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(54) **TUNDISH FOR CONTINUOUS CASTING AND METHOD OF STIRRING A MOLTEN METAL IN A TUNDISH**

VERTEILER FÜR STRANGGUSS UND VERFAHREN ZUM RÜHREN EINER METALLSCHMELZE IN VERTEILERN

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EP 4 313 443 B1

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Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to a tundish for continuous casting, having an EMS stirrer for electromagnetic stirring, and a method of stirring a molten metal in a tundish.

BACKGROUND ART

10 **[0002]** Several methods for improving the temperature homogenization and steel cleanliness in a tundish have been proposed. One method is EMS stirring. Gas purging has also been applied to increase the mixing of steel in tundish and inclusion removal.

[0003] US 20170173687A1 and WO 2015/110984A1 disclose the use of external electromagnetic stirrers to homogenize the temperature in a tundish.

15 **[0004]** US 2015/352635 A1 discloses a method of controlling the temperature of molten metal in a tundish during a ladle tapping cycle in a continuous casting process. The method comprises a) obtaining a measure of a temperature of molten metal in the tundish; b) comparing the measured temperature with a desired tundish melt temperature; c) determining whether the measured temperature is lower than desired; d) controlling the temperature of the molten metal in the tundish by with a heating arrangement, and an electromagnetic stirrer which stirs the molten metal in order to distribute heated
20 molten metal in the tundish such that the temperature of the molten metal approaches the desired temperature.

[0005] EP 1 273 370 A2 discloses an apparatus for removing non-metallic foreign matter in a molten steel including a tundish and a coil device. The tundish is an intermediate container receiving the molten steel from a ladle and feeding a purified molten steel by removing the non-metallic foreign matter in the molten steel. For removing the non-metallic foreign matter, the tundish has a swirl flow bath and a floatation bath. In the circumference of the swirl flow bath of the tundish, a coil device is arranged for flowing the molten steel in the swirl flow bath in swirl fashion. The tundish and the coil device are
25 formed separately and constructed for relative movement to each other. The molten steel in the swirl flow bath of the tundish is flown in swirl fashion in the horizontal direction by a magnetic field generated by the coil device. At this time, the molten steel forms a parabolic concaved surface. The non-metallic foreign matter in the molten steel is forcedly floated up on the parabolic surface portion of the molten steel, which is removed by an appropriate means. The molten steel thus
30 purified flows into the floatation bath from the swirl flow bath. With the static flow in the floatation bath, the residual non-metallic foreign matter floats up. The purified molten steel is poured into the mold through the bottom of the floatation bath. Since the tundish and the coil device are formed separately, the number of coil device can be smaller than the number of the tundish to lower the cost for the facility and replacing and repair of the tundish can be done easily and in short period.

[0006] JP H04 89160 A discloses to stably keep the temperature of a molten metal uniform by setting a plasma heating device between both nozzles of a ladle and a tundish and an electromagnetic molten steel stirring device near the heating device. The molten steel 2 is poured in the tundish 10 from the ladle incorporating the molten steel 2 through the ladle nozzle 3 and further, poured into a mold through the tundish nozzle 4 to execute continuous casting. Then, the plasma heating device 5 for heating the molten steel 2 is set between the ladle nozzle 3 and the tundish nozzle 4. Further, the molten steel stirring device 11 for stirring the molten steel with electromagnetic force is set near the plasma heating device
40 5. An AC linear motor electromagnetic coil or an electric magnet is used to the molten steel stirring device. By this method, inclusion brought in the mold can be reduced.

[0007] JP S59 4954 A discloses to suppress the evaporation of lead and to produce steel in which lead is uniformly dispersed and contained, by dispersing the lead in the molten steel admitted into an auxiliary tundish provided in continuation with a main tundish while supplying the lead thereto then casting the steel. The molten steel in a ladle 1 is charged into a main tundish 2, and is further admitted through a flow passage 4 into an auxiliary tundish 3. When a certain amount of the molten steel accumulates in the tundish 3, a lead wire is delivered off from an adding device 9 for lead provided on the top cover of the tundish 3, and is supplied until the lead content of the molten steel attains a target value. The gate nozzle in the discharge port provided in the lower part of the tundish 3 is opened, and the molten steel is charged by an immersion nozzle 5 into a mold 6, whereby casting is started. The molten steel in the tundish 3 is stirred by the flow discharged from the tundish 2 so that the lead in the molten steel is uniformly dispersed. More preferably, the dispersion of the lead is intensified further by an inert gas blowing device or an electromagnetic stirrer 12 for stirring the molten steel.

[0008] CN 211 915 486 U discloses a continuous casting tundish capable of improving purity of molten steel. The tundish comprises a tundish body and a slag blocking wall which is arranged in the tundish body and divides an inner cavity of the tundish body into an impact area and a pouring area. The impact area is positioned on the rear side of the left end of the inner cavity of the bag body; the impact area is provided with a steel ladle long nozzle; according to the tundish, the internal structure of the tundish is mainly changed; the slag blocking wall is arranged to be arc-shaped; non-magnetic stainless steel welding is adopted in a specific area of the tundish wall; the molten steel in the tundish is transversely stirred through the electromagnetic force of an external electromagnetic field; the tundish flow field is improved in the tundish, transverse

flowing and temperature uniformization of molten steel and inclusions in the continuous casting tundish are enhanced, a dead zone of the molten steel is removed, transverse collision, aggregation, growth and floating removal of the inclusions in the molten steel are promoted, the temperature of the molten steel is uniformized, the inclusions are removed, and the purity of the special molten steel is improved.

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TECHNICAL PROBLEM TO BE SOLVED

[0009] Due to the increasingly stringent requirements for cleanliness of metals, even small inclusions should be removed from the molten metal in the tundish. It is therefore desired to remove inclusions with higher efficiency, especially also inclusions with small particle diameters.

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[0010] Also, especially for a tundish with more than 2 strands, temperature homogenization is important, to keep the constant sequential casting of every strand.

MEANS FOR SOLVING THE PROBLEM

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[0011] The present inventors carried out diligent research in view of achieving the above objective. In particular, the present inventors investigated the stirring direction of electromagnetic stirring, as well as the configuration of tundish furniture in relation to the electromagnetic stirring, as well as the stirring speed, and other factors, to achieve the present invention as described below.

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[0012] The inventors realized that it is advantageous to combine EMS stirring with flow separator devices such as dams/weirs/baffles in order to define the region in which stirring takes place, and to control the flow of molten metal in that region during stirring. The inventors also realized that the flow separator devices may cause a dead zone in the tundish. The dead zone has a low exchange of molten metal flow and a low heat transfer with the surrounding molten metal. Thus, the dead zone can cause temperature inhomogeneities, and can easily lead to clogging of the nozzles. It is also difficult to remove inclusions in the dead zone. The flow separator devices should therefore be arranged in a manner that does not lead to an excessive dead zone.

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[0013] Thus, according to an aspect of the present invention, a tundish for continuous casting according to claim 1, and a method of stirring a molten metal in a tundish according to claim 9 is provided. Embodiments of present invention may reduce the volume fraction of inclusions, particularly small inclusions (smaller than 10 μm) and medium size inclusions (between 10 μm and 60 μm), and/or allow stirring a high proportion of the volume of the tundish, to minimize or eliminate dead zones, and/or achieve excellent temperature homogenization, while also reducing slag entrapment at the inlet.

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DESCRIPTION OF FIGURES

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[0014]

Fig. 1 shows an example of a tundish according to the present invention, and Fig. 2 shows a comparative tundish. Fig. 3 is a view from above the example of the tundish according to the present invention.

Figs. 4a and 4b show a water model used to simulate the example of a tundish according to the present invention. Fig. 4a shows the water model from above, and Fig. 4b shows the water model from the side.

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Figs. 5a and 5b respectively show the measured RTD curves at the outlets of the examples of the comparative and inventive tundish.

Fig. 6 shows the proportions of dead zone volume, mixing flow volume, and plug flow volume of the examples of the comparative and inventive tundish.

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Figs. 7a and 7b respectively show the flow velocity vector plots at the horizontal midplane, of the examples of the comparative and inventive tundish.

Figs. 8a and 8b respectively show the distribution of volume fraction of inclusions at the vertical cross section across the outlets after 300 seconds, for the examples of the comparative and inventive tundish.

Fig. 9a shows the volume fraction of inclusions inside the tundish, and Fig. 9b shows the volume fraction of inclusions at the outlets of the tundish over time, for the examples of the comparative and inventive tundish.

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Figs. 10a to 10d show the disposition of the flow separator, EMS stirrer(s), EMS stirring direction, and the flow circulation and vortices according to the present invention, for examples of various tundish configurations with 4 outlets.

Figs. 11a shows the influence of EMS on the number density of inclusions up to 10 μm at the outlet of tundish, and Fig. 11b shows the influence of EMS on the number density of inclusions from 10 μm to 60 μm at the outlet of tundish, for the examples of the comparative and inventive tundish.

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DETAILED DESCRIPTION

[0015] The tundish 1 of the present invention is a tundish used for continuous casting of a molten metal. The molten metal may preferably be molten steel.

[0016] The inner volume 2 of a tundish 1 is defined as a volume enclosed by the side walls and bottom wall of the tundish, and optionally a tundish roof. The inner volume 2 is the portion of the tundish 1 which is configured to contain the molten metal. The total volume of the inner volume 2 of the tundish 1 may preferably be 1 m³ to 10 m³, more preferably 2 m³ to 8 m³.

[0017] The inner volume 2 of the tundish 1 comprises at least an inlet portion 3 comprising an inlet 4 for receiving molten metal, an outlet portion 5 comprising at least one outlet 6 for discharging molten metal, and a flow separator 20.

[0018] The inlet portion 3 is a portion of the inner volume 2 of the tundish 1 which includes an inlet 4 which receives molten metal. The molten metal may be supplied to the tundish 1 from a ladle.

[0019] The outlet portion 5 is a portion of the inner volume 2 of the tundish 1 which comprises one or more outlets 6 for discharging molten metal. Each outlet 6 may also be referred to as a strand. The outlets 6 may provide the molten metal to a continuous casting mold. The outlets 6 are preferably located at a bottom wall of the tundish.

[0020] The flow separator 20 is positioned in the inner volume 2 of the tundish, between the inlet portion 3 and the outlet portion 5. The flow separator 20 may define the inlet portion 3 and the outlet portion 5 by separating them from each other. The flow separator 20 is configured to restrict the stirring of the molten metal by the EMS stirrer 10 in the inlet portion 3. In this way, the flow separator 20 can be arranged to provide flow separation between the inlet portion 3 and the outlet portion 5 within the inner volume 2 of the tundish.

[0021] The inlet portion 3 and the outlet portion 5 may still communicate with each other, but the flow separator 20 provides sufficient separation so that a stirring in one of these portions, especially in the outlet portion 5, is not significantly transmitted to the other portion, especially to the inlet portion 3. As a result, one portion can be stirred without significant transfer of the stirring motion to the other portion. In other words, the flow separator 20 provides approximate boundary conditions for the stirring motion within the outlet portion 5.

[0022] The flow separator 20 is preferably at least one piece of tundish furniture. Examples of a flow separator 20 are a baffle, a weir, or a dam. For example, in the present invention, the flow separator 20 may comprise a combination of a weir 22 and a dam 21, e.g., with the weir 22 being attached to at an upper portion of a wall in the tundish inner volume 2, and the dam 21 being attached to a lower portion of a wall in the tundish inner volume 2. In this case, there may be a gap between the weir and the dam, so that molten metal in the inlet portion 3 is in communication with the molten metal in the outlet portion 5. As another example, the flow separator 20 may comprise a baffle, e.g., attached to the top and bottom portion of the walls in the inner volume 2 of the tundish.

[0023] The influence of the EMS stirring may cause turbulence at the inlet portion 3. Such turbulence can lead to slag entrapment, and reduce the cleanliness of the steel. Positioning the flow separator 20 between the inlet portion 3 and the outlet portion 5 reduces turbulence of the flow at the inlet portion 3 due to the EMS stirring, which can reduce slag entrapment and inclusions.

[0024] In the present invention, the flow separator 20 is preferably a combination of a weir and a dam. The weir and the dam are preferably configured to prevent the EMS stirring turbulence at the inlet portion 3 due to the EMS stirring.

[0025] Moreover, the flow separator 20 of the present invention is preferably a non-electromagnetic flow separator 20. This means that the flow separator 20 itself is not equipped to carry out electromagnetic braking, or electromagnetic stirring.

[0026] A non-electromagnetic flow separator is simple and inexpensive, requires less maintenance, and takes up less of the tundish inner volume 2, compared to an electromagnetic flow separator which is equipped to carry out electromagnetic stirring or braking.

[0027] An EMS stirrer 10 is an electromagnetic stirrer. An electromagnetic stirrer stirs the molten metal in the tundish 1 by means of interaction between an induction coil and the electrically conductive molten metal in the tundish.

[0028] The EMS stirrer 10 is disposed outside of the tundish. Positioning the EMS stirrer 10 outside of the tundish 1 (i.e., outside of the tundish volume for the molten metal) has the advantage that it does not occupy a part of the inner volume 2 of the tundish 1, and allows ready access for maintenance.

[0029] The EMS stirrer 10 is disposed at a vertical position below the top of the inner volume 2 of the tundish, and above the bottom of the inner volume 2 of the tundish 1. The position of the EMS stirrer 10 is defined as the position of a center of the induction coil of the EMS stirrer 10. In other words, the center of the induction coil is preferably below the top of the inner volume 2 of the tundish, and above the bottom of the inner volume 2 of the tundish 1. More preferably, the EMS stirrer 10 is disposed at a vertical position below the level of the molten metal in the tundish 1 during operation of the tundish 1, and above the bottom of the inner volume 2 of the tundish. Positioning the EMS stirrer 10 in this way has the effect of maximizing the stirring efficiency.

[0030] The EMS stirrer 10 is disposed so as to cause a flow of the molten metal in a horizontal direction. Herein, a flow of the molten metal in a horizontal direction means that the flow directly caused by the EMS stirrer (e.g., the momentum imparted by the EMS stirrer without considering preexisting flow, e.g., from inlet to outlet) is essentially horizontal, with

essentially no vertical component. Horizontal is defined as being perpendicular to the direction of gravity.

[0031] The flow directly caused by the EMS stirrer is defined as the flow of the molten metal closest to the EMS stirrer (subject to the largest EM field exerted by the EMS stirrer), and caused by the electromagnetic force of the stirrer acting on the molten metal.

[0032] In the present invention, in order to achieve a flow of the molten metal in a horizontal direction, the center axis of the coil of the EMS stirrer is preferably as close to horizontal as possible, and preferably differs by no more than $\pm 45^\circ$, more preferably within $\pm 30^\circ$, and more preferably $\pm 15^\circ$, from horizontal.

[0033] Making the molten metal flow in a horizontal direction has the advantage of maximizing stirring of the outlet portion 5, while reducing the turbulence at the surface of the molten metal, which reduces entrapment of impurity particles, and allows for improved separation of impurity particles, particularly impurity particles with a particle diameter of less than 100 μm , and more particularly impurity particles with a diameter of less than 50 μm .

[0034] The EMS stirrer 10 is disposed so that the flow of molten metal which is directly induced by the EMS stirrer 10 flows away from the inlet 4. In other words, the electromagnetic force of the EMS stirrer 10 acting on the molten metal which is closest to the EMS stirrer 10 makes the molten metal closest to the EMS stirrer 10 flow in a direction away from the inlet 4.

This can be achieved by suitably choosing the location of the EMS stirrer 10, and suitably controlling the supply of current to the EMS stirrer 10.

[0035] For example, as shown in each of Figs. 10a to 10d, the molten metal is caused to circulate in the tundish 1 by one or two EMS stirrers 10. The portion of the flow of molten metal represented by the arrows which are closest to the EMS stirrer(s) 10 represents the flow which is directly induced by the EMS stirrer 10, and this flow flows away from the inlet 4 of the tundish. If more than one EMS stirrer 10 is present, each EMS stirrer 10 is disposed so as to make the molten metal in the outlet portion 5 flow in a horizontal direction, away from the inlet 4.

[0036] Preferably, the stirring causes no more than two vortices (as illustrated in Figs. 10a-c), preferably no more than one vortex (as illustrated in Fig. 10d), of molten metal in the tundish. In the present invention, a flow which circulates in one circuit about the outlet portion 5 is defined as having one vortex. Such a flow is generally caused by a single EMS stirrer 10. Such a flow is illustrated in Fig. 10d. In contrast, a flow which flows in two circuits about the outlet portion 5 is defined as having two vortices. Such a flow is generally caused by two EMS stirrers 10. Such a flow is illustrated in Figs. 10a, 10b, and 10c. A flow of no more than two vortices can be advantageous because of the reduced risk of dead zones and turbulence.

[0037] Preferably, the EMS stirrer 10 is disposed so as to stir the entire volume of the molten metal in the outlet portion 5. By disposing the EMS stirrer 10 in this way, it is possible to prevent dead zones in the flow of the molten metal, which increases the temperature homogeneity of the molten metal in the tundish. Preferably, the dead zone volume of the tundish 1 is no greater than 10% of the total volume of molten metal in the outlet portion 5, more preferably no greater than 5%, more preferably no greater than 3%, and more preferably no greater than 2%.

[0038] The EMS stirrer 10 is preferably disposed along a long wall of the tundish. This can achieve stirring of the entire volume of the molten metal, and reduce the dead zone volume of the tundish. A long wall is defined as one of the two longest walls of the tundish. Examples of configurations where the EMS stirrer is disposed along a long wall of the tundish are shown in Figs. 1, 3, and 10a to 10d.

[0039] A tundish 1 generally has a back side 8, which may also be referred to as the ladle turret side, and an operator side 7 which is opposite the back side 8. The two longest walls of the tundish are preferably at the operator side 7, and back side 8. Preferably, the EMS stirrer 10 is mounted on the back side 8 of the tundish 1, or on the operator side 7 of the tundish 1. Mounting the EMS stirrer 10 on the back side 8 or the operator side 7 of the tundish 1 can provide stirring of the entire volume of the molten metal.

[0040] Preferably, the stirring direction and stirring strength of each EMS stirrer 10 is adjustable.

[0041] Preferably, a maximum surface speed of the molten metal in the outlet portion 5 is no more than 0.5 m/sec. Higher values of the maximum surface speed may result in increased entrapment of slag, which reduces the cleanliness of the molten metal. The maximum surface speed of the molten metal in the outlet portion 5 is more preferably less than 0.5 m/sec, more preferably 0.4 m/sec or less, and more preferably 0.3 m/sec or less.

[0042] The maximum surface speed can be appropriately set by adjusting the position and stirring strength of each EMS stirrer 10. The maximum surface speed can also be computed by CFD.

[0043] Preferably, the volume average speed of the molten metal in the outlet portion 5 is no less than 0.05 m/sec. If the volume average speed of the molten metal in the outlet portion 5 is less than 0.05 m/sec, the temperature homogenization may become insufficient, or a dead zone may develop. The volume average speed of the molten metal in the outlet portion 5 is more preferably greater than 0.05 m/sec, more preferably 0.06 m/sec or more, more preferably 0.7 m/sec or more. The volume average speed is estimated by CFD simulation as below:

$$\bar{V} = \frac{\int_{\Omega} \text{abs}(V) d\Omega}{\Omega},$$

where V is the speed in the melt, m/sec, Ω is the volume of the outlet portion, in m^3 , \bar{V} is the volume average speed, in m/sec.

[0044] The volume average speed can be appropriately set by adjusting the position and stirring strength of each EMS stirrer 10.

[0045] The specific stirring energy is preferably no less than 8.0 w/ton. If the specific stirring energy is less than 8.0 w/ton, the temperature homogenization may become insufficient. The specific stirring energy is more preferably more than 8.0 w/ton, more preferably 9.0 w/ton or more, and more preferably 10.0 w/ton or more.

[0046] The present invention also encompasses a method of stirring a molten metal in a tundish 1, In the method of the present invention, the molten metal in the outlet portion 5 is stirred to flow in a horizontal direction, and so that the flow which is directly induced by the EMS stirrer 10 flows in a direction away from the inlet

EXAMPLES

Water Modeling

[0047] Fig. 1 shows a tundish 1 according to the present invention, including the tundish 1, the tundish inner volume 2, comprising the inlet portion 3, the outlet portion 5, and the flow separator 20. The EMS stirrer 10 is disposed on an outer wall of the tundish 1, as shown in Fig. 3. The inlet portion 3 includes the inlet 4, and the outlet portion 5 includes the outlets 6. For the water modeling, a tundish 1 according to the present invention, as shown in Fig. 1 was studied, with a maximum throughput of the tundish of 1.9 ton/min, a normal working capacity of 40 ton, a bath depth of 850 mm, a ladle size of 110 ton, and four outlets 6. The flow separator 20 comprises a dam 21 and a weir 22. The flow separator 20 divides the inner volume 2 into the inlet portion 3 and the outlet portion 5.

[0048] Fig. 2 shows a comparative tundish, having an inlet portion 3 and an outlet portion 5 separated by a baffle 30. This comparative tundish had the same shape and size as the inventive tundish, however, the comparative tundish lacked an EMS stirrer, and instead of the flow separator 20 of the inventive tundish, the comparative tundish is provided with a baffle 30 with three holes, as shown in Fig. 2.

[0049] The above inventive and comparative tundishes were studied by water modelling. For the inventive tundish 1, three water pumps 12 were used to simulate the electromagnetic stirring, as shown in Figs. 4a and 4b. Fig. 4a shows the water model of the inventive tundish 1 from above, and Fig. 4b shows a side view of the water model of the inventive tundish 1, seen through the operator side 8. The stirring direction of the water pumps could be adjusted towards the tundish inlet 4, or away from the inlet 4 as shown by the arrows in Fig. 4a.

[0050] A tracer color was added to the inlets 4 of both tundishes to visualize the mixing and homogenizing phenomena of different configurations. For the comparative tundish with a baffle wall 30 and without EMS stirring, about 409 seconds were required to achieve complete mixing in the tundish. However, for the tundish 1 of the present invention with EMS stirring, complete mixing was achieved in about 236 seconds. Complete mixing was determined by color homogenization at the outlet portion.

[0051] These RTD (residence time distribution) results are shown in Fig. 5a for the comparative tundish, and Fig. 5b for the inventive tundish 1. In Figs. 5a and 5b, the vertical axis shows dimensionless concentration, and the horizontal axis shows dimensionless time. These figures show the measured residence time distribution (RTD) curves at each of the strands 1 to 4. The strands 1 to 4 respectively correspond to each of the outlets 6 shown in Fig. 4b, and are numbered so that strand 1 is located furthest from the inlet 4, and strand 4 is closest to the inlet 4. As can be seen by comparing Figs 5a and 5b, in the inventive tundish 1, strand similarity, namely, the homogeneity of the simulated molten metal among strands 1 to 4, was improved over the comparative tundish, and the RTD overall curve was significantly closer to an ideal mixing curve.

[0052] Fig. 6 shows a comparison of the dead zone volume, mixing flow volume, and plug flow volume of the inventive tundish 1 and the comparative tundish. The mixing flow volume, plug flow volume and dead zone volume were calculated from the RTD curves. In the comparative tundish, a relatively large proportion of plug flow volume and dead zone volume were found, which are significant disadvantages. In contrast, in the inventive tundish 1, the plug flow volume and dead zone volume are almost entirely eliminated as shown in Fig. 6.

[0053] The improved mixing and the smaller dead zone indicate that the temperature homogeneity of the inventive tundish 1 is significantly improved over the comparative tundish. Furthermore, from the reduced plug flow volume of the inventive tundish, a longer residence time, which leads to a reduction in inclusions, can be expected.

[0054] From this water modeling, it was also found that it is advantageous to set the stirrers 12 (which model the EMS stirrer) so that the flow which is directly induced by the stirrers flows away from the inlet 4, because this reduces turbulence at the inlet portion 3, which leads to a reduction in slag entrapment

CFD Modeling

[0055] The above examples of the inventive tundish 1 and comparative tundish were also studied by CFD (computa-

tional fluid dynamics), to investigate the flow characteristics such as flow velocity and stirring energy. Fig. 7a shows results for the comparative example, and Fig. 7b shows results for the inventive example. Figs. 7a and 7b show the flow velocity vector plots at the horizontal midplane of tundish. In order to quantify the flow characteristics, the whole tundish volume was divided into the inlet portion 3 and the outlet portion 5. From Figs. 7a and 7b, it can be seen that, with EMS stirring, a macro rotating flow is formed in the outlet portion 5. This rotating flow homogenizes the temperature among the outlets 6, and also transforms the whole outlet portion 5 into a mixing volume. It was thus confirmed that the entire volume of the molten metal in the outlet portion 5 of the tundish 1 can be stirred.

[0056] The specific stirring energy is defined as follows:

$$\dot{\epsilon} = \frac{\int_0^{\Omega} \epsilon \, d\Omega}{\int_0^{\Omega} d\Omega} \cdot g \cdot 10^3 \quad \text{Equation 1}$$

[0057] Where $\dot{\epsilon}$ is the specific stirring energy, w/ton, ϵ is the dissipation rate of the turbulent kinetic energy, m^2/s^3 , g is the gravitational acceleration, m/s^2 . The simulation was performed using ANSYS Fluent.

[0058] Table 1 lists the flow speed quantification for the inventive tundish 1 and the comparative tundish. For the comparative tundish, the volume averaged speed and specific stirring energy is very low. This is unfavorable for inclusion collision and coalescence. For the inventive tundish 1, both the stirring speed and specific stirring energy are increased, and the inclusion collision and coalescence will be accelerated (as explained below). However, the maximum surface speed of the inventive tundish 1 was low, and close to that of the comparative example. A low surface speed can reduce or prevent slag entrapment.

Table 1:

	Volume averaged speed in the outlet zone (m/sec)	Max surface speed in the outlet zone (m/sec)	Specific stirring energy in the outlet zone (w/ton)
Comparative tundish	0.024	0.35	0.83
Inventive tundish	0.11	0.38	15.3

Inclusion Modeling

[0059] Mathematical modeling was also carried out to predict transient concentration and size distribution of inclusions, and the removal of inclusions at the slag layer was also modeled by considering the relationship between collision time and rupture time.

[0060] The simulations of collisions, coalescence and growth of inclusions were carried out via Population Balance Model in Ansys Fluent. The coalescence rate was determined by the sum of Brownian, Stokes and turbulence collisions. To reduce the computation time, only Al_2O_3 inclusions were considered.

[0061] The inclusions were divided into 16 classes in diameter between $1\mu m$ and $97\mu m$, and the initial volume fraction in the inlet portion 3 and tundish 1 was set as 10ppm. A detailed description of the model is described in H. Ling, "Mathematical modeling on the growth and removal of non-metallic inclusions in the molten steel in a two-strand continuous casting tundish," Metallurgical and Materials Transactions B, vol. 47B, pp. 2991-3016, October 2016. The simulated process time was 300 seconds.

[0062] Figure 8a shows the result for the comparative tundish without EMS, and Fig. 8b shows the result for the inventive tundish 1. Figs. 8a and 8b show the distribution of volume fraction of inclusion at the vertical cross section across the outlets 6 after 300 seconds simulation time. It can be seen that, for the inventive tundish 1, the volume fraction of inclusions is homogeneously distributed in the whole outlet portion 5 and reduced to a lower level than the comparative tundish.

[0063] Fig. 9a shows the volume fraction of inclusions inside the tundish, and Fig. 9b shows the volume fraction of inclusions at the outlets of the tundish over time. Figures 9a and 9b show that the volume fraction of inclusions both inside the tundish 1 and at the outlets 6 decreases at a faster rate for the inventive tundish.

[0064] Figures 11a and 11b show the influence of EMS stirring on the number density of inclusions with different sizes, at the outlet of tundish. Fig. 11a shows that small inclusions (diameters smaller than $10\mu m$) are reduced for the inventive tundish. Fig. 11b shows that medium size inclusions (diameters between $10\mu m$ and $60\mu m$) are also reduced for the inventive tundish. However, the number density of large inclusions (larger than $60\mu m$) were small for both the inventive and comparative tundishes, and were considered negligible.

Configuration of refractory furniture and stirring direction

[0065] The electromagnetic stirring can circulate the molten metal throughout the whole tundish 1. However, it is not wished to have a strong turbulence in the inlet portion 3, because strong turbulence in the inlet portion 3 may cause slag entrapment. It is therefore necessary to add a flow separator 20 around the inlet portion 3 to reduce the influence of stirring momentum on the inlet portion 3.

[0066] Figures 10a to 10d show possible arrangements of the flow separator 20 and the EMS stirring direction by the EMS stirrer 10 in tundishes according to the present invention. The arrows in the EMS stirrers 10 represent the stirring direction of the EMS stirring, and the arrows in the outlet portion 5 represent the flow of molten metal. From the above studies, it was found that that a flow separator 20 should be positioned in the inner volume 2 of the tundish 1, between the inlet portion 3 and the outlet portion 5, and that the stirring direction of EMS should be away from the inlet 4, so that the electromagnetic stirring shall has a minimum effect on the turbulence level inside the inlet portion 3.

[0067] Based on the above, a tundish 1 and method of stirring according to the present invention can provide improved temperature homogeneity within the tundish 1, while also reducing the concentration of inclusions, particularly inclusions with a particle diameter smaller than 50 μm , in a tundish 1 for continuous casting.

LIST OF REFERENCE NUMERALS

[0068]

- 1 tundish
- 2 inner volume
- 3 inlet portion
- 4 inlet
- 5 outlet portion
- 6 outlet
- 7 operator side
- 8 back side
- 10 EMS stirrer
- 12 water pump
- 20 flow separator
- 21 dam
- 22 weir
- 30 baffle

Claims

1. A tundish (1) for continuous casting, the tundish (1) having an inner volume (2) comprising: an inlet portion (3) comprising an inlet (4) for receiving molten metal, an outlet portion (5) comprising at least one outlet (6) for discharging molten metal, and a flow separator (20),
the tundish (1) further comprising an EMS stirrer (10) for electromagnetic stirring, wherein,
the flow separator (20) is positioned between the inlet portion (3) and the outlet portion (5),
the EMS stirrer (10) is disposed outside of the tundish (1), at a vertical position below the top of the inner volume (2) of the tundish (1) and above the bottom of the inner volume (2) of the tundish (1),

the EMS stirrer (10) is disposed to stir the molten metal in an essentially horizontal direction, with essentially no vertical component, and to make the molten metal in the outlet portion (5) flow in a horizontal direction, and the flow which is directly induced by the EMS stirrer (10) flows away from the inlet (4), and wherein the flow separator (20) is configured to restrict the stirring of the molten metal by the EMS stirrer (10) in the inlet portion (3).

2. A tundish (1) according to claim 1, wherein the stirring causes no more than two vortices of molten metal in the tundish (1).
3. A tundish (1) according to any of the preceding claims, wherein the EMS stirrer (10) is disposed to stir the entire volume of the molten metal in the outlet portion (5).
4. A tundish (1) according to any of the preceding claims, wherein the tundish (1) has an operator side (7), and a back side (8) which is opposite to the operator side (7), and the stirrer is mounted on the back side (8) of the tundish (1), or on the operator side (7) of the tundish (1).
5. A tundish (1) according to any of the preceding claims, wherein the stirring direction of each stirrer is adjustable.
6. A tundish (1) according to any of the preceding claims, wherein the stirring strength of each stirrer is adjustable.
7. A tundish (1) according to any of the preceding claims, wherein the flow separator (20) is at least one of a baffle (30), a weir (22), and a dam (21).
8. A tundish (1) according to any of the preceding claims, wherein a maximum surface speed of the molten metal in the outlet portion (5) is no more than 0.50 m/sec, and/or the volume average speed of molten metal in the outlet portion (5) is no less than 0.05 m/sec, and/or the specific stirring energy is no less than 8.0 w/ton.
9. A method of stirring a molten metal in a tundish (1), wherein the tundish (1) comprises:
 - a tundish body provided with an inlet portion (3) having an inlet (4) for molten metal, an outlet portion (5) having at least one outlet (6), a flow separator (20), and an EMS stirrer (10) for electromagnetic stirring, wherein, the flow separator (20) is positioned between the inlet portion (3) and the outlet portion (5) and restricts the stirring of the molten metal by the EMS stirrer (10) in the inlet portion (3),
 - the EMS stirrer (10) is disposed horizontally, outside of the tundish (1), at a vertical position below the top of the inner volume (2) of the tundish (1) and above the bottom of the inner volume (2) of the tundish (1),
 - the method comprising stirring the molten metal in the outlet portion (5) to flow in an essentially horizontal direction, with essentially no vertical component, and so that the flow which is directly induced by the EMS stirrer (10) flows away from the inlet (4).
10. A method of stirring a molten metal in a tundish (1) according to claim 9, wherein the stirring causes no more than two vortices of molten metal in the tundish (1).
11. A method of stirring a molten metal in a tundish (1) according to any of claims 9 to 10, wherein the strength and direction of stirring by the EMS stirrer (10) are adjusted so that a maximum surface speed of the molten metal in the outlet portion (5) is no more than 0.50 m/sec, and/or the volume average speed of molten metal in the outlet portion (5) is no less than 0.05 m/sec, and/or the specific stirring energy is no less than 8.0 w/ton.

Patentansprüche

1. EIngusstiegel (1) zum Stranggießen, wobei der EIngusstiegel (1) ein Innenvolumen (2) aufweist, umfassend: einen Einlassabschnitt (3), umfassend einen Einlass (4) zum Aufnehmen von geschmolzenem Metall, einen Auslassabschnitt (5), umfassend einen Auslass (6) zum Ablassen von geschmolzenem Metall und einen Strömungstrenner (20),

der EIngusstiegel (1) ferner umfassend einen EMS-Rührer (10) zum elektromagnetischen Rühren, wobei, der Strömungstrenner (20) zwischen dem Einlassabschnitt (3) und dem Auslassabschnitt (5) angeordnet ist, der EMS-Rührer (10) außerhalb des EIngusstiegels (1) angeordnet ist, in einer vertikalen Position unterhalb des

oberen Endes des Innenvolumens (2) des Eingusstiegels (1) und oberhalb des Bodens des Innenvolumens (2) des Eingusstiegels (1),
 der EMS-Rührer (10) angeordnet ist, um das geschmolzene Metall in einer im Wesentlichen horizontalen Richtung, im Wesentlichen ohne eine vertikale Komponente zu rühren und um zu bewirken, dass das geschmolzene Metall im Auslassabschnitt (5) in einer horizontalen Richtung strömt, und
 die Strömung, die direkt durch den EMS-Rührer (10) induziert wird, vom Einlass (4) weg strömt, und wobei der Strömungstrenner (20) dazu ausgelegt ist, das Rühren des geschmolzenen Metalls durch den EMS-Rührer (10) im Einlassabschnitt (3) zu beschränken.

2. Eingusstiegel (1) nach Anspruch 1, wobei das Rühren bewirkt, dass nicht mehr als zwei Wirbel aus geschmolzenem Metall in dem Eingusstiegel (1) erzeugt werden.

3. Eingusstiegel (1) nach einem der vorhergehenden Ansprüche, wobei der EMS-Rührer (10) angeordnet ist, das gesamte Volumen aus dem geschmolzenen Metall im Auslassabschnitt (5) zu rühren.

4. Eingusstiegel (1) nach einem der vorhergehenden Ansprüche, wobei der Eingusstiegel (1) eine Bedienerseite (7) und eine der Bedienerseite (7) gegenüberliegende Rückseite (8) aufweist, und der Rührer auf der Rückseite (8) des Eingusstiegels (1) oder auf der Bedienerseite (7) des Eingusstiegels (1) befestigt ist.

5. Eingusstiegel (1) nach einem der vorhergehenden Ansprüche, wobei die Rührrichtung eines jeden Rührers einstellbar ist.

6. Eingusstiegel (1) nach einem der vorhergehenden Ansprüche, wobei die Stärke eines jeden Rührers einstellbar ist.

7. Eingusstiegel (1) nach einem der vorhergehenden Ansprüche, wobei der Strömungstrenner (20) mindestens eines aus einer Prallwand (30), einem Wehr (22) und einem Damm (21) ist.

8. Eingusstiegel (1) nach einem der vorhergehenden Ansprüche, wobei eine maximale Oberflächengeschwindigkeit des geschmolzenen Metalls in dem Auslassabschnitt (5) höchstens 0,50 m/Sek. beträgt und/oder die volumendurchschnittliche Geschwindigkeit von geschmolzenem Metall im Auslassabschnitt (5) mindestens 0,05 m/s beträgt und/oder die spezifische Rührenergie mindestens 8,0 W/t beträgt.

9. Verfahren zum Rühren eines geschmolzenen Metalls in einem Eingusstiegel (1), wobei der Eingusstiegel (1) umfasst:

einen Eingusstiegelkörper, versehen mit einem Einlassabschnitt (3) mit einem Einlass (4) für geschmolzenes Metall, einem Auslassabschnitt (5) mit mindestens einem Auslass (6), einem Strömungstrenner (20) und einem EMS-Rührer (10) für elektromagnetisches Rühren, wobei der Strömungstrenner (20) zwischen dem Einlassabschnitt (3) und dem Auslassabschnitt (5) angeordnet ist und das Rühren des geschmolzenen Metalls durch den EMS-Rührer (10) im Einlassabschnitt (3) einschränkt, der EMS-Rührer (10) horizontal außerhalb des Eingusstiegels (1) angeordnet ist, in einer vertikalen Position unterhalb des oberen Endes des Innenvolumens (2) des Eingusstiegels (1) und oberhalb des Bodens des Innenvolumens (2) des Eingusstiegels (1),
 das Verfahren umfassend Rühren des geschmolzenen Metalls im Auslassabschnitt (5), sodass es in einer im Wesentlichen horizontalen Richtung mit im Wesentlichen keiner vertikalen Komponente strömt, und sodass die direkt durch den EMS-Rührer (10) induzierte Strömung vom Einlass (4) weg strömt.

10. Verfahren zum Rühren eines geschmolzenen Metalls in einem Eingusstiegel (1) nach Anspruch 9, wobei das Rühren bewirkt, dass nicht mehr als zwei Wirbel aus geschmolzenem Metall in dem Eingusstiegel (1) erzeugt werden.

11. Verfahren zum Rühren eines geschmolzenen Metalls in einem Eingusstiegel (1) nach einem der Ansprüche 9 bis 10, wobei die Stärke und die Richtung des Rührens durch die Rührvorgänge des EMS-Rührers (10) so eingestellt sind, dass eine maximale Oberflächengeschwindigkeit des geschmolzenen Metalls in dem Auslassabschnitt (5) höchstens 0,50 m/Sek. beträgt und/oder die volumendurchschnittliche Geschwindigkeit von geschmolzenem Metall im Auslassabschnitt (5) mindestens 0,05 m/s beträgt und/oder die spezifische Rührenergie mindestens 8,0 W/t beträgt.

Revendications

1. Répartiteur (1) pour coulée continue, le répartiteur (1) ayant un volume interne (2) comprenant : une partie d'entrée (3) comprenant une entrée (4) destinée à recevoir du métal fondu, une partie de sortie (5) comprenant au moins une sortie (6) destinée à décharger du métal fondu, et un séparateur d'écoulement (20),
 5 le répartiteur (1) comprenant en outre un agitateur EMS (10) pour assurer une agitation électromagnétique, dans lequel le séparateur d'écoulement (20) est positionné entre la partie d'entrée (3) et la partie de sortie (5),
 10 l'agitateur EMS (10) est disposé à l'extérieur du répartiteur (1), à une position verticale en dessous du haut du volume interne (2) du répartiteur (1) et au-dessus du bas du volume interne (2) du répartiteur (1), l'agitateur EMS (10) est disposé pour agiter le métal fondu dans une direction essentiellement horizontale, avec pratiquement aucune composante verticale, et pour faire en sorte que le métal fondu dans la partie de sortie (5) s'écoule dans une direction horizontale, et
 15 l'écoulement qui est directement induit par l'agitateur EMS (10) s'éloigne de l'entrée (4), et dans lequel le séparateur d'écoulement (20) est conçu pour limiter l'agitation du métal fondu par l'agitateur EMS (10) dans la partie d'entrée (3).
2. Répartiteur (1) selon la revendication 1, dans lequel l'agitation n'induit pas plus de deux tourbillons de métal fondu dans le répartiteur (1).
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3. Répartiteur (1) selon l'une quelconque des revendications précédentes, dans lequel l'agitateur EMS (10) est disposé pour agiter le volume entier du métal fondu dans la partie de sortie (5).
- 25 4. Répartiteur (1) selon l'une quelconque des revendications précédentes, le répartiteur (1) ayant un côté opérateur (7), et un côté arrière (8) qui est à l'opposé du côté opérateur (7), et l'agitateur étant monté sur le côté arrière (8) du répartiteur (1), ou sur le côté opérateur (7) du répartiteur (1).
- 30 5. Répartiteur (1) selon l'une quelconque des revendications précédentes, dans lequel la direction d'agitation de chaque agitateur est réglable.
6. Répartiteur (1) selon l'une quelconque des revendications précédentes, dans lequel la force d'agitation de chaque agitateur est réglable.
- 35 7. Répartiteur (1) selon l'une quelconque des revendications précédentes, dans lequel le séparateur d'écoulement (20) est au moins un élément parmi une chicane (30), un déversoir (22), et un barrage (21).
- 40 8. Répartiteur (1) selon l'une quelconque des revendications précédentes, dans lequel une vitesse de surface maximale du métal fondu dans la partie de sortie (5) ne dépasse pas 0,50 m/s, et/ou la vitesse volumique moyenne de métal fondu dans la partie de sortie (5) est supérieure ou égale à 0,05 m/s, et/ou l'énergie spécifique d'agitation est supérieure ou égale à 8,0 W/t.
9. Procédé d'agitation d'un métal fondu dans un répartiteur (1), le répartiteur (1) comprenant :
 45 un corps de répartiteur pourvu d'une partie d'entrée (3) ayant une entrée (4) pour du métal fondu, une partie de sortie (5) ayant au moins une sortie (6), un séparateur d'écoulement (20), et un agitateur EMS (10) pour assurer une agitation électromagnétique, dans lequel le séparateur d'écoulement (20) est positionné entre la partie d'entrée (3) et la partie de sortie (5) et limite l'agitation du métal fondu par l'agitateur EMS (10) dans la partie d'entrée (3),
 50 l'agitateur EMS (10) est disposé horizontalement, à l'extérieur du répartiteur (1), à une position verticale en dessous du haut du volume interne (2) du répartiteur (1) et au-dessus du bas du volume interne (2) du répartiteur (1), le procédé comprenant l'agitation du métal fondu dans la partie de sortie (5) pour qu'il s'écoule dans une direction essentiellement horizontale, avec pratiquement aucune composante verticale, et de telle sorte que l'écoulement qui est directement induit par l'agitateur EMS (10) s'éloigne de l'entrée (4).
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10. Procédé d'agitation d'un métal fondu dans un répartiteur (1) selon la revendication 9, dans lequel l'agitation n'induit pas plus de deux tourbillons de métal fondu dans le répartiteur (1).

EP 4 313 443 B1

11. Procédé d'agitation d'un métal fondu dans un répartiteur (1) selon l'une quelconque des revendications 9 à 10, dans lequel la force et la direction d'agitation avec lesquelles l'agitateur EMS (10) agite sont réglées de telle sorte qu'une vitesse de surface maximale du métal fondu dans la partie de sortie (5) ne dépasse pas 0,50 m/s, et/ou la vitesse volumique moyenne de métal fondu dans la partie de sortie (5) est supérieure ou égale à 0,05 m/s, et/ou l'énergie spécifique d'agitation est supérieure ou égale à 8,0 W/t.

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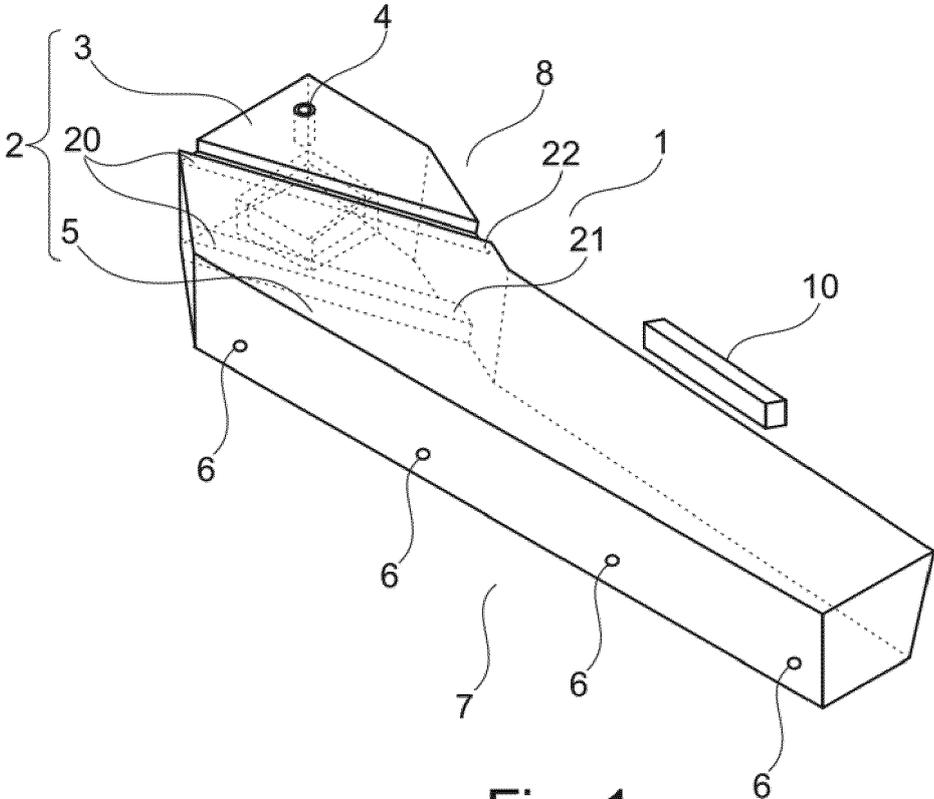


Fig. 1

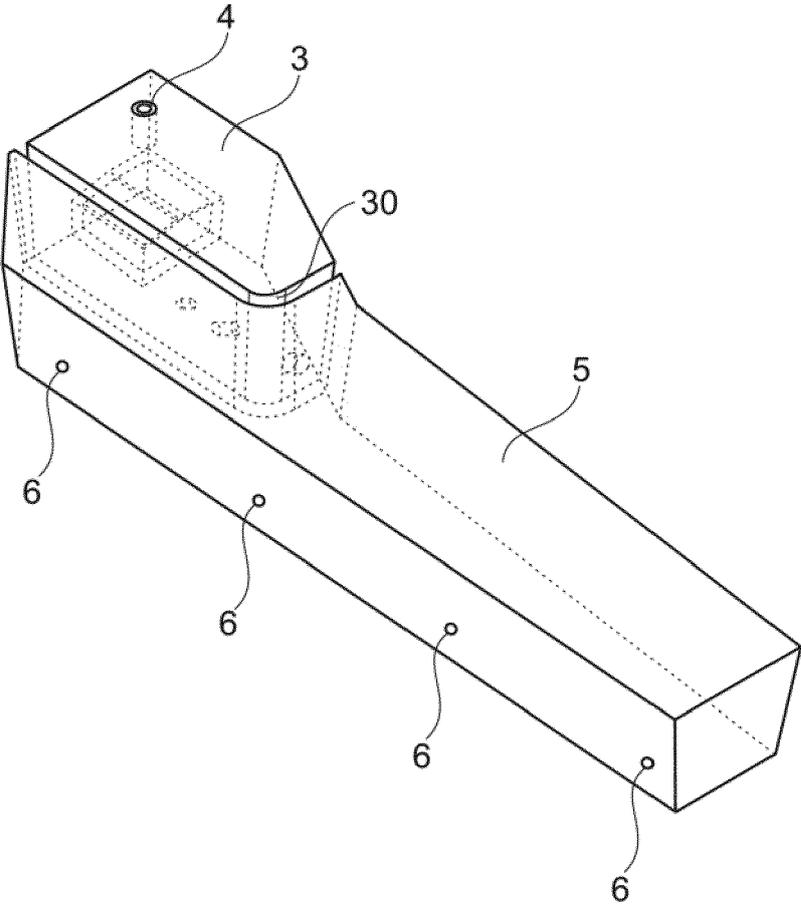


Fig. 2

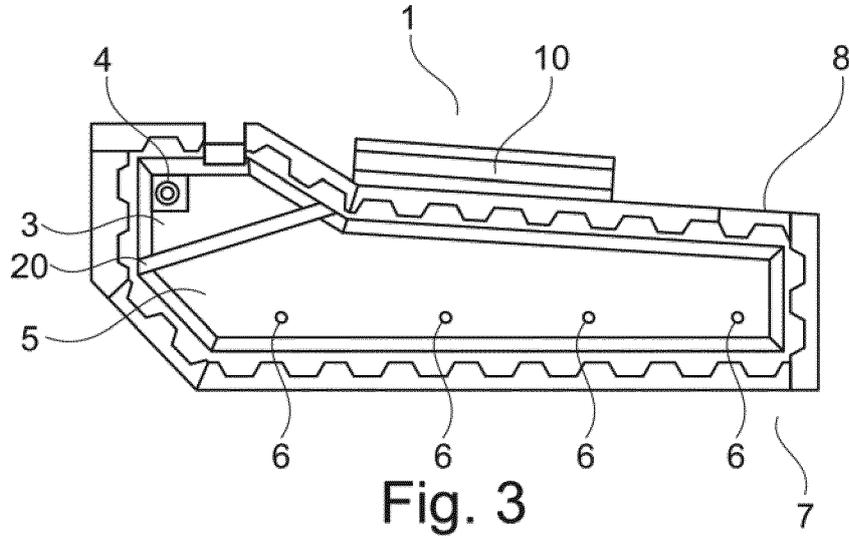


Fig. 3

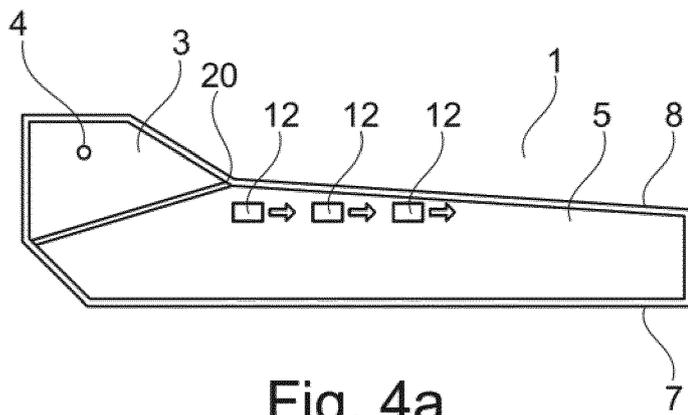


Fig. 4a

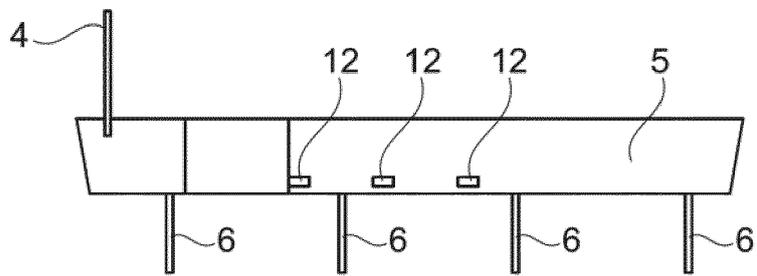


Fig. 4b

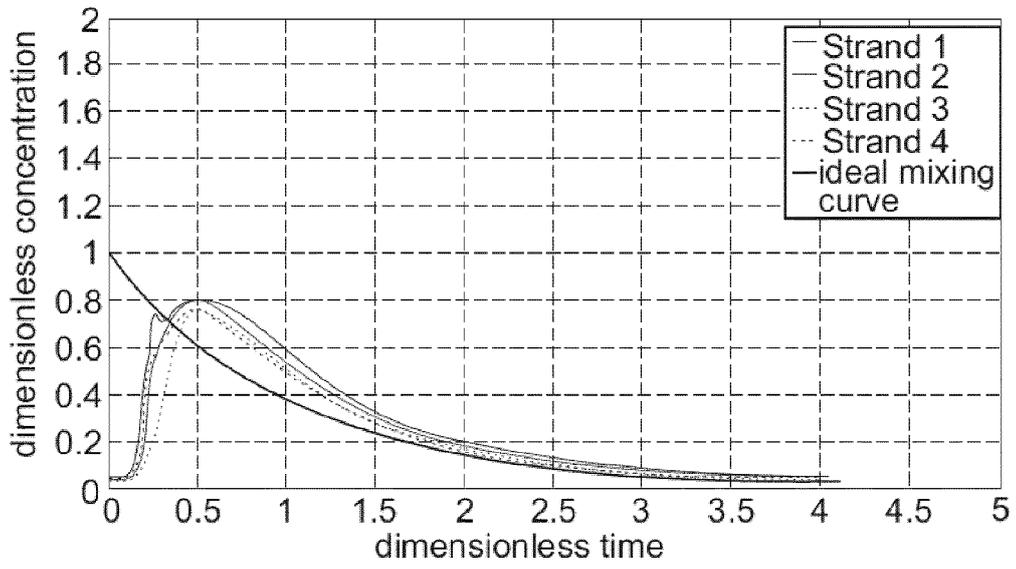


Fig. 5a

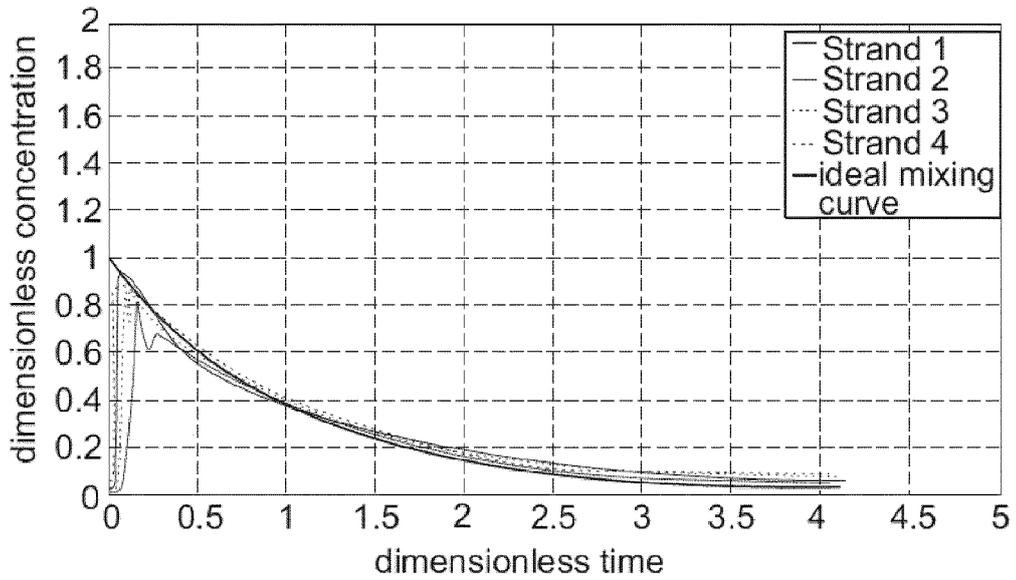


Fig. 5b

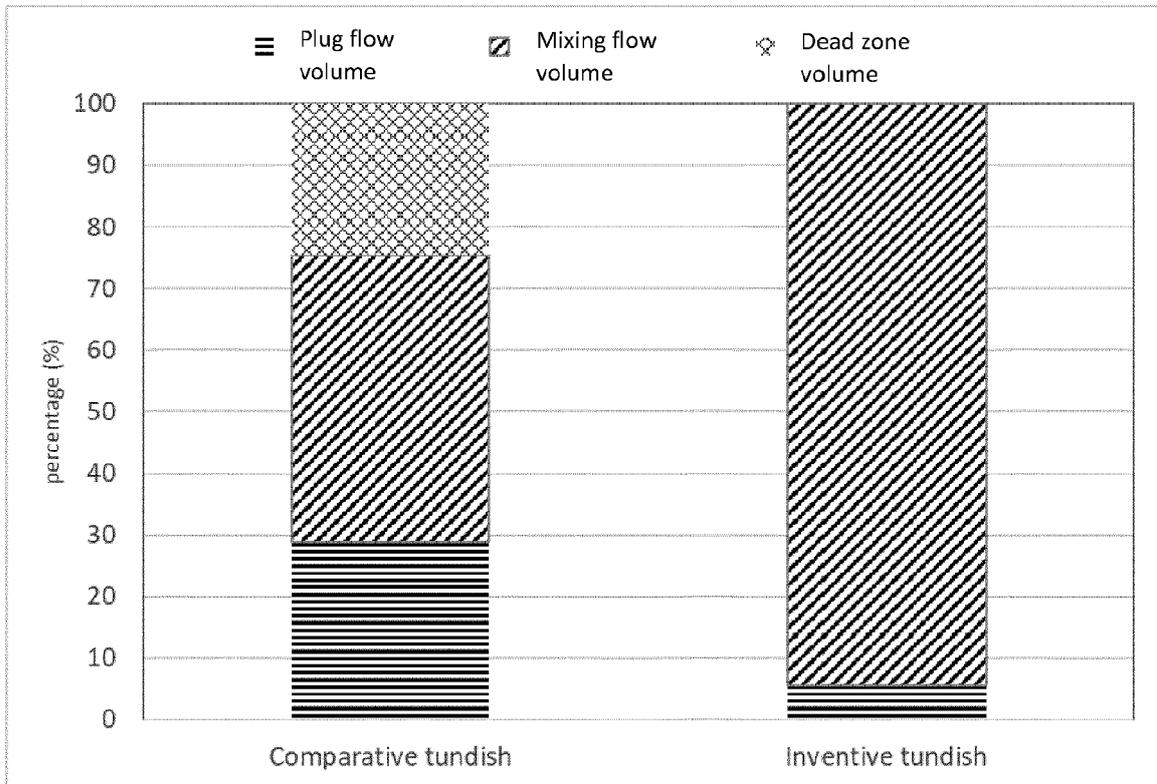


Fig. 6

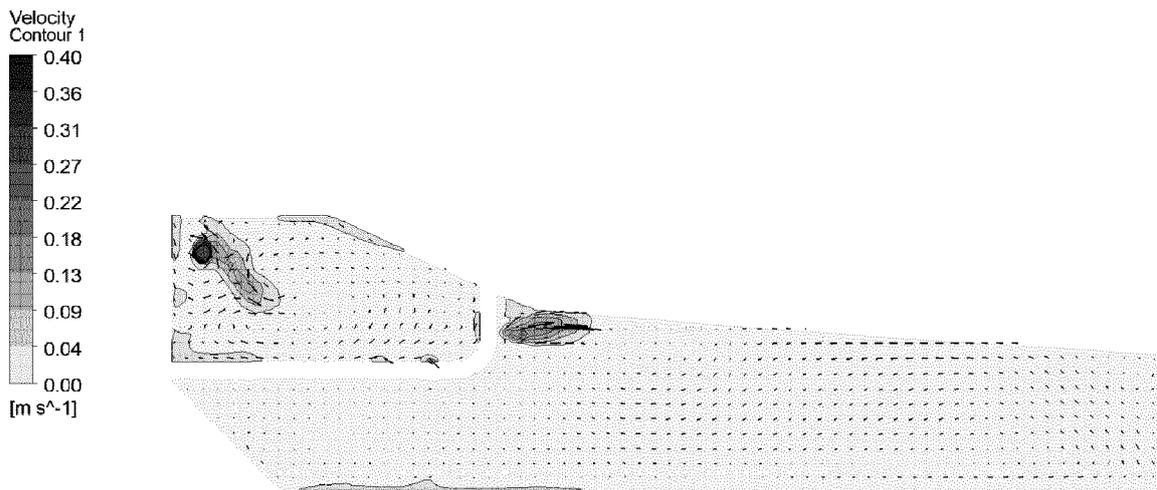


Fig. 7a

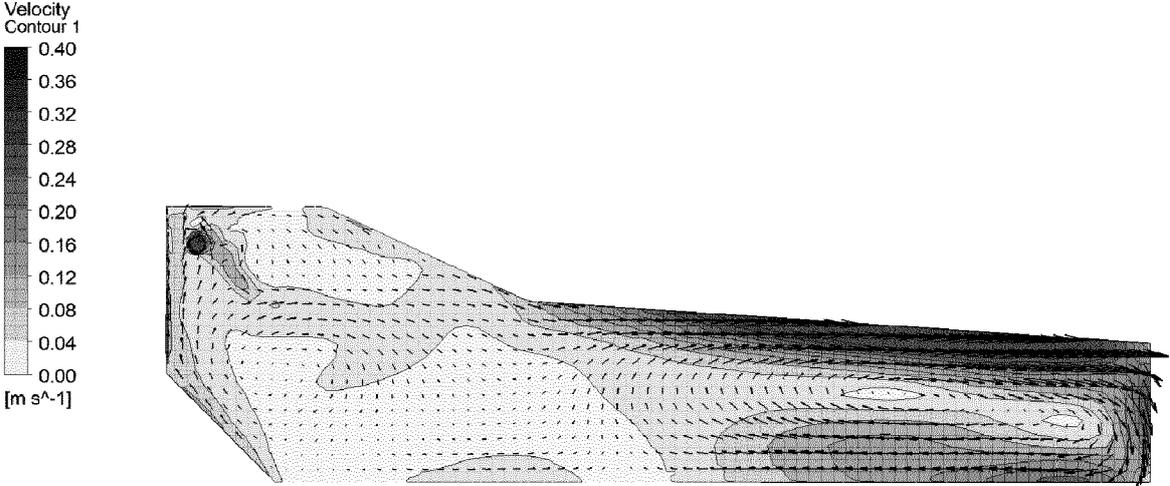


Fig.7b

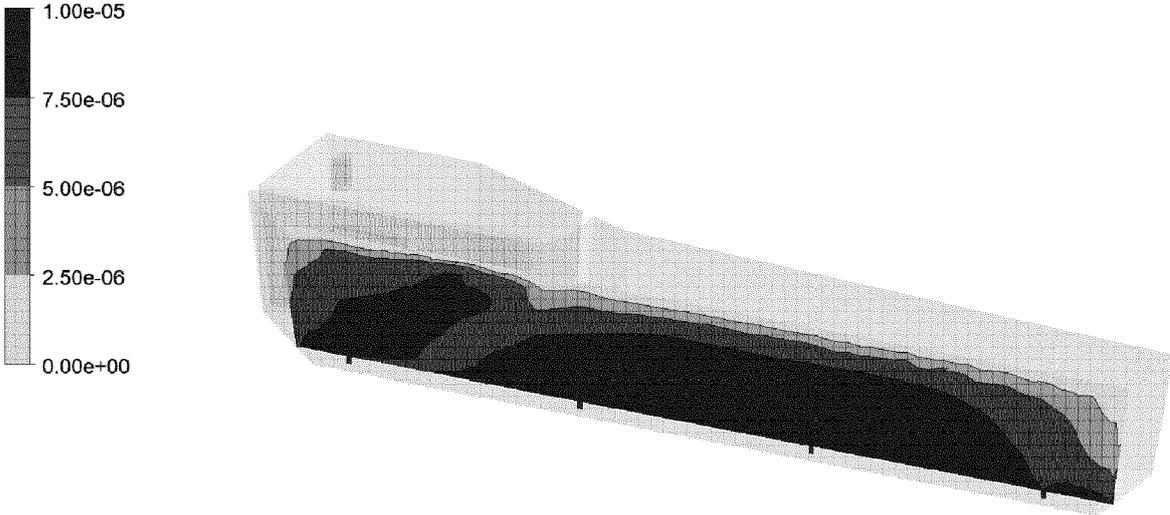


Fig.8a

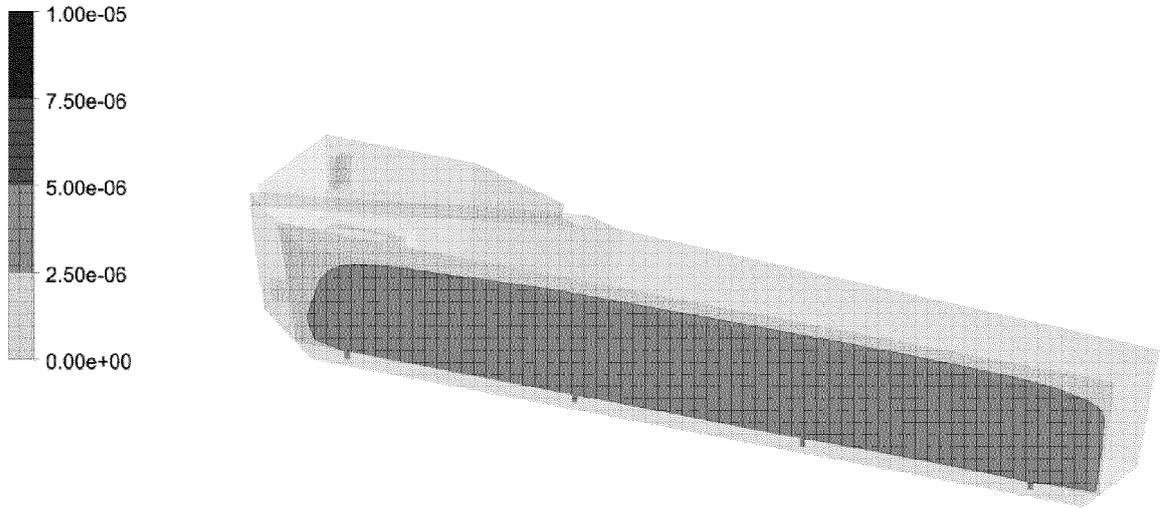


Fig.8b

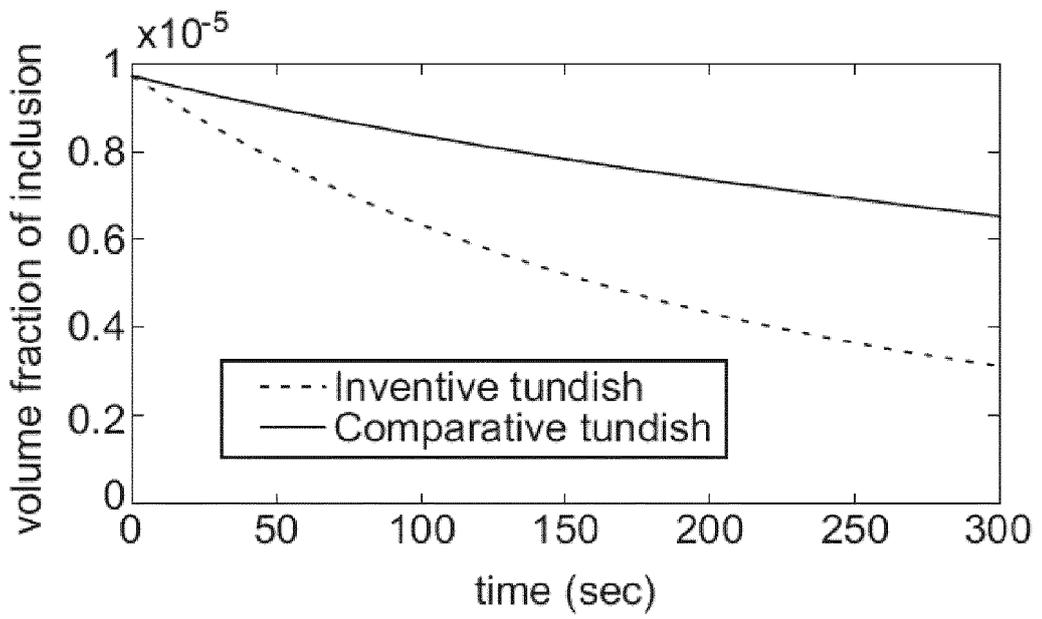


Fig.9a

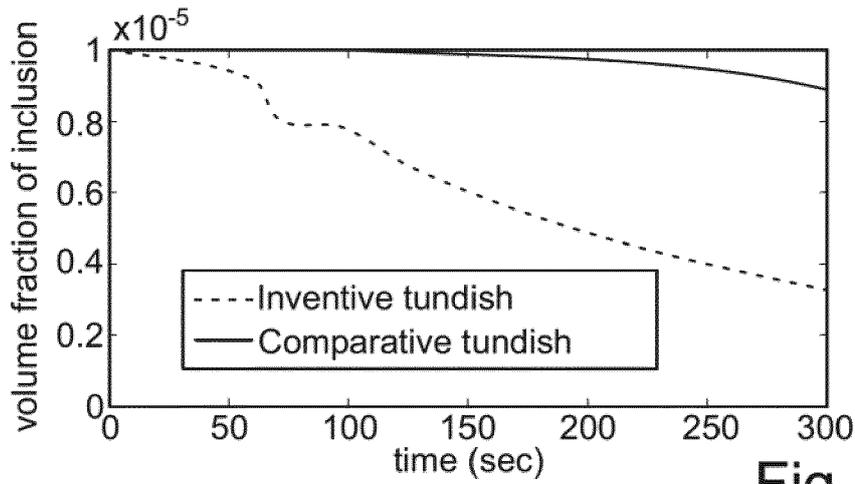


Fig. 9b

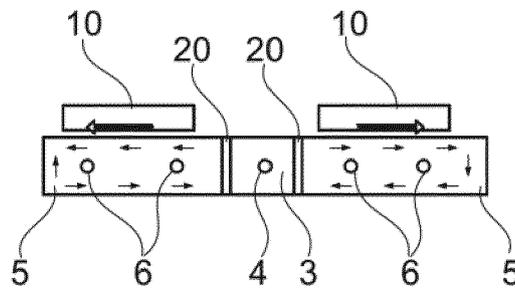


Fig. 10a

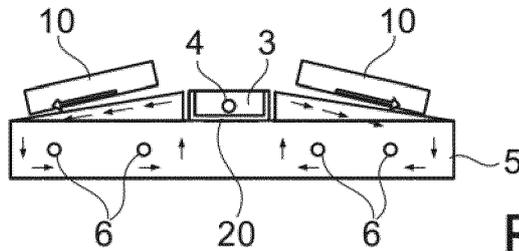


Fig. 10b

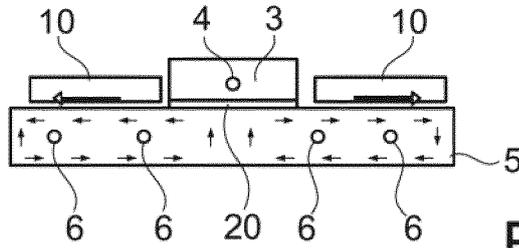


Fig. 10c

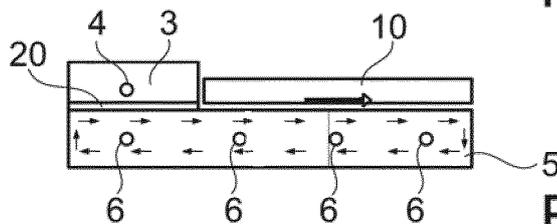


Fig. 10d

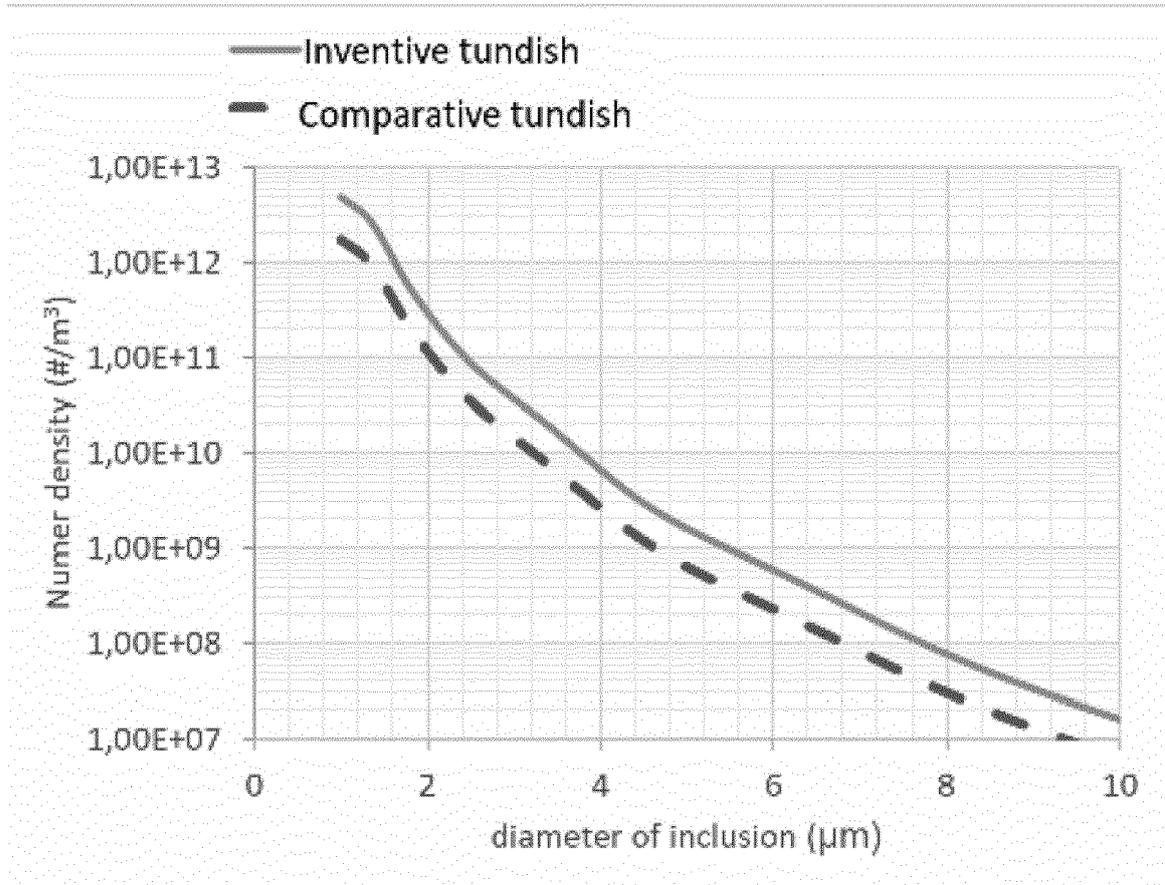


Fig. 11a

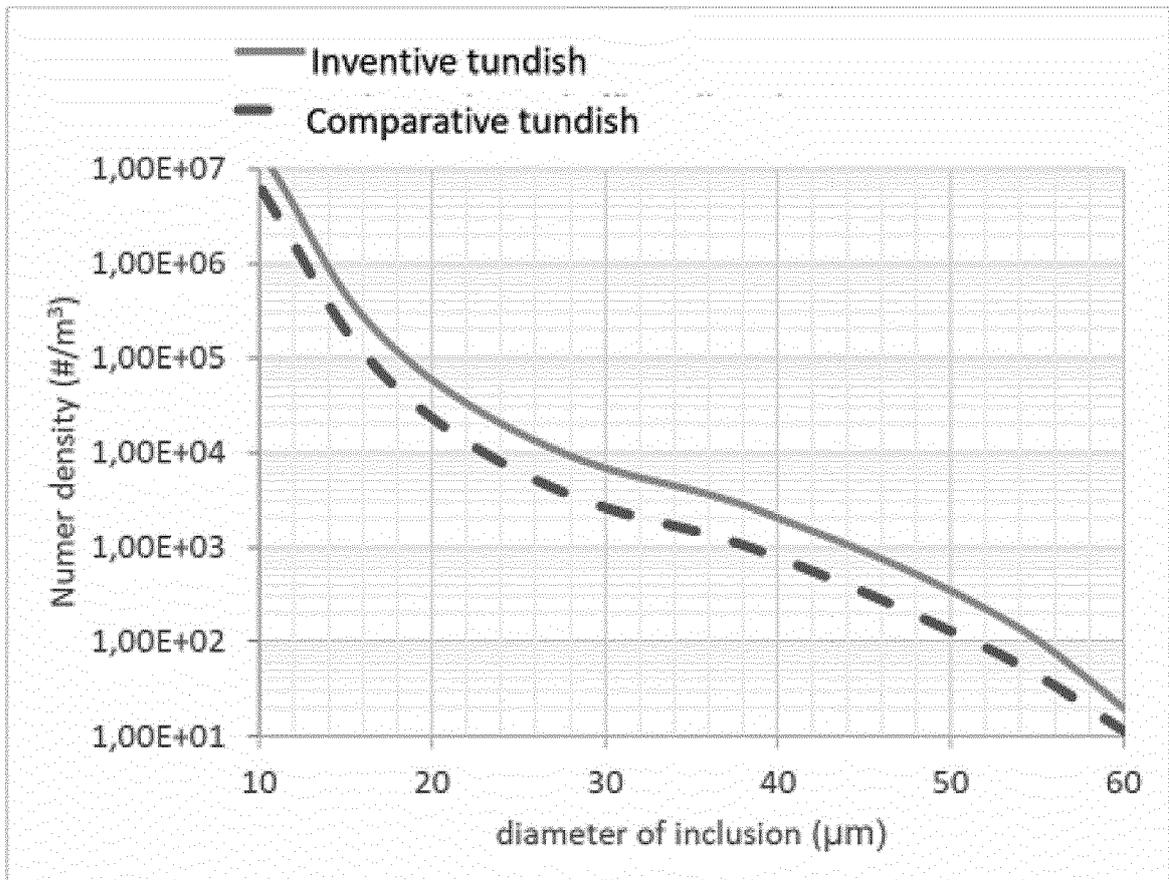


Fig. 11b

REFERENCES CITED IN THE DESCRIPTION

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