributes to the maintenance of a substantially constant metallostatic head pressure at the nozzle, even with minor variations in metal volume in the tundish 22.

It is also preferable that the inside surfaces 30 and 34 converge toward one another in the direction of the nozzle, and that such surfaces 30 and 34 be radiused, rounded or generally curvilinear at locations of turns or bends in the tundish 22 to minimize metal turbulence therein during the casting operation.

The molten metal holding area, formed between the inside surfaces 30 and 34, should be enclosed with sidewalls 38 and 40, as indicated in Figure 3. It is noted that no fixed width dimension is shown in Figure 3. It has been found that a tundish and nozzle forming part of apparatus of the present invention may be constructed by first cutting or carving refractory boards, such as insulating boards made from fiberized kaolin, into the desired tundish shape, such as that shown in Figure 2. Any number of these boards 42 may be stacked upon one another to obtain the desired tundish and nozzle width. There is not expected to be a restriction on the maximum width of the tundish and nozzle of the present invention, and widths in excess of 915mm (thirty six inches) are comprehended by the present invention. After the requisite number of boards are stacked the inside surfaces 30 and 34 formed by the stack may be sanded or otherwise finished to provide generally smooth inside surfaces 30 and 34 across the width of the stacked elements forming the tundish 22. It should also be understood that single piece materials may be used to construct the tundish in which case stacking would not be necessary. After the carved boards 42 are stacked, the stack may be disposed between uncarved

boards 44, which may serve as the sidewalls 38 and 40 for the tundish 22.

To hold the stacked boards, including the sidewalls 38 and 40 in position, it has been found convenient to dispose a metal plate 46 against the outside surface of each sidewall and to bolt the plates together at a suitable number of locations about the tundish, thereby tightly compacting the tundish assembly. With such assembly, a minor amount of molten metal may tend to flow into the seams between the boards, but the compaction of the assembly and the high insulative value of the boards causes the metal to freeze, and thereby arrest the flow before it adversely affects the tundish or the strip casting operation. It should be understood that the tundish 22 of the present invention may be assembled with refractory cements, or the like, or may be constructed as a monolithic structure which does not require assembly.

As discussed above, a nozzle 24 is located in the tundish 22, preferably in a lower portion thereof. The nozzle 24 comprises an orifice passage 80 defined between the first inside surface 34 of the rear wall 28 of the tundish 22 and the second inside surface 48 of an insert 50. A portion of the inside surface 48 of the insert 50 (Figure 2) is disposed against a portion of a ridge 52 formed by the outside surface 32 of the front wall 26 of the tundish 22. As shown in Figure 3, the insert 50 extends across the full length of the orifice passage, or slot 80 such that the end portions of the inside surface 48 of the insert 50 are disposed against ridges on the

sidewalls 38 and 40 of the tundish 22. Such disposition may be necessary to maintain the stability of the insert 50. In a preferred embodiment, a portion of the inside surface 48 of the insert 50 extends beyond the front wall 26 of the tundish 22 in the direction of the casting surface 14. It should be appreciated that the extent of the insert 50 may be flush with the extent of the front wall 32 of the tundish as measured in a direction toward the casting surface.

Preferably, the extent of the insert, as indicated by numeral 70 in Figure 2, is maintained at a distance of at least 0.254mm (0.010 inch) from the inside surface 34 of the rear wall 28, at the orifice passage 80.

Preferably, the insert 50 is reciprocal on the ridge 52 of the tundish 22 in a direction toward and away from the casting surface 14. Such reciprocal disposition of the insert 50 may be obtained by manual adjustment, but preferably the insert 50 should be automatically adjustable and continuously measurable to ensure that desired spacings, gaps and the like are maintained during casting. In a preferred embodiment, as shown in Figure 2, the insert 50 is reciprocal in a generally horizontal plane. However, it should be understood that the insert 50 may be reciprocal along an angular path, as shown in Figures 4 and 6, along an arcuate path as shown in Figure 5, or in a generally vertical plane as shown in Figure 7. In another embodiment, as illustrated in Figure 12, the insert 50 may be disposed on an element 55 which element 55 may be adjusted to any

number of positions by rotation thereof about a pivot point 58 to obtain the desired disposition of the insert 50.

Although the insert 50 may be reciprocal toward and away from the casting surface 14, the insert 50 must not be permitted to lift from its fixed position against the ridge 52 of the tundish 22. This fixed position is necessary to counteract the pressure which the molten metal may exhibit against the inside surface 48 of the insert 50. In one embodiment, a weight may be placed on a top surface 56 of the insert 50. In another embodiment, a pressure exerting device such as a spring biased device, a hydraulic cylinder arrangement, a clamp or the like, may be used to urge the insert against the ridge 52 of the tundish 22. In a further embodiment, as illustrated in Figure 8, the insert 50 may be held in a slot which provides such required fixed support for the insert 50. Note that even with the arrangement illustrated in Figure 8, the insert 50 is still reciprocal toward and away from the casting surface.

In addition to being reciprocal toward and away from the casting surface 14, the insert 50 may be able to be canted such that one end portion 60 of the insert 50 may be moved toward the respective end portion of the casting surface 14 while the other end portion 62 is moved away from the other respective end portion of the casting surface 14, as shown in Figure 13. An insert structure which may be utilized to facilitate such canting, as shown in Figure 13, includes an arcuate rear surface 64 for the insert 50, a portion of which abuts a rearward wall 66 of the tundish 22

at a pivot point 68. By rolling the rear surface 64 of the insert 50, minor canting alignments can be effected. Regardless of the means employed to cant the insert 50 with respect to the casting surface 14, such canting variations may be helpful to assure that uniform gauge strip material is produced, especially during prolonged casting operations. Such canting variations may also assist in removing entrapped material from the nozzle during casting, or for intentionally casting strip material having a varying gauge across the width of the strip material.

It should be appreciated that the insert 50 of the present invention may be easily replaced, although it is preferred that the insert 50 and the tundish 22 be reused either together or separately. It should also be noted that damage to an insert 50 will not render the entire tundish 22 unserviceable. In the event of such insert damage, the insert 50 is merely replaced and the process continues.

In a preferred embodiment, as shown in enlarged cross-section in Figure 14, the insert 50 is provided with a front edge surface 70. In such embodiment, as the insert 50 has been reciprocated to its operating position, the front edge surface 70 faces the casting surface 14 and is disposed to within less than 3.048mm (0.120 inch) of the casting surface 14. Preferably, the front edge surface 70 is disposed to within 2.032mm (0.080 inch) and in a more preferred embodiment, to within 0.508mm (0.020 inch) of the casting surface 14. It is also preferred that in such

embodiment the front edge surface 70 be in substantially complete parallelism with the casting surface 14. When utilizing a drum or wheel, and a refractory insert 50, such complete parallelism may be accomplished by placing a sheet of sandpaper, or the like, against the casting surface 14 with the grit side of the sandpaper facing the insert 50. By moving the insert 50 into tight contact with the casting surface 14, with the sandpaper disposed therebetween, and by moving the casting surface and sandpaper simultaneously past the insert 50, the front edge surface 70 is ground by the grit side of the sandpaper into substantially complete parallelism with the casting surface 14. Such substantially complete parallelism may be achieved even when round or other curvilinear casting surfaces are employed. To achieve such parallelism by this procedure 400 to 600 grit sandpaper has been found to be adequate. The outside surface 36 of the rear wall 28 disposed adjacent the casting surface 14 may be brought into substantially complete parallelism therewith by this same procedure.

By maintaining the front edge surface 70 in substantially complete parallelism with the casting surface 14, the standoff distance, or gap h between the front edge surface 70 and the casting surface 14 is maintained throughout the length thereof. It has been found that the gap h between the front edge surface 70 and the casting surface 14 must be maintained at less than 3.048mm (0.120 inch) in order to successfully cast strip material. Preferably, this gap is maintained at less than 2.032mm (0.080 inch) and

for casting certain alloys into thin gauge strip, gaps less than 0.508 mm (0.020 inch) are preferred. Alternatively, the front edge surface 70 of the insert 50 may comprise a line extending across the tundish, at a 90° junction, or corner, of the front edge of the insert 50, as opposed to a defined surface length \underline{b} as discussed above. To this extent the length \underline{b} of the front edge surface 70 could be zero. Even if surface 70 approaches a line across the tundish, such surface must be disposed within 3.048mm (0.120 inch) of the casting surface 14 to successfully cast strip material.

It has also been found that the gap \underline{e} between the outside surface 36 of the rear wall 28 and the casting surface 14, as best shown in Figure 14, does not appear to be as critical. What is preferred with respect to the outside surface 36 of the rear wall 28 is that the surface 36 be disposed as close as possible to the casting surface 14, without causing any interference for the moveable casting surface therebelow. Accordingly, the outside surface 36 of the rear wall 28 at the orifice passage 80 of the nozzle may just clear the casting surface 14, i.e., perhaps within about 0.0508mm (.002 inch), as shown in the drawing. Such spacing must not be large enough to allow significant molten metal backflow therebetween during casting. Alternatively, the outside surface 36 may be tapered from the orifice of the nozzle in a direction away from the casting surface 14.

The crucible 22 is preferably constructed of a material having superior insulating ability. If the insulating ability is not sufficient to retain the molten material at a relatively constant temperature, auxiliary heaters such as induction coils may have to be provided in and/or around the crucible 22, or resistance elements such as wires may be provided. As mentioned above, a convenient material for the crucible is an insulating board made from fiberized kaolin, a naturally occurring, high purity, alumina-silica fire clay. Such insulating material is available under the trade name Kaowool HS board. However, for sustained operations, and for casting higher melting temperature alloys, various other materials may have to be employed for constructing the crucible or the insert including graphite, quartz, clay graphite, boron nitride, silicon nitride, boron carbide, silicon carbide, alumina, zirconia, and various combinations or mixtures of such materials.

Although other materials are comprehended by the present invention, the insert 50 is preferably constructed of boron nitride, silicon nitride, silicon carbide, boron carbide, zirconia or quartz.

It is imperative that the orifice passage 80 of the nozzle 24 remain open and its configuration remain substantially stable throughout a strip casting operation. It is understandable that the orifice passage 80 should not erode or clog, significantly during a strip casting sequence or certain objectives such as maintaining

uniformity in the casting operation and of minimizing metal flow turbulence in the tundish 22 may be defeated. Along these lines, it appears that certain insulating materials may not be able to maintain their dimensional stability over long casting periods. To obviate this problem the nozzle 24, especially that portion defined by the insert 50, may be constructed of a material which is better able to maintain dimensional stability and integrity during exposure to high molten metal temperatures for prolonged time periods.

The drive system and housing for the drum, wheel or other casting surface 14 of the present invention should be rigidly constructed to permit drum rotation without structural instability which could cause the drum to slip or vibrate. In particular, care should be taken to avoid resonant frequencies at the operating speeds for the drum. The casting surface should be capable of moving at a surface speed of from 61 linear surface metres per minute (200 linear surface feet per minute) to 3048 linear surface metres per minute (10,000 linear surface feet per minute). When utilizing a drum having a circumference of about 2.4 metres (8 feet), this rate calculates to a drum speed of from about 25 rpm to about 1250 rpm. A three horsepower variable speed reversible, dynamically braked motor provides an adequate drive system for an integral copper casting drum 50.8 to 254mm (2 to 10 inches) thick and about 2.4 metres (8 feet) in circumference. Power requirements may have to be modified depending upon the type and size of casting

surface 14 employed. It should be appreciated that the casting surface 14 can be moved in a direction opposite to that illustrated in the drawing, and that the tundish 22 may be disposed at any location about the casting wheel illustrated in the drawing.

In one embodiment, the casting surface 14 on the wheel or drum of the apparatus of the present invention is smooth. It has been found that in certain applications for producing amorphous materials, finishing the peripheral surface 14 of a casting drum 12 with 400-grit sandpaper and preferably with 600-grit sandpaper may yield improved product uniformity. It is anticipated that an etched surface may yield the best, smooth surface, product uniformity.

A preferred structure for the nozzle 24 of the apparatus of the present invention is shown in enlarged cross-section in Figure 14. In one embodiment of this apparatus, the dimensions indicated in Figure 14 have the following preferred limitations.

| <u>dimension</u> | <u>designation</u> | <u>preferred limitation</u> | <u>more preferred limitation</u> |
|------------------|------------------------------|---------------------------------|----------------------------------|
| <u>a</u> | nozzle gap | .0254-2.032mm (.010-.080 in) | 0.635-0.889mm (.025-.035in) |
| <u>b</u> | length of front edge surface | 0-4.064mm (.00-.16in) | 0.508-1.524mm (.02-.06in) |
| <u>h</u> | insert gap | less than 2.032mm (.080in) | 0.254-0.508mm (.010-.020in) |
| <u>e</u> | rear wall gap | less than 0.508mm (.020 in) | less than 0.254mm (.010 in) |

Dimension c, representing the width of the rear wall at the orifice of the nozzle 24 and d representing the width

of the insert 50, appear to be arbitrary and do not appear to be significantly critical to the strip casting operation. In fact, it should be appreciated that dimension c could approach zero if the inside surface 34 of the rear wall could be tapered completely through the orifice passage 80.

Molten metal turbulence during strip casting should be minimized, and perhaps avoided by relieving sharp corners of the nozzle in the direction of casting. It will be understood that such rounding may be accomplished by constructing the tundish walls of an eroding material, such as Kaowool HS board, which may provide natural erosion as a result of the strip casting operation. Turbulence may also be minimized by rounding other corners such as corner 72 on the insert 50 and corner 74 on the rear wall 28 at the nozzle as shown in Figure 14.

In an exemplary operation of the apparatus of the present invention, molten metal is delivered to a heated crucible 22. It is understood that a heater, such as induction coils or resistance wire, may be provided in and above the crucible 22 to maintain relatively constant molten metal temperatures as may be desired. Also heating devices may be employed on or near the insert 50 because of the general accessibility of the insert 50 in the apparatus of the present invention. For example, resistance wires, or heating coils may be provided in a bottom portion of a pressure exerting device located on or near the insert 50. Also, a torch may have its flame directed against the insert 50 during casting. In the operation of the apparatus of

this invention metal may be poured directly into a preheated crucible. Such metal preheat temperature and the heating of the tundish 22 and insert 50 should prevent freezing or clogging of the orifice passage or slot 80 during the initial casting operation, and the temperature of the flowing metal should thereafter keep the crucible 22 and the insert 50 at sufficient temperature to ensure uninterrupted molten metal flow through the orifice passage 80. In certain applications, the nozzle should be externally heated throughout the casting operation. Also, the metal which is fed to the crucible 22 may be superheated to allow a certain degree of temperature loss without adversely affecting metal flow.

Also, metallostatic head height in the tundish 22 should be maintained at a relatively constant level throughout the casting operation to assure that a relatively constant static head pressure may be maintained at the orifice of the nozzle 24. This may be accomplished by initially pouring the molten metal into the crucible to the desired height and thereafter controlling the rate at which additional molten metal is poured into the crucible to maintain the metallostatic head. It is understandable that the rate at which additional molten metal is fed to the crucible 22 should be in substantial conformity with the rate at which metal flows from the nozzle orifice onto the casting surface 14 in forming strip material. Maintenance of a relatively constant height of metal in the crucible assures that the molten metal flow pressure through the orifice is maintained relatively constant so as not to adversely affect the casting operation or the quality of

the strip material. Alternatively, externally applied pressure may be employed to control the pressure at the nozzle.

In a preferred embodiment of the present invention, the tundish 22 and the insert 50 are independently or dependently moveable toward and away from the casting surface 14. As shown sequentially in Figures 9, 10 and 11. The tundish 22 and the insert 50 thereon, are in a position away from the casting surface 14. The casting surface 14 is being moved past the nozzle 24 at a rate of from 61 to 3048 linear metres per minute (200 to 10,000 linear feet per minute). Prior to or simultaneously with the pouring of molten metal into the tundish, the tundish 22 is moved toward the casting surface 14, such that the outside surface 36 of the rear wall 28 at the nozzle 24 is located to within 0.508mm (0.020 inch), and preferably to within 0.254mm (0.010 inch), of the casting surface 14 as shown in Figure 10. In a preferred embodiment the outside surface 36 is moved as close as possible to the casting surface 14 without interfering with the motion of the casting surface 14 therebelow.

Usually, the insert 50 is not moved from its position relative to the tundish 22, as the tundish 22 is moved toward the casting surface 14. However, either after the outside surface 36 of the rear wall 28 is in position, or while the outside surface 36 is being positioned, the position of the insert 50 should be adjusted such that the front edge surface 70 is within 3.048mm (0.120 inch) and more preferably to about 0.254 to 0.508mm (0.010 to .020 inch) of the casting surface 14

as shown in Figure 11. The tundish 22 and insert 50 should be in final adjusted position soon after casting begins. It will be appreciated that the extent of the gaps h and/or e may be adjusted during casting by the apparatus of the present invention, which provides significant flexibility in the casting operation.

It should be understood that the position of the insert 50 on the tundish 22 may be established, set and maintained before the entire assembly, i.e., tundish 22 including the insert 50, is moved toward its casting position. With such arrangement the disposition of the insert 50 is properly attained as the disposition of the outside surface 36 of the rear wall 28 is attained. In such embodiment the insert 50 may be fixedly mounted in proper relative position on the tundish 22.

During casting of strip material, the tendency of the strip 10 to adhere to the casting surface 14 for a significant distance, such as several hundred millimetres or more, beyond the nozzle has been observed. It is understandable that if the strip material remains on a rotating casting drum or wheel 12 for a full revolution damage to the crucible could result. It has been found that the use of a doctor blade, such as a knife type element riding at or near the drum surface 14, approximately 0.762 to 1.8288 metres (2.5 to 6 feet) from the orifice easily counters such adherence. With such an arrangement, the cast strip may be removed from the drum by such doctor blade. Such doctor blade has been found particularly useful in the production of thinner amorphous strip materials which appear

to have a greater tendency to adhere to the casting surface 14 than do the crystalline strip materials. It is believed that the force which retains the strip on the casting surface reflects the quality of the thermal contact between the strip and the casting surface. Alternative arrangements, such as an air knife, may also be employed to separate the strip from the wheel.

The casting of relatively high quality strip material including amorphous material, which for the purpose of this invention includes materials which are at least 25% amorphous, is feasible and practical using the apparatus and procedures described above. Understandably, the quench rates must be higher for amorphous material as compared to crystalline material. Quench rates may be accelerated such as by increasing the speed of the casting surface, or the like. It is important to recognize that the process operates in two effective modes. With the orifice quite close to the drum surface, strip perhaps 0.0254 to 0.0762mm (0.001 to 0.003 inch) thick can be cast of either amorphous or crystalline materials. If the front edge surface 70 of the insert 50 is moved away from the casting surface 14, and as casting surface speeds are reduced, strip perhaps 0.127 to 1.27mm (0.005 to 0.050 inch) thick can be cast. In this latter mode the quench rate is much lower due primarily to increased product thickness.

The problems associated with the flexibility reproducibility and in-process control of strip casting operations, as well as certain problems related to metal turbulence can be overcome by the apparatus of the present invention.

CLAIMS:-

1. Apparatus for continuously casting strip material comprising:

a tundish for receiving and holding molten metal having a nozzle therein through which molten metal is delivered to a casting surface movable past the nozzle at a speed of from 61 to 3048 linear surface metres per minute (200 to 10,000 linear surface feet per minute),

said nozzle comprising an orifice passage having substantially uniform cross-sectional dimensions throughout the longitudinal extent thereof, defined between a first inside surface and a second inside surface, wherein at least a portion of at least one of said inside surfaces forms part of an insert disposed in the tundish, and a minimum gap of at least 0.254mm (.010 inch) is maintained between said inside surfaces, and

said insert having a front edge surface capable of being disposed to within 3.048mm (0.120 inch) of the casting surface.

2. Apparatus according to claim 1, wherein the insert is reciprocal towards and away from the casting surface.

3. Apparatus according to claim 1, wherein the tundish is reciprocal towards and away from the casting surface.

4. Apparatus according to claim 1, 2 and 3, wherein pressure is exerted against the insert sufficient to overcome the counter pressure of molten metal bearing against the surface of the insert forming an inside surface of the orifice passage.

5. Apparatus according to claim 4, wherein the

pressure is provided by a weight on the insert.

6. Apparatus according to claim 4, wherein the pressure is provided by a spring biased device bearing against the insert.

7. Apparatus according to claim 4, wherein the pressure is provided by clamping the insert to the tundish.

8. Apparatus according to any one of the preceding claims, wherein the insert is elongate and is reciprocal in the lateral direction thereof.

9. Apparatus according to claim 8, wherein said lateral direction is generally horizontal.

10. Apparatus according to claim 8, wherein said lateral direction is generally vertical.

11. Apparatus according to any one of the preceding claims, wherein the insert is reciprocal in an angular direction.

12. Apparatus according to claim 2, wherein the insert is reciprocal in an arcuate direction.

13. Apparatus according to any one of the preceding claims, wherein said front edge surface of the insert has a length in the casting direction less than 4.064mm (.16 inch).

14. Apparatus according to claim 13, wherein said front edge surface of the insert has a length in the casting direction of from 0.508mm to 1.524mm (.02 to .06 inch).

15. Apparatus according to claim 1, wherein the front edge surface of the insert substantially comprises a line across the tundish at a junction of the insert.

16. Apparatus according to any one of the preceding claims, wherein the front edge surface of the insert is able to be disposed to within 2.032mm (0.080 inch) of the casting surface.

17. Apparatus according to claim 16, wherein the front edge surface of the insert is able to be disposed to within 0.508 mm (0.020 inch) of the casting surface.

18. Apparatus according to claim 17, wherein the front edge surface of the insert is able to be disposed to within 0.381mm (0.015 inch) of the casting surface.

19. Apparatus according to claim 18, wherein the front edge surface of the insert is able to be disposed to within 0.254mm (0.010 inch) of the casting surface.

20. Apparatus according to claim 13, wherein the front edge surface of the insert is in substantially complete parallelism with the casting surface during casting.

21. Apparatus according to any one of the preceding claims, wherein the insert is able to be tilted such that the front edge surface may be disposed toward or away from the casting surface.

22. Apparatus according to any one of the preceding claims, wherein the insert may be canted such that the end portions of the insert may be moved toward or away from the casting surface, respectively.

23. Apparatus according to any one of the preceding claims, wherein said tundish comprises a front wall and a rear wall with respect to the casting direction, with each wall having inside and outside surfaces with respect to the molten metal holding portion of the tundish, and sidewalls enclosing the front and rear walls of the tundish, wherein at least a portion of the outside surface of the rear wall, adjacent the orifice passage is able to be disposed to within at least 0.508mm (0.020 inch) of the casting surface.

24. Apparatus according to claim 23, wherein at least a portion of the outside surface of the rear wall, adjacent the orifice passage, is able to be disposed to within at least 0.254mm (0.010 inch) of the casting surface.

25. Apparatus according to any one of the preceding claims, wherein at least a portion of each inside surface forms part of an insert disposed in the tundish.

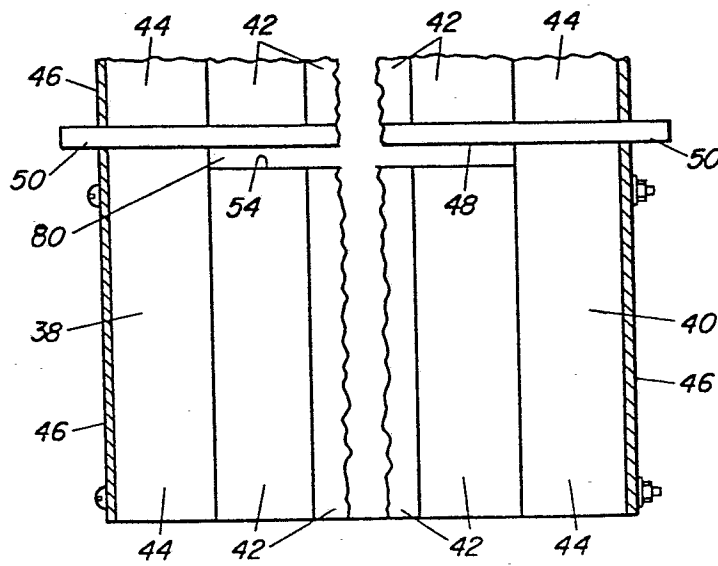
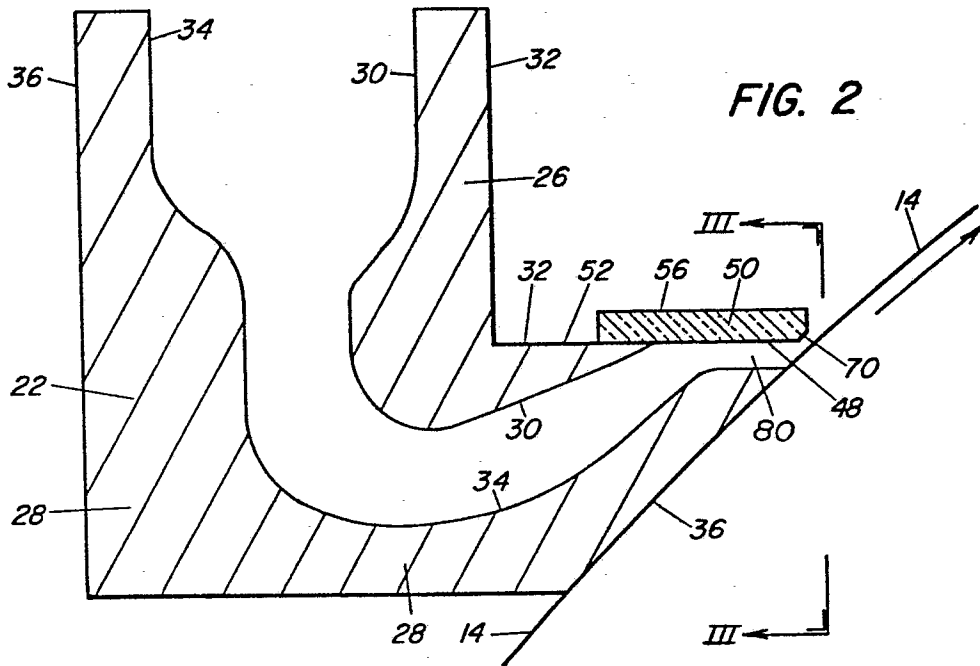
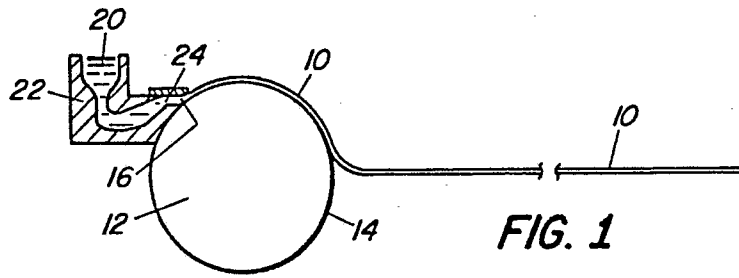
26. Apparatus according to any one of the preceding claims, wherein the tundish is constructed of a material selected from graphite, alumina graphite, clay graphite, quartz, fiberized kaolin, boron nitride, silicon nitride, silicon carbide, boron carbide, alumina, zirconia, stabilized zirconia silicate, magnesia and combinations thereof.

27. Apparatus according to any one of the preceding claims, wherein the insert is constructed of a material selected from boron nitride, silicon nitride, boron carbide, silicon carbide, zirconia, quartz and combinations thereof.

28. Apparatus for continuously casting strip material comprising :

a tundish for receiving and holding molten metal, having a front wall and a rear wall with respect to the casting direction with each wall having inside and outside surfaces with respect to the molten metal holding portion of the tundish, said inside surfaces extending toward and forming an orifice passage through a nozzle through which molten metal is delivered to a casting surface movable past the nozzle at a speed of from 61 to 3048 linear metres per minute (200 to 10,000 linear surface feet per minute) and sidewalls enclosing the front and rear walls of the tundish,

an insert disposed against a portion of the outside surface of the front wall a segment of which forms at least a portion of the inside surface of the front wall, said insert extending beyond the front wall in the direction of the casting surface and maintaining a minimum gap of at least 0.254 (0.010 inch) at the orifice passage defined between the inside surface of the rear wall and the insert, said insert having a front edge surface thereof able to be disposed to within 3.048mm (0.120 inch) of the casting surface, with at least a portion of the outside surface of the rear wall adjacent the orifice passage of the nozzle able to be disposed to within at least 0.508mm (0.020 inch) of the casting surface.



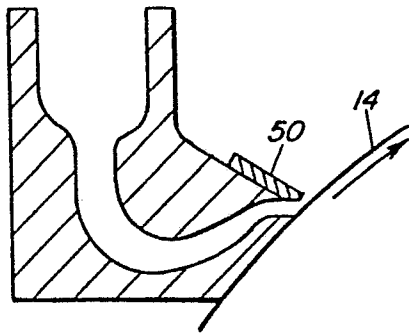


FIG. 4

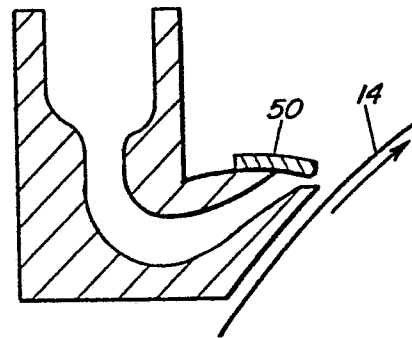


FIG. 5

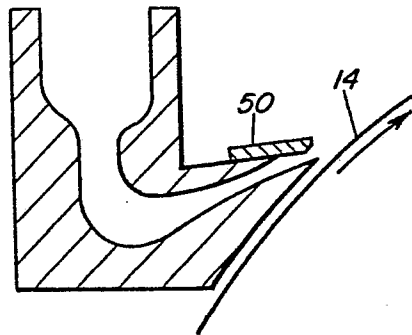


FIG. 6

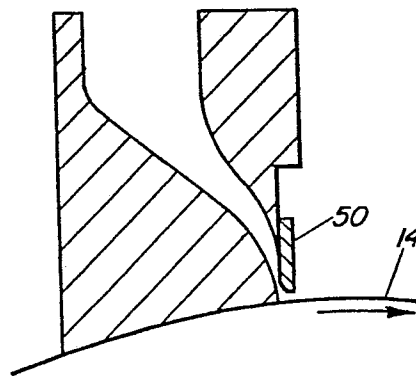


FIG. 7

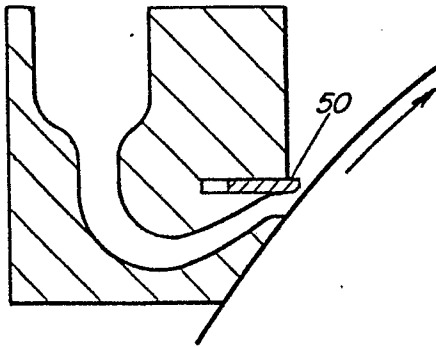


FIG. 8

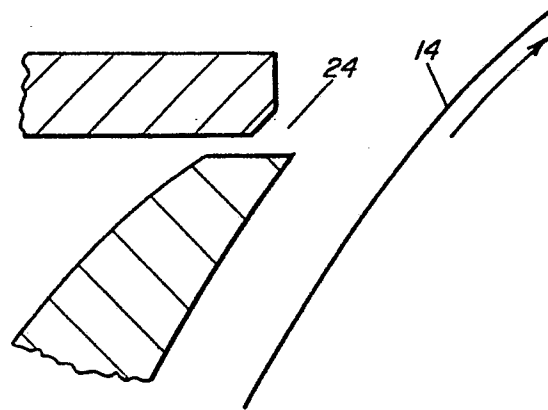


FIG. 9

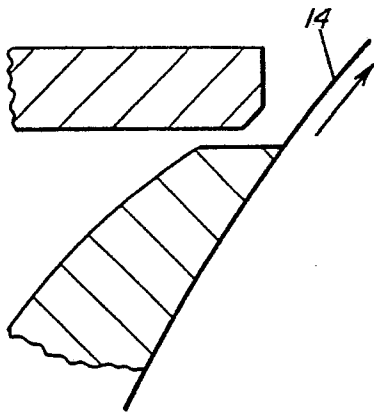


FIG. 10

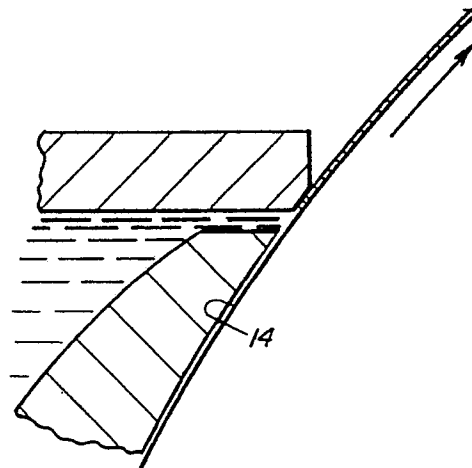


FIG. 11

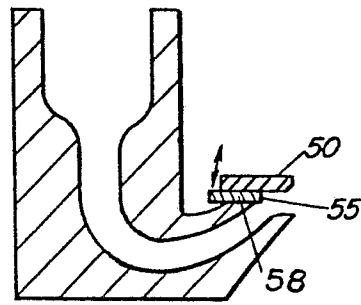


FIG. 12

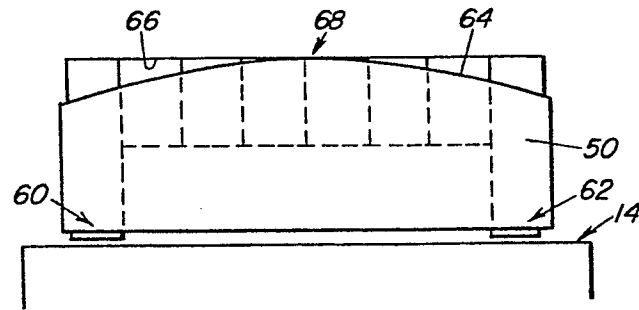


FIG. 13

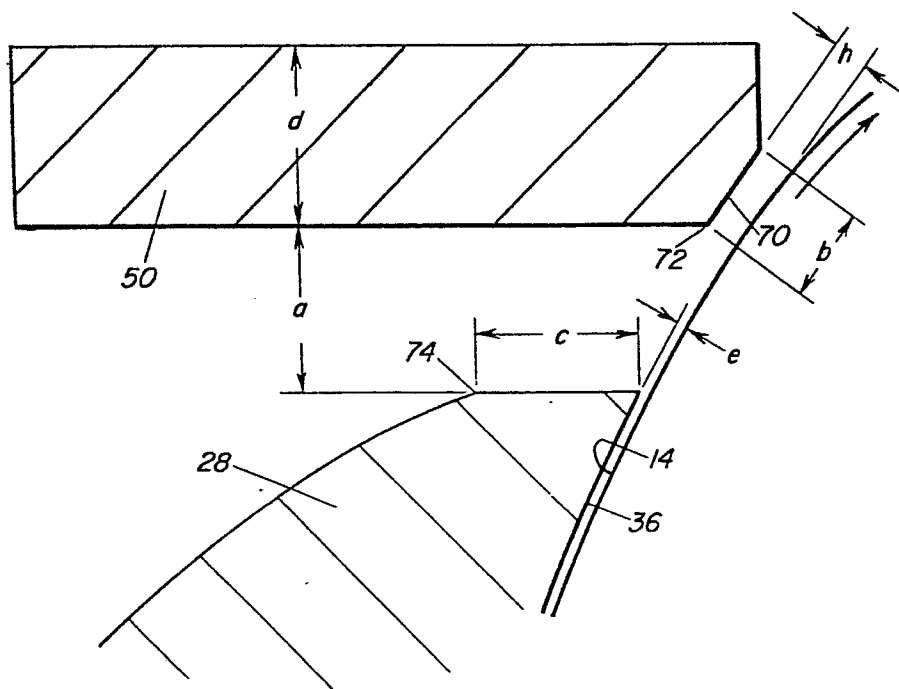


FIG. 14



| DOCUMENTS CONSIDERED TO BE RELEVANT | | | CLASSIFICATION OF THE APPLICATION (Int. Cl. ³) |
|------------------------------------------------------------|-------------------------------------------------------------------------------|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | |
| DA | <u>US - A - 4 142 571</u> (ALLIED CHEMICAL CORP.) | | B 22 D 11/06 11/00 |
| DA | <u>GB - A - 26 260 AD 1910</u> (STRANGE) & <u>US - A - 993 904</u> | | |
| A | <u>FR - A - 2 410 368</u> (SHIRO MEDA) * Claim 6 * | | |
| ----- | | | |
| | | | TECHNICAL FIELDS SEARCHED (Int. Cl. ³) |
| | | | B 22 D 11/06 11/00 C 21 C 1/00 |
| | | | CATEGORY OF CITED DOCUMENTS |
| | | | X: particularly relevant A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: conflicting application D: document cited in the application L: citation for other reasons |
| | | | &: member of the same patent family, corresponding document |
| The present search report has been drawn up for all claims | | | |
| Place of search | Date of completion of the search | Examiner | |
| The Hague | 12-08-1981 | SCHIMBERG | |