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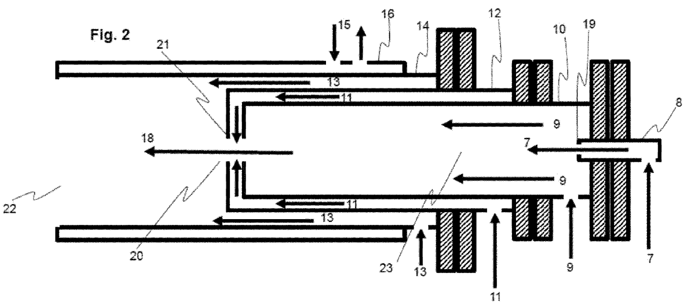
(54) A METHOD FOR HEATING OR REFINING A LIQUID MATERIAL IN A FURNACE

(57) The present invention relates to a method for heating, melting and/or refining a material in a furnace wherein the material is at least partially liquid, comprising the steps of: combusting a primary fuel with a gaseous oxidant in an injector comprising an inner combustion chamber and an injector outlet, combusting the primary fuel with the gaseous oxidant at an oxygen-fuel equivalence ratio between 5 and 20 in the inner combustion chamber to produce a hot combustion gas jet containing gaseous oxidant, and passing the hot combustion gas jet through the injector outlet and into the liquid material.

Fig. 2



EP 4 414 647 A1

Description

[0001] The present invention relates to a method for heating, melting and / or refining a liquid material in a furnace.

[0002] Heating, melting and refining furnaces are operated to raise the temperature of materials, to melt a material and/or to adjust the chemical composition of a liquid material such as a melt.

[0003] In some furnaces, the required energy is supplied directly to the melt by submerged plasma torches, that is by plasma torches arranged below the surface of the liquid material or melt. Such plasma torches have been used in submerged heating/melting/oxidizing and reduction. However, plasma technologies are expensive and the wear due to the extremely high temperatures in the plasma torch results in significant cooling losses, short life time and high maintenance need. Additionally, plasma injectors have a relative narrow operating range in terms of arc stability which also limits turn-up and turn-down gas flow capabilities.

[0004] It is also known to use submerged oxyfuel burners for heating the liquid material. The burner nozzles are arranged below the surface of the melt such that the burner flames and/or the combustion products from the burner pass directly through the melt. Since in oxyfuel combustion only low amounts of flue gases are produced relative to air fuel combustion, it is challenging to create sufficient melt or liquid bath movement with conventional oxyfuel combustion technology. There is a significant risk for on the one hand local overheating near the burner and, on the other hand, solidification further away from the burner due to lack of bath movement.

[0005] Accordingly, it is an object of the invention to provide a method for heating and/or refining a liquid material in a furnace which overcomes the above mentioned problems. This object is attained by the present invention which relates to a method for heating, melting and/or refining a material in a furnace wherein the material is at least partially liquid, comprising the steps of:

- combusting a primary fuel with a gaseous oxidant in an injector comprising an inner combustion chamber and an injector outlet,
- combusting the primary fuel with the gaseous oxidant at an oxygen-fuel equivalence ratio between 5 and 20 to produce a hot combustion gas jet containing gaseous oxidant,
- and passing the hot combustion gas jet through the injector outlet and into the liquid material.

[0006] The term "furnace" shall in particular include batch furnaces and continuous furnaces and any type of industrial furnace and any device or structure used in industrial heating, melting and/or refining applications. Examples include but are not limited to melting furnaces for glass or metal, muffle furnaces, metallurgical furnaces in general, shaft or blast furnaces, converters, ladle furnaces or ladles, drum type or rotary furnaces, TSL (top submerged lancing) furnaces and/or electric arc furnaces.

[0007] The injector comprises an inner combustion chamber and an injector outlet. A primary fuel and an oxidant are combusted in the inner combustion chamber. Depending on the primary fuel flow rate, on the oxidant flow rate and on the flow rate of possible auxiliary flows the injector can be operated as a burner or as a lance. Other factors may also affect the operation mode of the injector.

[0008] In a preferred embodiment the oxidant is supplied through an oxidant supply duct and the fuel is supplied through a fuel pipe. The fuel pipe and the oxidant supply duct are arranged pipe-in-pipe with the fuel pipe as the inner pipe recessed to the oxidant supply duct. The volume downstream of the fuel pipe forms the inner combustion chamber.

[0009] According to the present invention, a hot combustion gas jet is produced which is then introduced into the liquid material. By combusting a small amount of a primary fuel with an excess amount of oxygen a jet of high temperature, high momentum oxygen is produced that can be used as a lance or as a burner. The hot combustion gas jet has an oxygen concentration ranging from 50-90% at temperatures ranging from 1000-2300°C. The hot combustion gas jet will also be referred to as "hot oxygen". According to a preferred embodiment the inner combustion chamber is provided with an inner nozzle. When the "hot oxygen" is passed through the inner nozzle it is accelerated to create a jet with a high velocity of for example supersonic speed. The overall effect is a highly reactive jet with exceptional mixing capability. The jet entrains and reacts with the liquid material to produce the desired effect on the process. The mixing power can be controlled independent of the flow rates of the reactants (oxygen and fuel).

[0010] The inner nozzle through which the hot combustion gas jet is passed is preferably a convergent nozzle with decreasing cross section. According to another preferred embodiment the inner nozzle is a convergent-divergent nozzle or a de Laval nozzle. Such a nozzle has a convergent part with decreasing cross section, a throat or restriction with minimum cross section and a divergent part where the cross section is increasing.

[0011] According to another preferred embodiment the injector comprises an outer nozzle. The injector outlet is designed as an outer nozzle or the injector outlet is provided with an outer nozzle. The hot combustion gas jet leaves the inner combustion chamber and is subsequently passed through the outer nozzle. The outer nozzle could be a convergent nozzle or a convergent-divergent nozzle. Of course, it is also possible to provide both an inner nozzle and an outer nozzle.

[0012] The primary fuel and the oxidant are combusted at a super-stoichiometric ratio and in particular at an oxygen-fuel equivalence ratio between 5 and 20. The inventive operation at an equivalence ratio of 5 to 20 means that there is between 5 to 20 times as much oxygen provided than is needed to completely burn the primary fuel. In the following the term "equivalence ratio" shall mean the oxygen-fuel equivalence ratio and it shall be defined as the actual oxygen to fuel ratio divided by the stoichiometric oxygen to fuel ratio.

[0013] By varying the oxygen-fuel equivalence ratio the properties of the hot combustion gas jet can be adjusted. A lower equivalence ratio results in higher gas jet temperatures and higher gas jet momentum at a given flow. Higher equivalence ratios result in lower jet temperature and lower jet momentum. Decreasing the equivalence ratio to levels below 3 risks creating an internal combustion environment in the injector that could overheat and damage the injector. An equivalence ratio below 3 should only be chosen if the injector material can withstand such high temperatures and / or if adequate cooling of the injector is provided.

[0014] Preferably, the oxidant has an oxygen concentration of at least 30% by volume, at least 50% by volume, at least 80% by volume, at least 90% by volume or at least 98% by volume. For example, the oxidant is oxygen-enriched air or technically pure oxygen. It is particularly preferred to use vaporized cryogenic oxygen as oxidant.

[0015] A preferred embodiment of the invention uses the concept of submerged combustion for heating, refining, oxidation and/or reduction of the liquid material. The injector itself may be submerged in the liquid material but it is preferred to locate the injector outside the liquid material and to arrange the injector outlet submerged, i.e. the injector outlet is below the surface level of the liquid material. Locating the injector outside of the liquid material shall mean that more than 50%, more than 70%, more than 90% of the injector or the complete injector is arranged outside the liquid material.

[0016] According to this embodiment the injector outlet is submerged and below the surface of the liquid material. The hot combustion gas jet may enter the liquid material from the bottom, from the side or from the top. The direction of the hot combustion gas leaving the injector may be horizontal, vertical, upwards or downwards, or angled to the horizontal or vertical. The furnace may comprise an opening for the injector outlet in one of the furnace side walls, in the furnace floor or in the furnace roof.

[0017] According to another embodiment the injector is positioned above the liquid material and the hot combustion gases are injected into the liquid material through its surface. The injector can be installed just above the surface of the liquid material at an angle that forces the high momentum jet of hot combustion gases into the liquid material.

[0018] As mentioned above the invention can be employed in different types of furnaces including rotatable furnaces. In such a rotatable furnace the injector might be fixed to the rotating portion of the furnace and depending on the angle the furnace is rotated the injector might be positioned above or below the surface of the liquid material. The injector might be operated above the liquid surface for e.g. for heating and / or melting and then rolled under the liquid surface for further heating and / or refining.

[0019] The primary fuel and the oxidant are combusted in an inner combustion chamber within the injector. The inner combustion chamber could be a separate chamber to which the primary fuel and the oxidant are provided. The inner combustion chamber could also be a section of a tuyere or pipe in which the primary fuel and the oxidant come into contact and react with each other.

[0020] In one embodiment the oxidant is supplied via an oxidant supply duct with a larger cross section and the primary fuel is supplied via a fuel pipe with smaller cross section. The fuel pipe and its outlet are arranged within the oxidant supply duct. The outlet of the fuel pipe is preferably recessed with respect to the outlet of the oxidant supply duct. The volume downstream of the fuel pipe forms the inner combustion chamber. When the primary fuel leaves the fuel pipe it mixes with the surrounding oxidant and a combustion reaction takes place.

[0021] According to an embodiment the combustible mixture of primary fuel and oxidant is also ignited within the inner combustion chamber. Furthermore, the combustible mixture of primary fuel and oxidant can be stabilized within the inner combustion chamber.

[0022] In a preferred embodiment the resulting hot combustion gas jet is then passed through the inner and/or the outer nozzle and introduced into the liquid material from below its surface. The outlet of the injector through which the hot combustion gases leave the injector is preferably submerged in the liquid material. The hot combustion gases are released under the surface of the liquid material. The energy released by the combustion process is transferred as mixing power by direct contact with the liquid material.

[0023] The high velocity hot combustion gas jet may cause pressure waves within the liquid material which may result in backflow of liquid material into the injector. Therefore, it is preferred to adjust the equivalence ratio in such a way that the produced hot combustion gas jet is a choked flow. The velocity of the hot combustion gas jet depends on the inner nozzle, the outer nozzle, the flowrate and the temperature. Further, it depends on the volume of flue gases created by the particular fuel used for combustion. The temperature of the hot combustion gas jet depends on the equivalence ratio of the combustion of the primary fuel and the oxidant. With decreasing equivalence ratio the temperature of the hot combustion gas jet increases and its velocity increases. Therefore, by adjusting the equivalence ratio to lower values the velocity of the hot combustion gas jet can be increased. At a certain equivalence ratio the velocity of the hot combustion gas jet reaches sonic speed at the injector outlet. At these conditions the hot combustion gas jet is a choked flow. The mass flow rate of the hot combustion gas jet does no more depend on the pressure downstream of the injector outlet, that means possible pressure waves within the liquid material will have no effect on the hot combustion gas and / or on any equipment upstream of the injector outlet and backflow of liquid material into the injector is prevented.

[0024] The hot combustion gas jet is produced by super-stoichiometric combustion of the primary fuel and the oxidant. The hot combustion gas has an excess of oxygen and it shows oxidizing properties. In some applications it is desired to introduce a gas jet with neutral, reducing or other non-oxidizing properties into the liquid material. Such applications include but are not limited to treating non-ferrous material, for example copper reduction or copper deoxidation or poling. Therefore, it is preferred to combine the hot combustion gas with an auxiliary gas flow. Preferably, the auxiliary gas flow is entrained into the hot combustion gas before the hot combustion gas is introduced into the liquid material. If an outer nozzle is provided, this entrainment of the auxiliary gas flow into the hot combustion gas could be done upstream of the outer nozzle restriction or outer nozzle throat, at the nozzle restriction or downstream of the nozzle restriction. In a preferred embodiment the auxiliary gas flow is combined with the hot combustion gas in the convergent part of the outer nozzle.

[0025] Depending on the amount of auxiliary gas flow added to the hot combustion gas the chemical properties - oxidizing, stoichiometric, reducing or other - of the resulting hot combustion gas jet introduced into the liquid material can be adjusted. According to an advantageous embodiment, the auxiliary gas flow is a fuel or a refining gas. Possible auxiliary gases are hydrocarbons, hydrogen, carbon-monoxide and mixtures thereof. Other auxiliary gases could be inert gases such as nitrogen or argon or slightly oxidizing gases e.g. air, carbon-dioxide or water vapor.

[0026] When such an amount of oxidant is provided that an oxygen-fuel equivalence ratio of 20 is already reached, it may be difficult to add more oxidant or oxygen and at the same time to sustain the jet of hot combustion gases. In this case oxygen may be added as auxiliary gas in order to overcome equivalence ratio limitations of the inner combustion chamber. The addition of oxygen as an auxiliary gas could for example be advantageous when the liquid material contains significant amounts of substances to be oxidized and only low injector power is required.

[0027] Possible primary fuels are hydrocarbons, hydrogen, carbon monoxide and mixtures thereof. The fuel may be a gaseous fuel or a liquid fuel such as fuel oils, for example kerosene, diesel or gasoline.

[0028] Advantageously, the injection point of the auxiliary fuel into the hot combustion gas is adjustable in an axial direction so that the velocity of the auxiliary gas flow can be adjusted. Alternatively or additionally the inclination angle between the auxiliary gas flow and the hot combustion gas jet can be adjusted.

[0029] According to a preferred embodiment of the invention the hot combustion gas jet is introduced into the liquid material at a level below the surface of the liquid material. Therefore, the injector can be exposed to high temperatures which could damage the injector. According to a preferred embodiment the injector is provided with or the injector outlet is surrounded by a cooling tuyere or by a sheath and a cooling fluid is passed through the cooling tuyere. Preferably, the cooling fluid is water. Additionally or alternatively to the use of a cooling fluid the injector and/or the inner nozzle and/or the outer nozzle are provided with refractory material which withstands high temperatures. The provision of refractory material instead of a water cooling has an safety benefit because possible explosions are avoided which might occur in the event of a water leakage.

[0030] In another preferred embodiment a purge tuyere is provided and a purge gas is passed through the purge tuyere. The purge gas purges the the inner and / or the outer nozzle, part of the inner and / or the outer nozzle and / or the injector outlet. The purge tuyere is preferably arranged coaxial with the inner or outer nozzle and provided with a purge gas outlet upstream, downstream or at the inner or outer nozzle throat. The purge gas is used to purge the inner and/or outer nozzle and / or the injector outlet and to prevent that any material contaminates or blocks the inner or outer nozzle or the injector outlet when the injector is not in operation. The purge gas could be an inert gas or an active gas. Examples are nitrogen, oxygen or air.

[0031] The purge gas can also be used as an additional cooling and / or to obtain a cool buffer layer near the injector outlet, the inner nozzle or the outer nozzle. Additionally, the purge tuyere can be used to provide oxygen to the hot combustion gases jet so that a high momentum jet with even higher equivalence ratio of more than 20 can be attained. Further, the purge tuyere may also be used to add additional process gases.

[0032] According to another embodiment the injector is provided with a flame detection device or flame detection sensor in order to detect the existence or non-existence of an injector flame.

[0033] The invention can be used for heating, melting, oxidizing, de-oxidizing, desulphurizing decarburization and/or refining of a metallic material, of a slag, of vitrifiable material such as glass, of waste or of any other material. In one embodiment the material is heated, melted and/or refined by the inventive method only. According to another embodiment the material is partially heated, melted and/or refined by the inventive method and partially by another heating, melting or refining method.

[0034] Some preferred operation modes of the present invention will be explained in more detail below.

[0035] The first is a hot oxidation mode. In this case, the jet of hot combustion gases with an excess of oxidant is injected into the liquid material, e.g. into a liquid metal bath, to remove impurities, such as sulfur, carbon, silicon and other oxidizable elements, dissolved into the metal. The hot combustion gases do not only provide oxygen for oxidation, but also impart a controllable amount of heat and mixing power to the liquid material.

[0036] The second is the hot reduction mode. In this case, the hot combustion gas jet comprised of preheated reducing gases is injected into the liquid material to remove for example dissolved oxygen from a liquid metal. The operation of the injector is such that the reducing gases are partially pre-reformed into H2 and CO, which are strong reducing species for deoxidation. In the reduction mode, the injector also imparts heat to the liquid material and the amount of heat and the mixing power are controllable.

[0037] The third mode is an oxyfuel mode. In this case, the injector mode is especially effective in the near-field whereby increasing the heat transfer efficiency to the molten material. This is useful for trimming the temperature of the material upon heat loss or when adding cold charge such as solid scrap to the melt.

[0038] The fourth mode is also an oxyfuel mode that is used to preheat and deskull the furnace. The preheating function brings the furnace from cold start to operating temperature before solid and/or molten metal is charged. The deskulling mode is used to remove accretions that typically form in furnaces or refining vessels that gradually reduce the internal working volume which in turn reduces production rate in proportion by reducing heat/charge size.

[0039] Preferably, the invention is not used in one mode only but depending on the requirements the injector is controlled to operate in different modes. For example, the injector is switched between one or more of the above mentioned operation modes.

[0040] The inventive method has several advantages over the prior art:

- It is a simpler and more robust technology than plasma.
- The injector can be operated at conditions to produce a hot combustion gas jet with at least sonic velocity so that pulsations from the bath of liquid material in the furnace do not influence the internal combustion of primary fuel and oxidant. Further, plugging of the injector outlet(s) from back splash or molten material is reduced or prevented.
- The velocity of the auxiliary fuel can be adjusted by axial adjustment of the auxiliary fuel injection point relative to the injector.
- Ability to adjust the internal flame stoichiometry in the inner combustion chamber and thereby producing hot combustion gas jets of differing temperature and velocity without requiring nozzle changes
- Ability to adjust the external flame stoichiometry, allowing the injector to function as a heating injector, as an oxygen injector for decarburization and/or desulphurization or for reducing gas injection for deoxidations and reduction reactions. The amount of "left-over" oxygen is easily changed by simply adjusting the amount of auxiliary fuel relative to the firing rate of the injector. The invention also allows for a greater turn-down ratio to provide low power, for example to dry new refractory lined vessels or for temperature programmed preheating.
- The invention allows the control of penetration depth and mixing power transferred from the hot combustion gases to the liquid. Thereby temperature homogeneity and uniform refining conditions can be promoted. The properties of the hot combustion gas jet can be controlled independent of the mass flow rate supplied to the injector. In the prior art, this control is usually afforded through use of different nozzle geometries, which is not practical.

[0041] The inventive technology allows to control the mixing power independent of the flow rates of the reactants (fuel and oxygen) by varying how much precombustion of primary fuel and oxidant occurs upstream of the injector outlet. In the above described pipe-in-pipe arrangement of fuel pipe and oxidant supply duct this can be controlled by the recess distance of the fuel pipe.

[0042] It should be noted that the previously mentioned features and the features to be further described in the following are usable not only in the respectively indicated combination, but also in further combinations or taken alone, without departing from the scope of the present invention.

[0043] The present invention will now be described further, by way of example, with reference to the accompanying drawings, in which

Figure 1a	schematically shows a melting and/or refining furnace with a submerged injector according to the invention,
Figure 1b	schematically shows a melting furnace with an alternatively arranged submerged injector according to the invention,
Figure 1c	schematically shows a melting furnace with another alternatively arranged injector according to the invention,
Figure 2	schematically shows the inventive injector in detail,
Figure 3	shows an alternative embodiment of the invention.

Detailed description

[0044] Figure 1a shows a furnace 1 for heating, melting and/or refining a feedstock, such as metals, ores, scrap, waste electronic materials, slag, waste, glass or a vitrifiable material. The feedstock is fed to the furnace through a feed inlet 3. An injector 2 is located in the lower part of the furnace 1, preferably in the lower half or lower third of the furnace 1. The injector 2 may be arranged completely or partly in the furnace 1. The injector 2 may also be placed outside the furnace 1, however, at least the outlet 22 of the injector 2 is located at a level below the surface of the liquid material 6 so that combustion gases from the injector 2 can be directly introduced into the liquid material from below its surface. The injector 2 extends through one of the side walls of the furnace and hot combustion gases leaving the injector outlet enter the liquid material in an essentially horizontal direction. A taphole 5 is provided slightly above the floor of the furnace 1 and used to drain molten material 6 from the furnace 1. Flue gases are withdrawn via exhaust duct 4.

[0045] Figure 1b shows an alternative arrangement of the injector 2. Injector 2 extends through the floor of the furnace 1 and the hot combustion gases enter the liquid material from the bottom.

[0046] Figure 1 c shows another alternative arrangement of the injectors. According to this embodiment two injectors 2a, 2b are provided. Both injectors 2a, 2b are arranged such that the hot combustion gases leaving the injectors 2a, 2b enter the liquid material 6 from the top. In the embodiment shown in figure 1c the flow direction of the hot combustion gas leaving the injector 2a, 2b is not vertically but at an angle between 10° and 50° to the vertical. In other embodiments the injector might also be positioned vertical.

[0047] The injectors 2a, 2b may be mechanically fixed operating at a fixed position with respect to the liquid surface. The injectors 2a, 2b may also be connected to a motorized carriage that facilitates the positioning of the injector outlet with respect to the liquid surface. The latter gives positioning flexibility, especially when there is variable fill level in the furnace. For example in cases where a molten slag layer exists on top of a molten metal surface.

[0048] Of course, the injectors 2 shown in figures 1a and 1b can also be provided vertically. i.e. directed straight down, or at an angle between 10° and 45° to the horizontal or at an angle between 10° and 45° to the vertical. It is also possible to position both or one of the injectors 2a, 2b above the surface of the liquid material and to inject the hot combustion gas jet through the surface of the liquid material. Furthermore, depending on the size of the furnace, on the material to be heated and/or on the type of application the number of injectors may be one, two or more. If two or more injectors are used, each of the injectors can be located in one of the positions: in or through a side wall of the furnace, in or through the bottom or from the top.

[0049] Figure 2 shows the injector 2 in detail. The injector 2 comprises several coaxial pipes 8, 10, 12, 14, 16. The most inner pipe 8 is used as a fuel pipe 8 to supply fuel. The annular space between fuel pipe 8 and pipe 10 is used as oxidant supply duct 10.

[0050] Fuel pipe 8 is recessed with respect to the outlet 20 and with respect to the end of the oxidant supply duct 10. The interior of oxidant supply duct 10 downstream of the end of fuel pipe 8 forms an inner combustion chamber 23. Fuel pipe 8 communicates with the inner combustion chamber 23 through opening 19.

[0051] The outlet 20 of the inner combustion chamber 23 can be provided with an inner nozzle or the outlet of the inner combustion chamber can be designed and/or formed as an inner nozzle.

[0052] An auxiliary gas pipe 12 is coaxially arranged with the fuel pipe 8 and the oxidant supply duct 10 forming an annular channel around the oxidant supply duct 10. In the embodiment of figure 2 the outer wall 12 of the auxiliary gas pipe is parallel to the outer wall of oxidant supply duct 10. At the downstream end of oxygen supply duct 10 the auxiliary gas pipe has an angle of 90°. Thus, auxiliary gas 11 leaves the auxiliary gas pipe substantially perpendicular to the hot combustion gas 18 (for more details see below). In this embodiment the annular channel 12 has an outlet 21 close to the outlet 20 of the oxidant supply duct 10.

[0053] According to another embodiment, not shown in figure 2, the auxiliary gas pipe is a straight annular channel which is not angled 90°. The outlet of the auxiliary gas pipe is arranged at the downstream end of the auxiliary gas pipe such that the auxiliary gas leaves the auxiliary gas pipe essentially parallel to the hot combustion gas 18.

[0054] According to another embodiment, shown in figure 3, the oxidant supply duct 10 has a tapered end section with an outlet 20. That means the cross section of the oxidant supply duct 10 is decreasing in the downstream direction. The auxiliary gas pipe follows the tapered design of the oxidant supply duct 10, for example the outer wall 12 of the auxiliary gas pipe could be essentially parallel to the outer wall of the tapered oxidant supply duct 10. In this case, the auxiliary gas leaving the auxiliary gas pipe at its downstream outlet 21 enters the hot combustion gas 18 at an angle of more than 0° and less than 90°, preferably at an angle between 15° and 75°, 20° and 70°, 30° and 60° or 40° and 50°.

[0055] The auxiliary gas pipe can be provided with an annular outlet or with multiple small outlets. Such small outlets can be arranged as one or more rings of drill holes. The use of multiple small drill holes as outlets has the advantage of an enhanced cooling of the injector.

[0056] It shall be noted that the invention is not limited to one auxiliary pipe. It is also possible to provide two, three or more auxiliary pipes. The auxiliary pipes can be used to provide one or more of auxiliary fuel, oxidizing gas, refining gas or inert gas.

[0057] In any of the above described embodiments of the auxiliary gas pipe, a purge tuyere 14 can surround the auxiliary pipe 12 and a cooling tuyere 16 can be provided around the purge tuyere 14. The cooling tuyere 16 extends beyond the outlet 20 of the oxidant supply duct 10. Cooling water 15 is passed through the cooling tuyere 16 in order to cool the injector 2 and to prevent overheating of the injector 2.

[0058] According to another preferred embodiment the inner surface of the cooling tuyere 16 forms a convergent-divergent outer nozzle 17 in front of the outlet 20 of oxidant supply duct 10. Alternatively, there could be a separate convergent-divergent outer nozzle 17 downstream of the outlet 20 of the oxidant supply duct 10. Such an outer nozzle 17 will accelerate the hot combustion gas stream 18 leaving the oxidant supply duct 10. The outer nozzle 17 is shown in figure 3 only but can be applied to the embodiment of figure 2 as well.

[0059] In stand-by mode when the injector 2 is not operating and when no fuel is combusted or when the injector flame is required to be stopped, purge gas 13, for example purge air, is passed through the purge tuyere 14 to purge the volume around the injector outlet 22. The purge gas 13 is preferably flowing at a preset rate through the purge tuyere 14 to prevent process gas or feed material from entering and potentially fouling the injector 2.

[0060] In normal operation primary fuel 7, for example natural gas or vaporized petroleum gas, is provided to the fuel pipe 8 and an oxidant 9, for example gaseous oxygen or vaporized cryogenic oxygen, is provided to oxidant supply duct 10. The primary fuel 7 flows through the fuel pipe 8 and enters the oxidant supply duct 10 via opening 19. The space in front of the opening 19 has the function of an inner combustion chamber 23. The primary fuel 7 and the oxidant 9 react within the inner combustion chamber 23 to form hot combustion gases. The hot combustion gases 18 are passed into the furnace 1 in order to heat the furnace 1.

[0061] The properties of the hot combustion gas jet can be controlled independent of the mass flow rates of oxidant and fuel supplied to the injector. This can be achieved by varying how much precombustion of primary fuel and oxidant occurs in the inner combustion chamber, for example by varying the recess distance of the outlet 19 of the fuel pipe 8 with respect to the outlet 20 of the oxidant supply duct 10. This recess will affect the volume of the inner combustion chamber and thereby affect the precombustion of primary fuel 7 and oxidant 9. Thereby, it allows to control the penetration depth and the mixing power transferred from the hot combustion gases to the liquid. Temperature homogeneity and uniform refining conditions can be promoted.

[0062] Charge material is introduced into the furnace through feed inlet 3, heated up, melted and eventually the produced melt 6 submerges the injector outlet 22. For the heating and melting step the equivalence ratio of the primary fuel with the gaseous oxidant may be selected to be between 0,9 and 2.

[0063] When the injector outlet 22 is submerged by the melt, that is when the injector outlet 22 is lower than the surface of the molten or liquid material 6 in the furnace 1, the injector 2 is operated in hot oxygen mode. It is also possible to operate the injector 2 in hot oxygen mode when the material 6 has not yet been molten or is not yet in liquid form.

[0064] The above-described operation of the injector 2 with a super-stoichiometric amount of oxidant and combustion of the oxidant and the primary fuel in the inner combustion chamber 23 forms a hot jet of combustion gases which are rich in oxidant. This mode of operation shall be called hot oxygen mode.

[0065] In hot oxygen mode the primary fuel 7 is combusted with an excess amount of oxygen 9. The equivalence ratio of oxidant 9 to primary fuel 7 is preferably chosen to be between 5 and 20. For a certain amount of fuel the equivalence ratio is the amount of oxygen provided to the combustion divided by the amount of oxygen needed to perfectly burn the fuel. An equivalence ratio of 5 to 20 means that the amount of oxygen provided is 5 to 20 times the amount needed to burn the primary fuel. Thus, the hot combustion gases 18 resulting from the combustion of the primary fuel 7 with the oxidant 9 have a high oxygen concentration of for example more than 60% and up to or even more than 90% by volume. The hot combustion gas 18 can then be accelerated through outer nozzle 17 to create a hot combustion gas jet 18 with a velocity of for example 400 to 1000 m/s.

[0066] The equivalence ratio of oxygen supplied through oxidant supply duct 10 to the amount of primary fuel 7 shall be called primary equivalence ratio.

[0067] The primary fuel 7 and the oxidant 9 are reacted in the inner combustion chamber 23 which is located within the injector 2. That means, the injector 2 operates with an internal flame in the oxidant supply duct 10 and in particular in the inner combustion chamber 23. This internal flame could damage the injector 2 by operating too hot. Therefore, it is preferred to use the most inner pipe 8 for supply of the primary fuel and pipe 10 for supply of the oxidant. Thereby, the oxidant flow will contribute to protect the injector 2 from overheating. If overheating is not an issue the supply of primary fuel and oxidant could also be interchanged, i.e. oxidant is supplied through pipe 8 and primary fuel is supplied through pipe 10.

[0068] The equivalence ratio of primary fuel and oxidant has an impact on the flame composition, the flame temperature and the composition of the combustion gases. For example, flame temperatures peak at a equivalence ratio close to 1 and reduce as the equivalence ratio moves away from 1 (by either increasing or decreasing).

[0069] In hot oxygen mode the equivalence ratio is such that an excess of oxidant is provided to the injector in order to completely burn the primary fuel. In a preferred operation mode, the equivalence ratio is set and/or controlled to affect how aggressive the hot combustion gas jet 18 is. A lower equivalence ratio results in higher combustion gas jet temperatures and higher momentum of the combustion gas jet. However, decreasing the equivalence ratio to levels below 5 risks creating a combustion environment in inner combustion chamber 23 that could overheat and damage the injector 2. Therefore, it is preferred to set the equivalence ratio to values of 5 and more. A higher equivalence ratio results in lower combustion gas temperature and lower combustion gas jet momentum.

[0070] Additionally, an auxiliary fuel 11, for example natural gas, propane or another vaporized petroleum gas, may be fed through the auxiliary fuel pipe 12. Liquid fuels such as ethanol, fuel oils or bio-oils can also be used as auxiliary fuel. In the embodiment of figure 2 the auxiliary fuel 11 leaves the auxiliary fuel pipe 12 close to the outlet 20 of the oxidant supply duct 10. The hot combustion gas jet 18 flowing through outlet 20 entrains and reacts with the auxiliary fuel 11 before the resulting gas mixture is injected into the liquid metal 6 in furnace 1 where it provides heat and, depending on its composition, oxygen for oxidation which can be for example decarburization or desulphurization

[0071] Preferably, the auxiliary fuel supply is adjustable in an axial direction so that the velocity of the auxiliary fuel 11 can be increased or decreased.

[0072] As described above, the auxiliary fuel 11 will combust with the oxygen-rich combustion gas 18. In the following the auxiliary equivalence ratio is the ratio of oxygen provided to the injector 2 to the amount of oxygen required to completely burn both the primary fuel 7 and the auxiliary fuel 11.

[0073] According to a preferred embodiment the auxiliary equivalence ratio is chosen and/or controlled to be equal to or more than 1.0. For an auxiliary equivalence ratio value of 1.0, exactly enough auxiliary fuel will be provided to fully burn the remaining oxygen in the hot combustion gas jet 18. For auxiliary equivalence ratio values above 1, the amount of auxiliary fuel provided will be fully burned by the hot combustion gas jet, leaving some oxygen available for reaction in the furnace 2.

[0074] The inventive method comprises various operation modes of the injector. For example, the furnace can be heated up at a controlled rate to a specified temperature. In another mode the furnace temperature is maintained at a certain setpoint. Or the composition of the hot combustion gas jet shall be chosen such that sufficient oxygen is provided to the furnace for oxidation of the liquid material in the furnace or chosen to operate in a reducing mode.

[0075] Preferably, the invention allows to adjust the combustion conditions and the composition and characteristics of the generated hot combustion gas jet by supplying the control system with a furnace temperature setpoint or by directly setting the oxidant flow rate and/or the primary fuel flow rate and/or the auxiliary fuel flow rate. Preferably, the control system and/or the control algorithm set, change and/or control specific parameters to achieve the desired goal.

[0076] For example, when the temperature in the furnace 2 shall be increased, the firing rate of the injector 2 is increased. This is achieved by increasing the oxidant flow rate through oxidant supply duct 10 and increasing the flow of the primary fuel 7 and/or the auxiliary fuel 11. Preferably, first the oxidant flow rate is increased and then the primary and/or auxiliary flow rate is increased. Of course, for decreasing the furnace temperature these steps apply mutatis mutandis.

[0077] According to another example, the equivalence ratio is decreased when a more intense gas combustion jet is desired or more heat is to be delivered. A decrease of the equivalence ratio results in an increase of the internal flame temperature, that is the flame temperature in the inner combustion chamber 23, and an increase of the momentum of the hot combustion gas jet 18. This is preferably achieved by keeping the oxidant flowrate 10 stable and constant while the primary fuel flowrate is increased. The auxiliary fuel flowrate is preferably decreased in order to maintain the amount of excess oxidant.

[0078] The invention can also be used for oxidation of a liquid material. For melt oxidation e.g. decarburization excess oxygen has to be passed through the liquid material. According to the invention, this is achieved by decreasing the amount of auxiliary fuel while holding the oxidant flow and the primary fuel flow constant. This results in more oxygen than can be combusted with the available primary fuel and auxiliary fuel. The "leftover" oxygen reacts with the liquid material, i.e. with the melted furnace feed material, to decarburize it. Should the furnace temperature change as the oxygen reacts with the liquid material, the firing rate of the injector can be adjusted as described above in order to maintain the furnace temperature at the desired setpoint.

[0079] In another preferred embodiment a shutdown routine is carried out when the injector shall be stopped. The following sequence of actions is preferably carried out:

1. The primary fuel flow 7 is stopped. Fuel leftovers in the injector may subsequenly be purged out of the injector at a controlled rate using air, nitrogen or another gas.
2. The flow of purge air 13 through purge tuyere 14 is initiated. The purge air flows at a predetermined flowrate in order to purge the injector outlet 22.
3. When there is no flame anymore, the oxidant flow 9 through oxidant supply duct 10 is stopped. The existence/non-existence of a flame may for example be registered by means of a flame scanner.
4. The control system moves to standby mode and continues to purge the injector with the purge air 13.

[0080] In case of an emergency shutdown an advantageous operation mode is to stop the flows of oxidant, primary fuel and auxiliary fuel, start the purge air flow 13 and in addition pass purge air at a controlled rate through the primary fuel pipe 8 in order to quickly extinguish the flame.

[0081] The injector is preferably provided with safety and alarm devices to ensure a safe operation. The safety devices include but are not limited to a hardwired circuit of switches that instantly stops operation when any device in the circuit is triggered, a set of software alarms that alert operators to potential operational issues and a set of software shutdowns that automatically stop the system when critical values have been reached for a sufficient amount of time. When an alarm is triggered, the operator may be notified via a pop up window and/or via a text display. Alarms including the alarm type and trigger date and time may be recorded.

Reference list

[0082]

1	Furnace
2	Injector
3	Feed
4	Exhaust duct
5	Tap hole
6	Liquid metal
7	Primary fuel
8	Fuel pipe
9	Oxidant
10	Oxidant supply duct
11	Auxiliary fuel
12	Auxiliary gas pipe
13	Purge gas
14	Purge tuyere
15	Cooling water
16	Cooling tuyere
18	Hot combustion gas jet
19	Opening
20	Outlet
21	Outlet
22	Injector outlet
23	Inner combustion chamber

Claims

1. Method for heating, melting and/or refining a material in a furnace wherein the material is at least partially liquid, comprising the steps of:

combusting a primary fuel with a gaseous oxidant in an injector comprising an inner combustion chamber and an injector outlet,
combusting the primary fuel with the gaseous oxidant at an oxygen-fuel equivalence ratio between 5 and 20 in the inner combustion chamber to produce a hot combustion gas jet containing gaseous oxidant,
and passing the hot combustion gas jet through the injector outlet and into the liquid material.

2. Method according to claim 1, **characterized in that** the injector outlet is arranged below the surface of the liquid material.

3. Method according to claim 1 or 2, wherein the inner combustion chamber is provided with an inner nozzle.

4. Method according to any of the preceding claims, wherein the injector outlet is provided with or designed as an outer nozzle.

5. Method according to any of the preceding claims, **characterized in that** the oxidant has an oxygen concentration of at least 30% by volume, at least 50% by volume, at least 80% by volume or at least 90% by volume.

6. Method according to any of the preceding claims, **characterized in that** the equivalence ratio is adjusted such that the produced hot combustion gas jet is a choked flow.

7. Method according to any of the preceding claims, **characterized in that** an auxiliary gas flow is entrained into the hot combustion gas jet before the hot combustion gas jet is introduced into the liquid material.

8. Method according to claim 7, **characterized in that** the auxiliary gas flow is an auxiliary fuel, a refining gas, an inert gas or an oxidizing gas.

9. Method according to any of claims 7 or 8, **characterized in that** the resulting mixture of the hot combustion gas jet and the auxiliary gas flow has oxidizing, stoichiometric or reducing properties.

10. Method according to any of the preceding claims, **characterized in that** the injector is provided with a cooling tuyere and that a cooling fluid, in particular water, is passed through the cooling tuyere.

11. Method according to any of the preceding claims, **characterized in that** a purge tuyere is provided and that a purge gas is passed through the purge tuyere and that the purge gas purges the injector outlet and / or the outlet of the inner combustion chamber.

12. Method according to any of the preceding claims, **characterized in that** the primary fuel is the most inner flow surrounded by the oxidant flow.

13. Method according to any of the preceding claims, **characterized in that** the liquid material is a slag, a metallic melt, waste or a vitrifiable material, such as glass.

14. Method according to any of the previous claims, **characterized in that** the injection point of the auxiliary fuel into the hot combustion gas jet and/or the inclination angle between the auxiliary fuel and the hot combustion gas jet is adjustable.

15. Method according to any of the previous claims, **characterized in that** the primary fuel and/or the auxiliary gas flow are selected from the group of hydrocarbons, hydrogen, carbon-monoxide and/or mixtures thereof.

Fig. 1a:

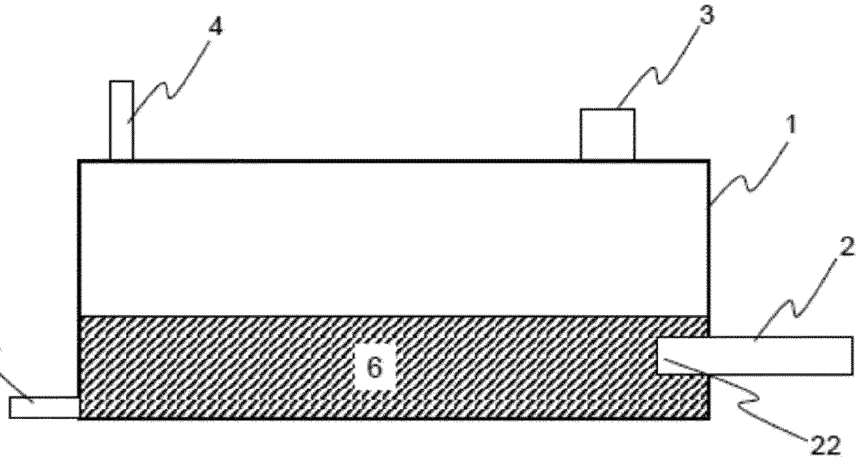


Fig. 1b:

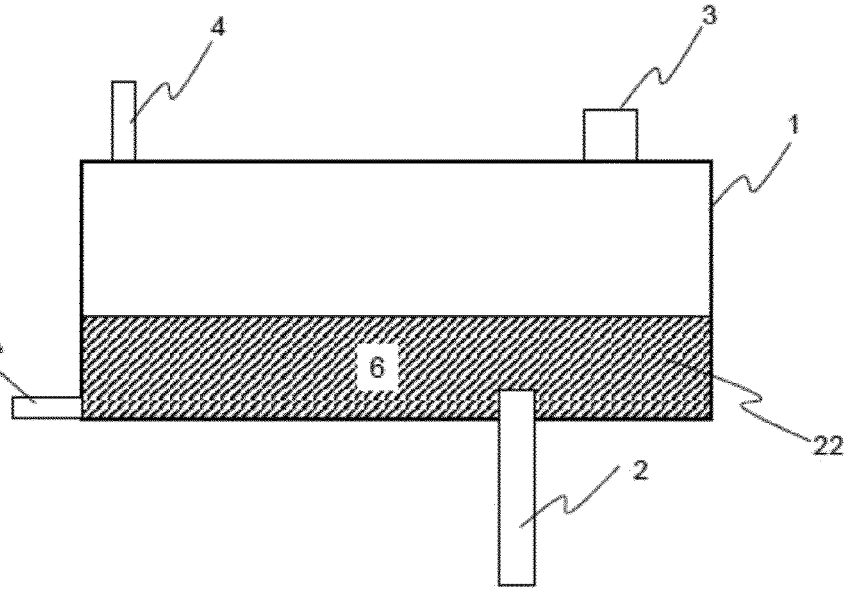
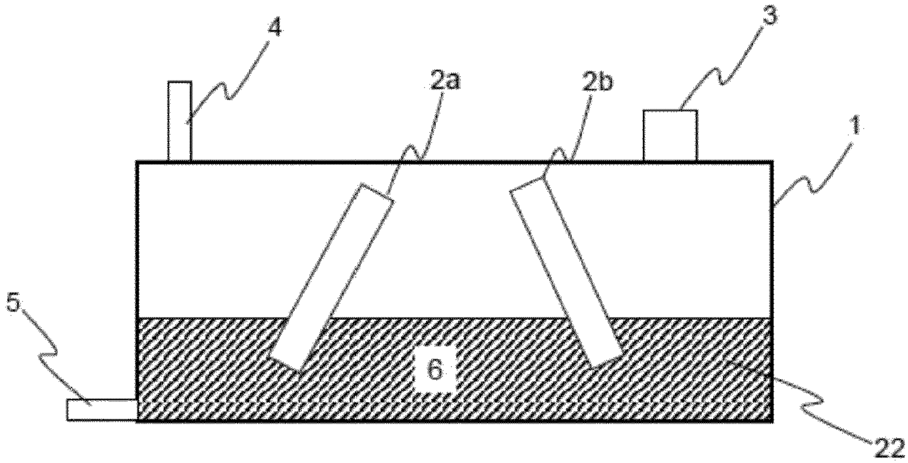


Fig. 1c:



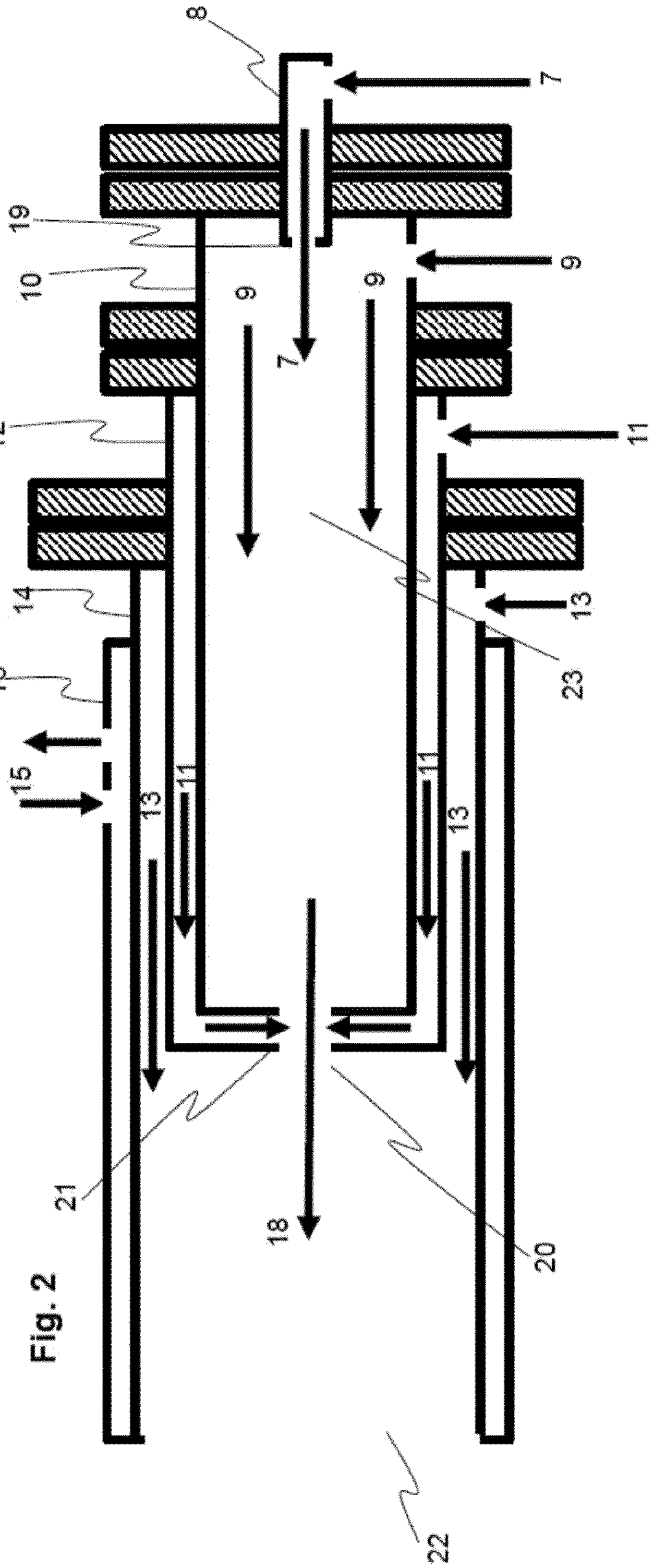


Fig. 2

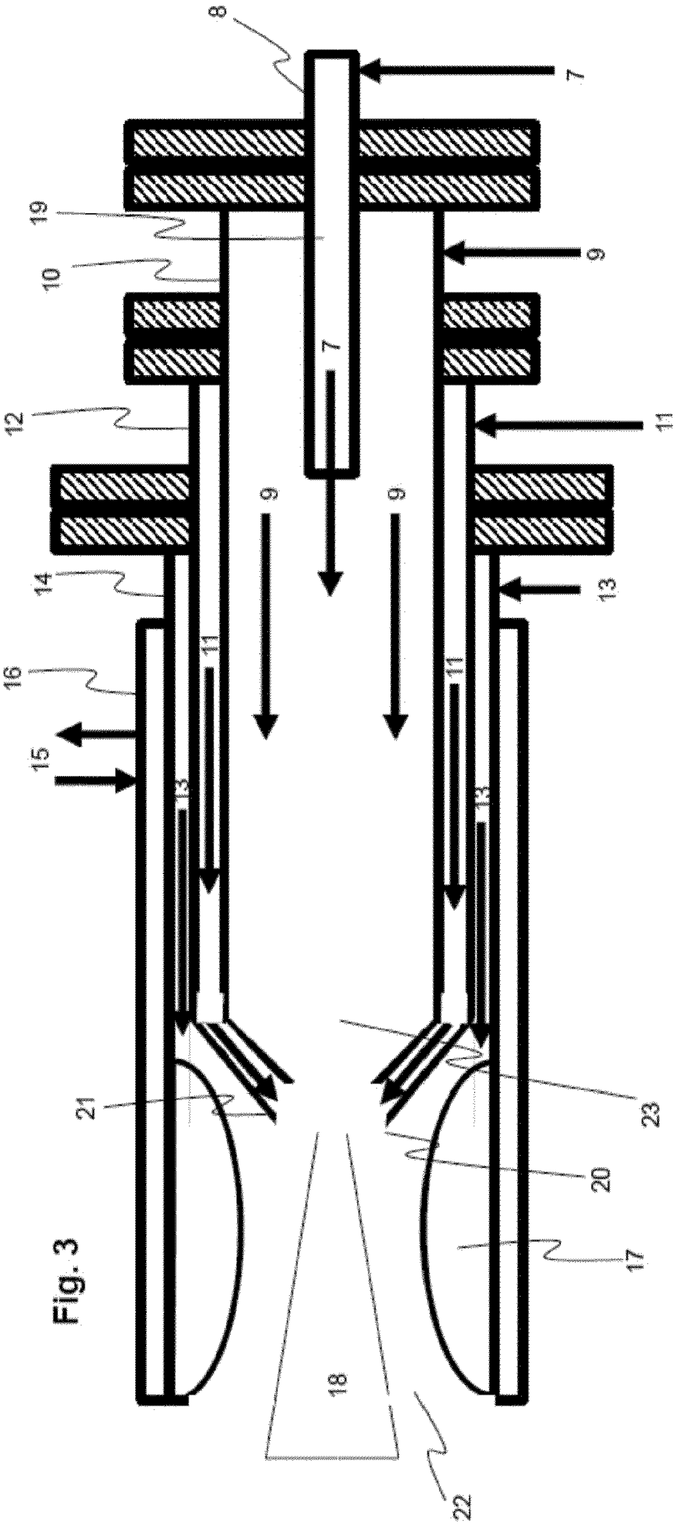


Fig. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 23 02 0068

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	EP 2 047 001 B1 (PRAXAIR TECHNOLOGY INC [US]) 26 October 2011 (2011-10-26) * columns 18,67; claim 1; figures 1,2,11-15 * -----	1-15	INV. F27D3/16 F27D99/00
Y	EP 0 565 196 A2 (SHELL INT RESEARCH [NL]) 13 October 1993 (1993-10-13) * claim 1; figures 1-3 * -----	1-15	
A	EP 0 939 059 A2 (AIR LIQUIDE [FR]) 1 September 1999 (1999-09-01) * the whole document * -----	1-15	
A	US 4 986 199 A (KOMENO MINORU [JP] ET AL) 22 January 1991 (1991-01-22) * the whole document * -----	1-15	

TECHNICAL FIELDS SEARCHED (IPC)

F27D
C21C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	11 July 2023	Gavriliu, Alexandru

CATEGORY OF CITED DOCUMENTS

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 23 02 0068

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The members are as contained in the European Patent Office EDP file on
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11-07-2023

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2047001 B1	26-10-2011	AT 530673 T	15-11-2011
		AU 2007265469 A1	03-01-2008
		BR PI0700468 A	19-02-2008
		CA 2654912 A1	03-01-2008
		CN 101096718 A	02-01-2008
		EP 2047001 A1	15-04-2009
		ES 2371200 T3	28-12-2011
		JP 5346803 B2	20-11-2013
		JP 2009542909 A	03-12-2009
		KR 20090023734 A	05-03-2009
		NO 342338 B1	07-05-2018
		RU 2009102641 A	10-08-2010
		US 2008000325 A1	03-01-2008
		WO 2008002585 A1	03-01-2008
		ZA 200810241 B	30-09-2009
EP 0565196 A2	13-10-1993	CA 2093601 A1	10-10-1993
		DE 69301328 T2	27-06-1996
		EP 0565196 A2	13-10-1993
		JP H0611117 A	21-01-1994
		US 5201650 A	13-04-1993
EP 0939059 A2	01-09-1999	BR 9911534 A	13-03-2001
		CA 2261454 A1	26-08-1999
		EP 0939059 A2	01-09-1999
		ES 2312201 T3	16-02-2009
		JP 4267121 B2	27-05-2009
		JP H11311403 A	09-11-1999
		JP 2008157622 A	10-07-2008
		US 5954498 A	21-09-1999
		US 6171100 B1	09-01-2001
US 4986199 A	22-01-1991	EP 0432293 A1	19-06-1991
		US 4986199 A	22-01-1991

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82