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THE FLAME OF WHICH CAN BE VARIED,
AND METHOD OF IMPLEMENTING IT**(86) PCT No.: **PCT/FR07/51598**

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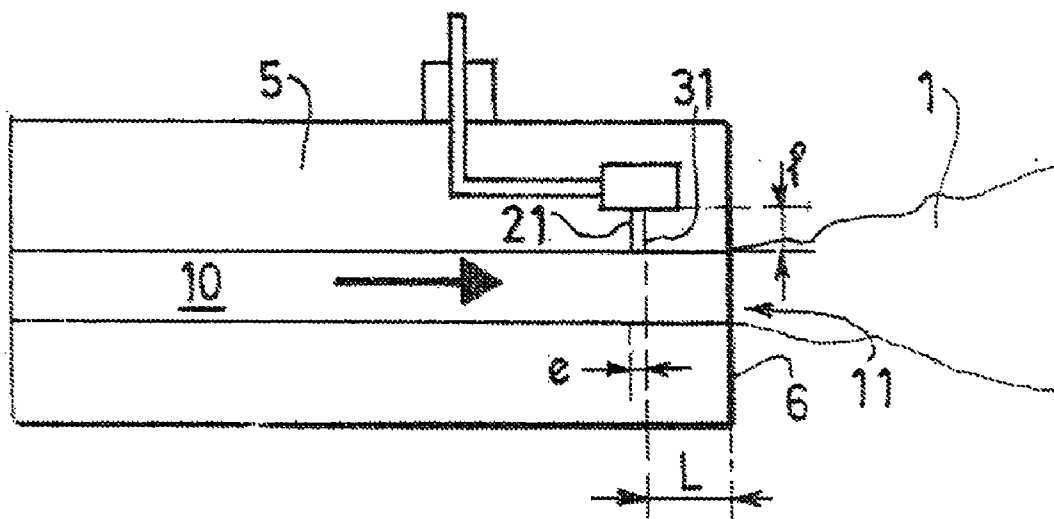
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Des Procédés Georges Claude,
Paris (FR)(21) Appl. No.: **12/307,737**(22) PCT Filed: **Jul. 5, 2007**

Burner comprising at least one passage for injecting at least a primary jet, such as a jet of oxidant and/or fuel and/or of a premix of oxidant and fuel, and means of injecting at least one secondary jet of fluid opening into said passage, the interaction between the primary jet and the at least one secondary jet making it possible to vary the direction and/or the size of the flame. Use of said burner for heating a charge with the variable-direction and/or variable-size flame.



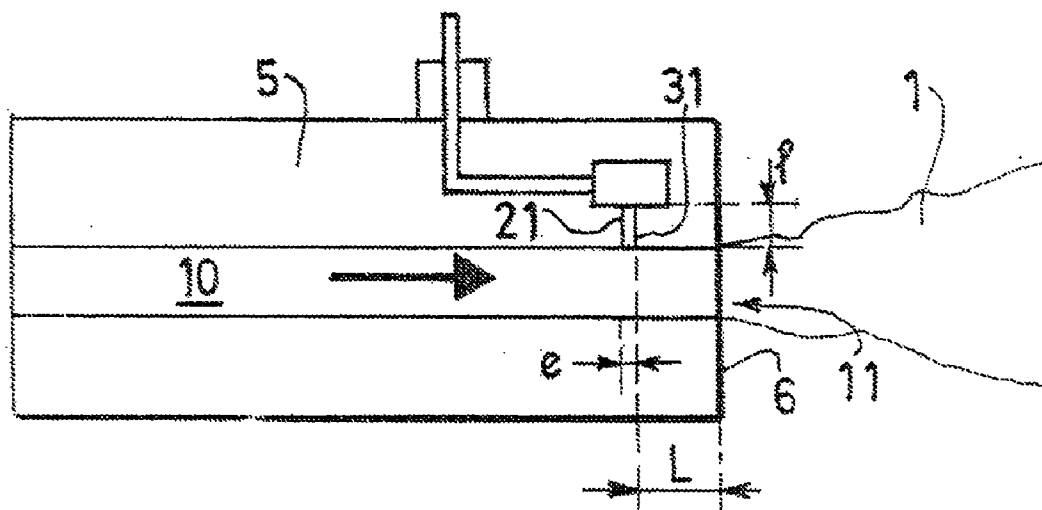


FIG. 1

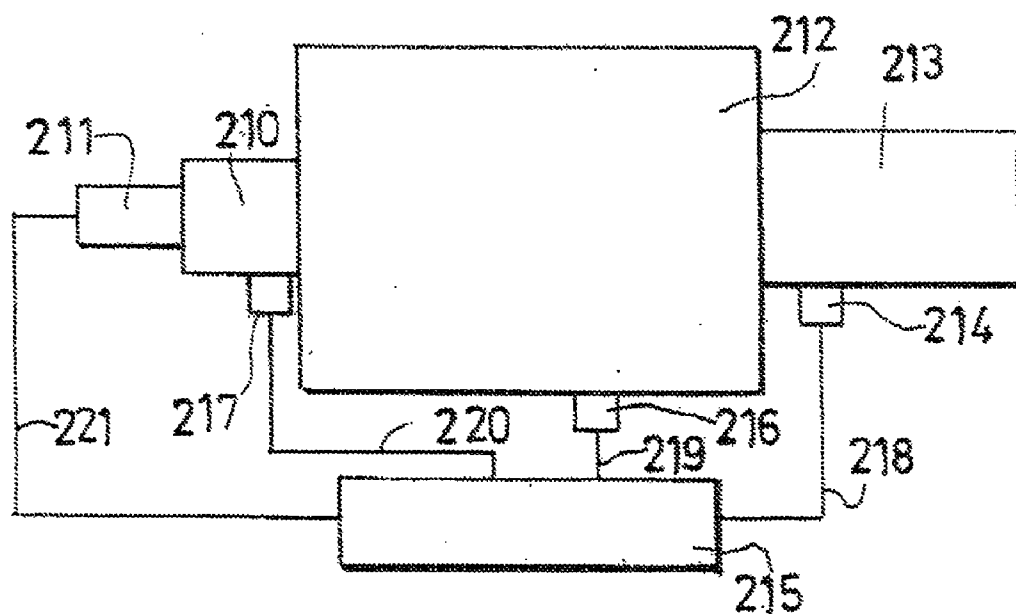


FIG. 2

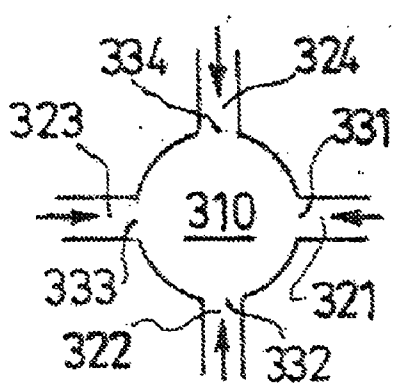


FIG. 3A

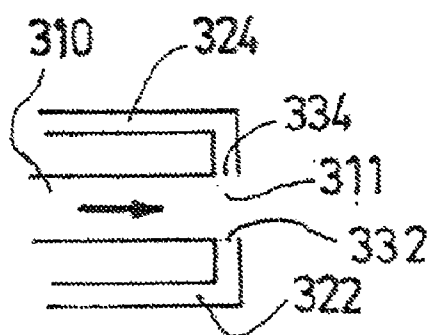


FIG. 3B

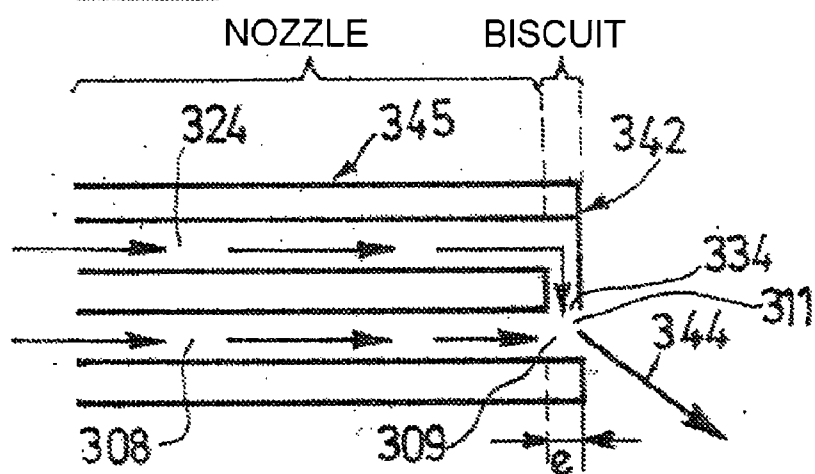


FIG. 3c

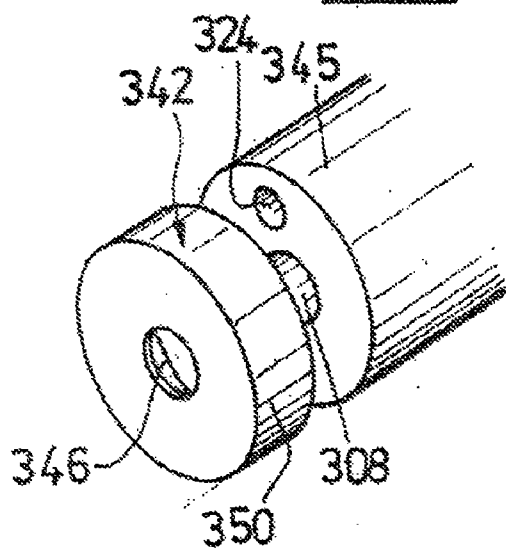


FIG. 3d

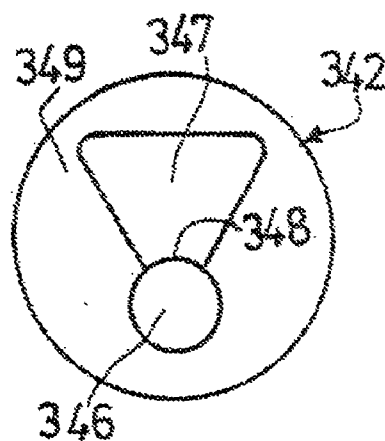


FIG. 3e

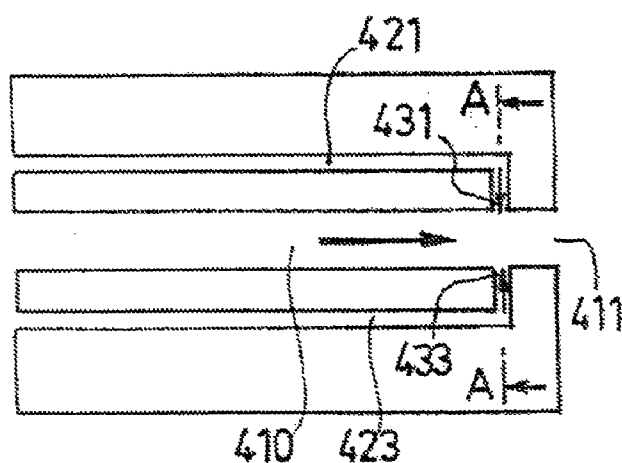


FIG. 4a

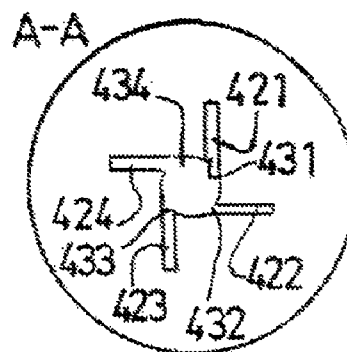


FIG. 4b

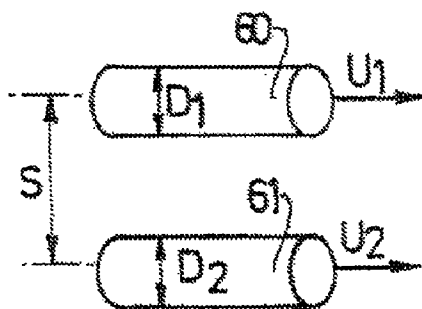


FIG. 5a

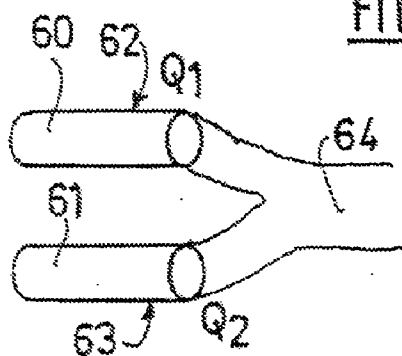


FIG. 5b

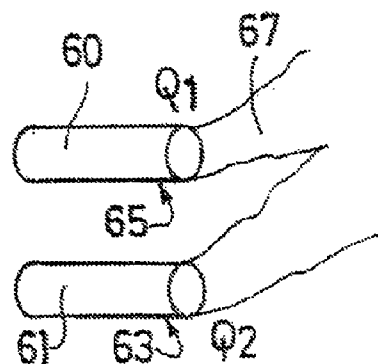
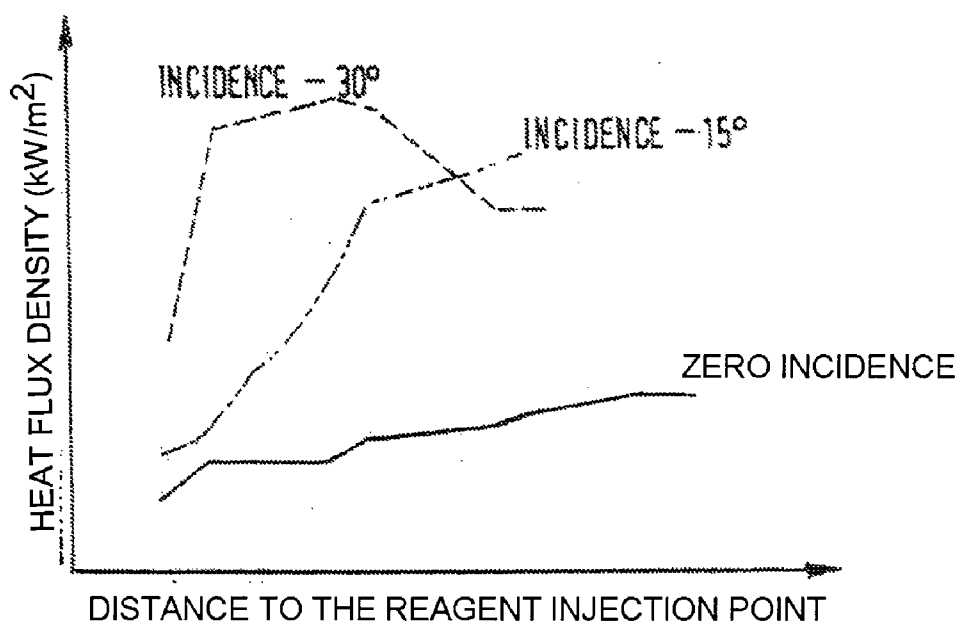
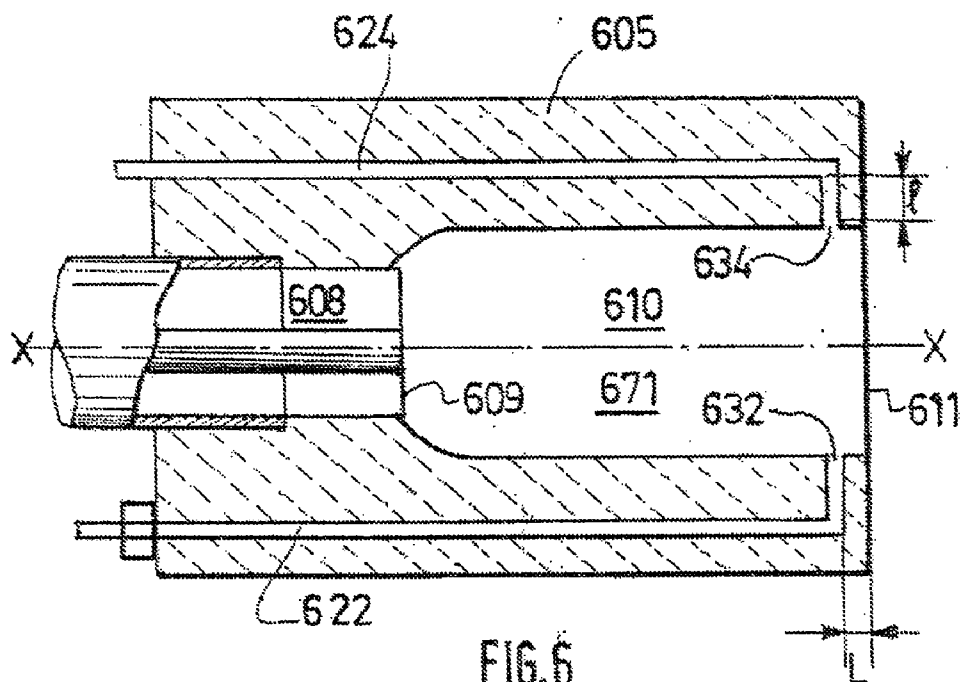
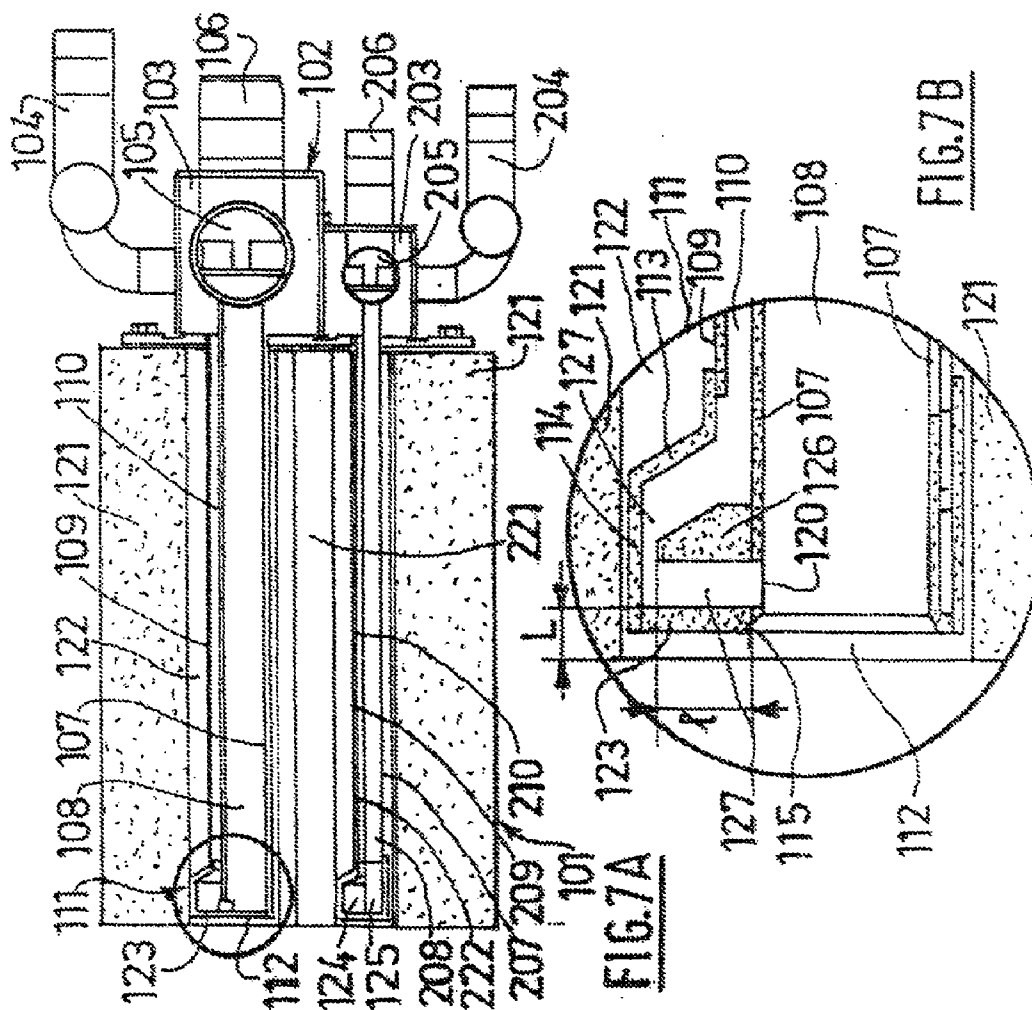
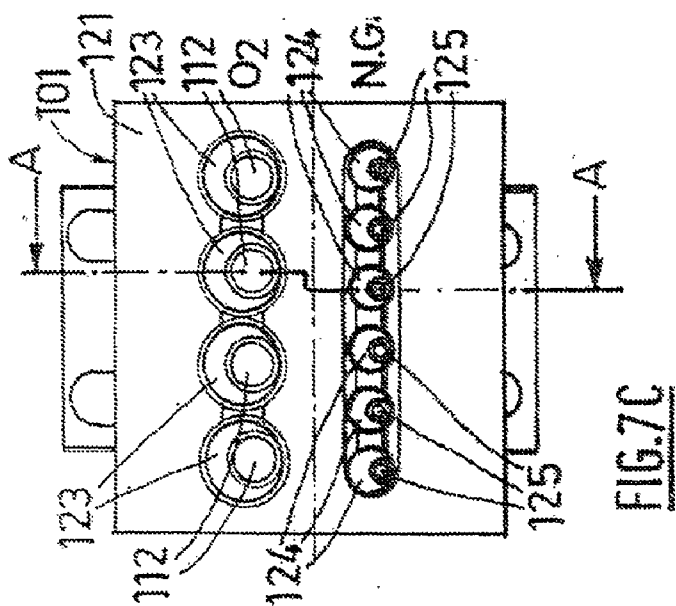


FIG. 5c





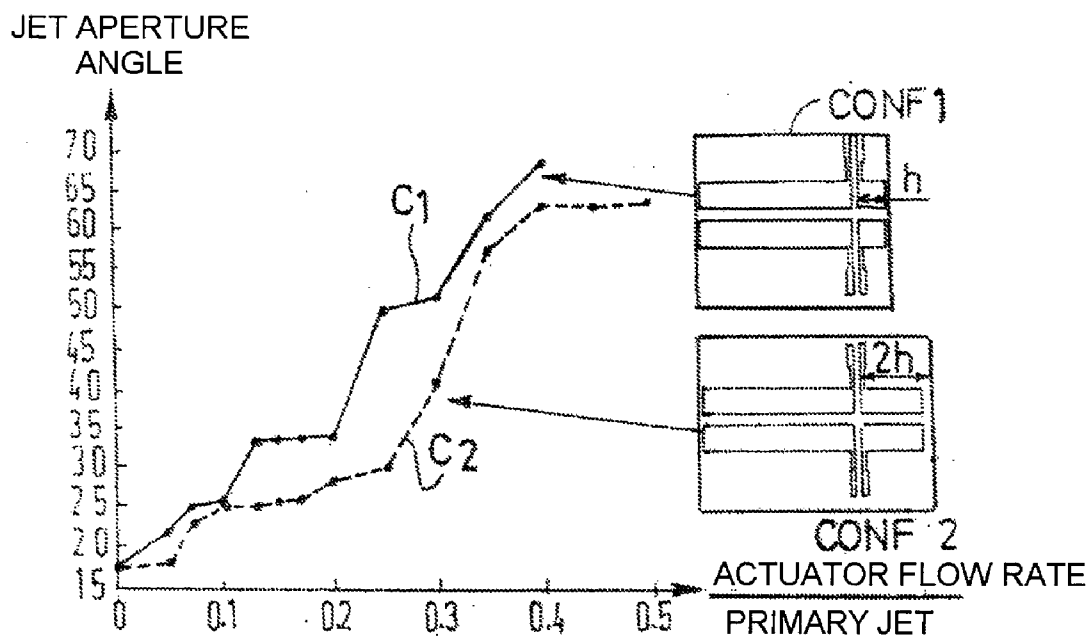


FIG. 9A

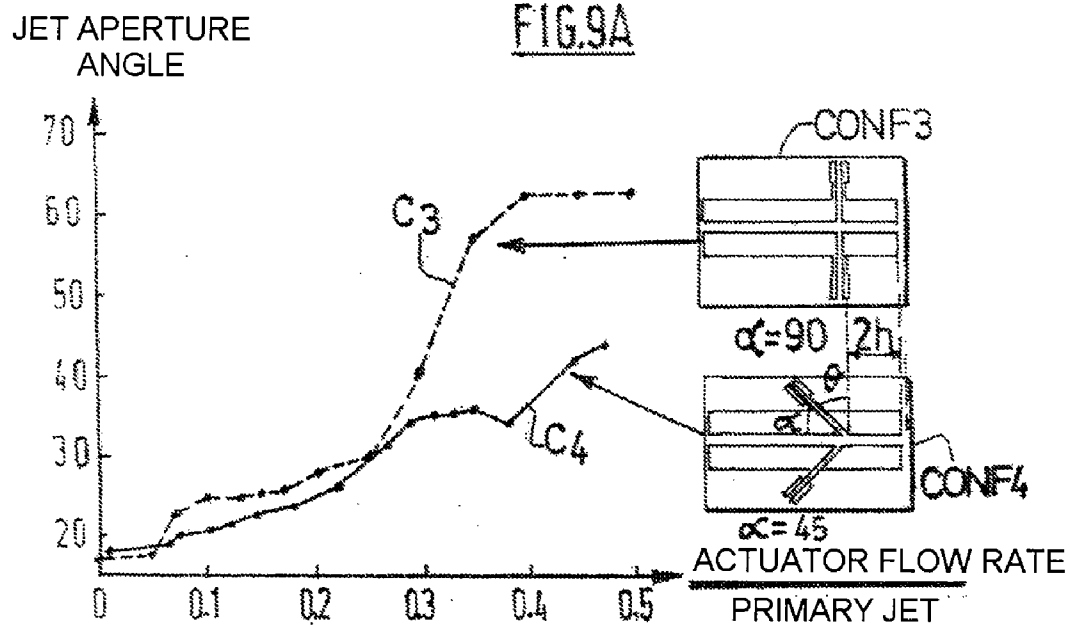
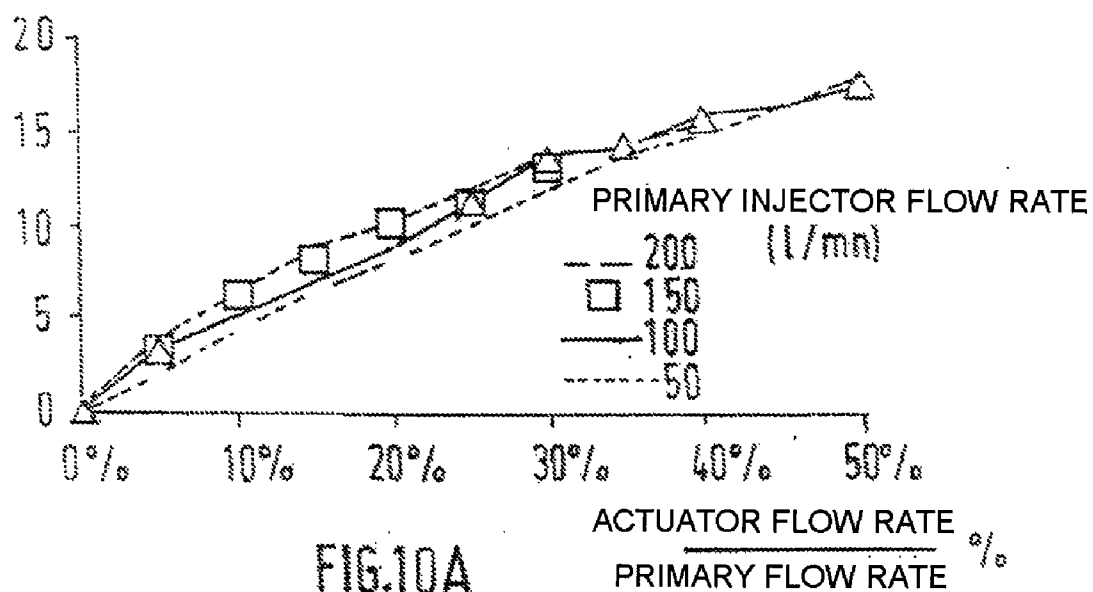
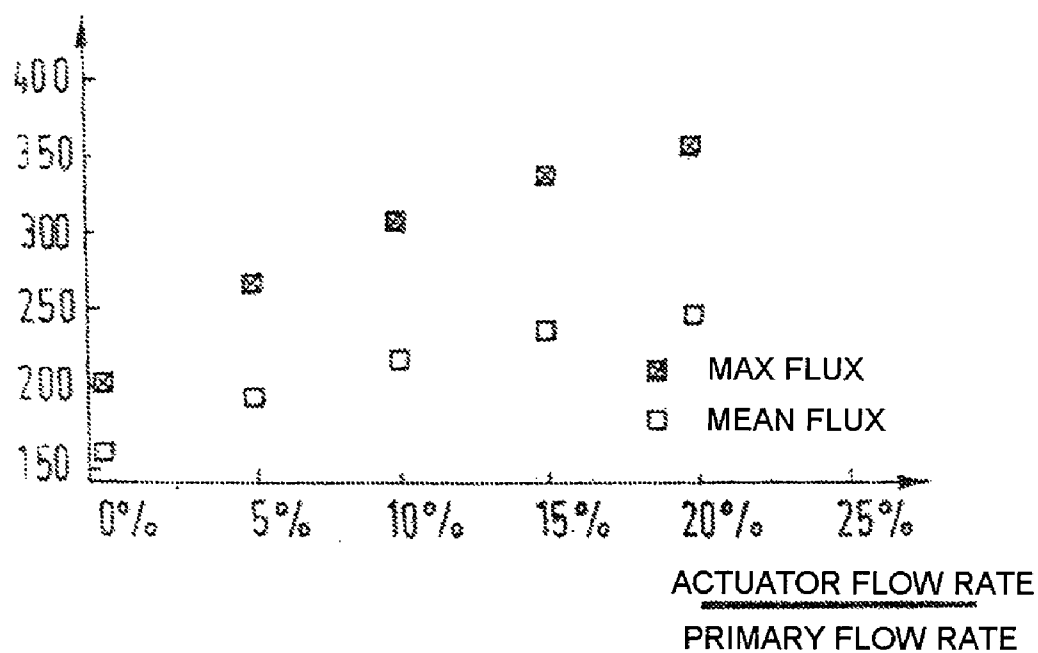


FIG. 9B



TRANSFER OF HEAT TO A CHARGE



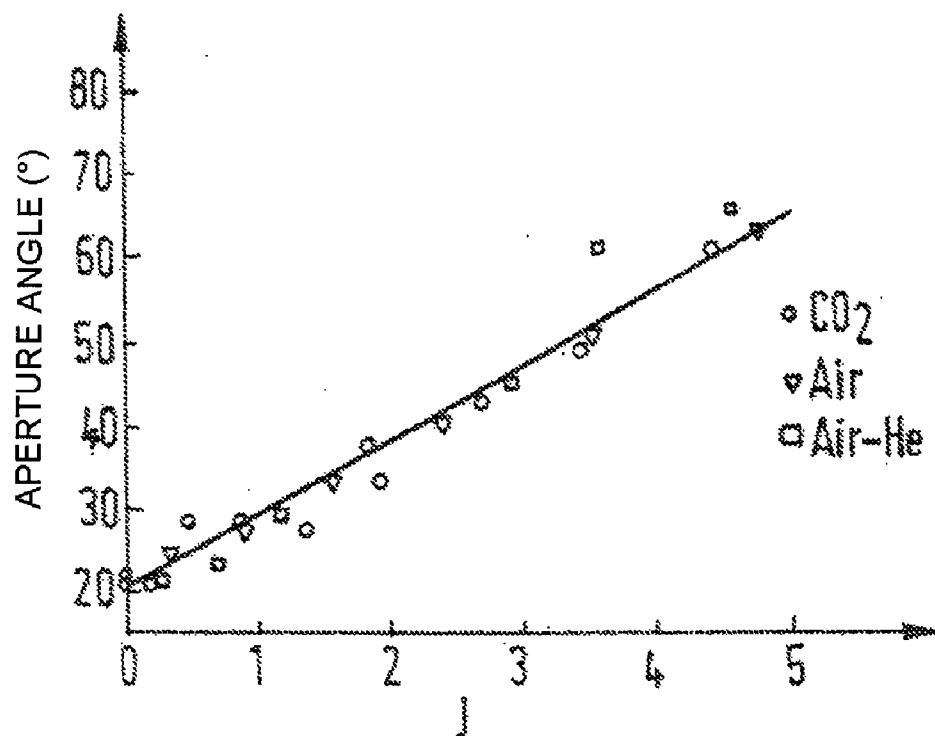


FIG.11

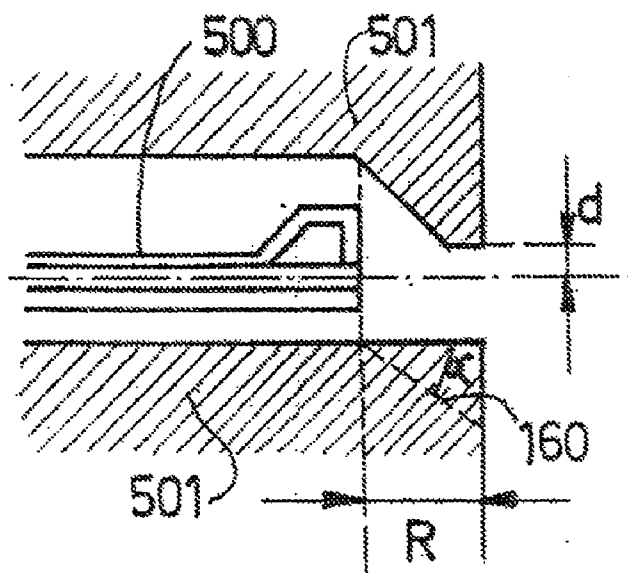


FIG.16

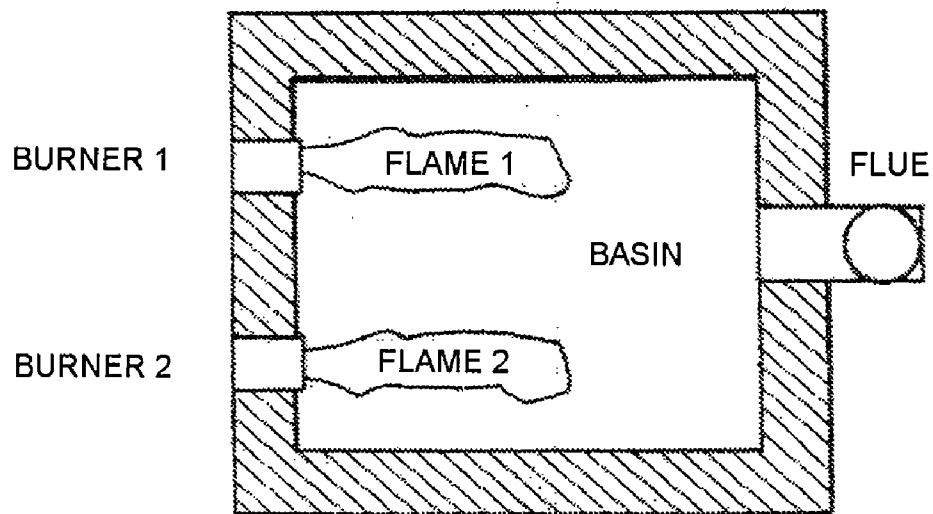


FIG. 12A

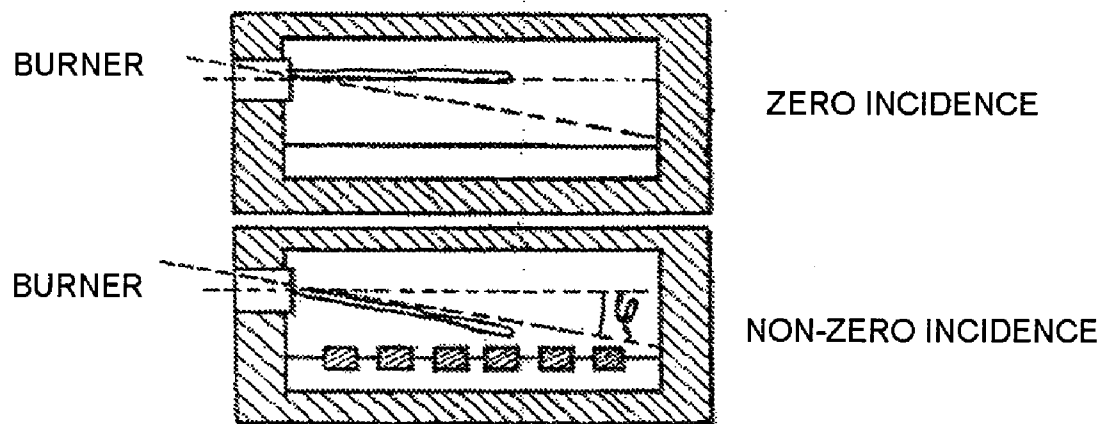


FIG. 12B

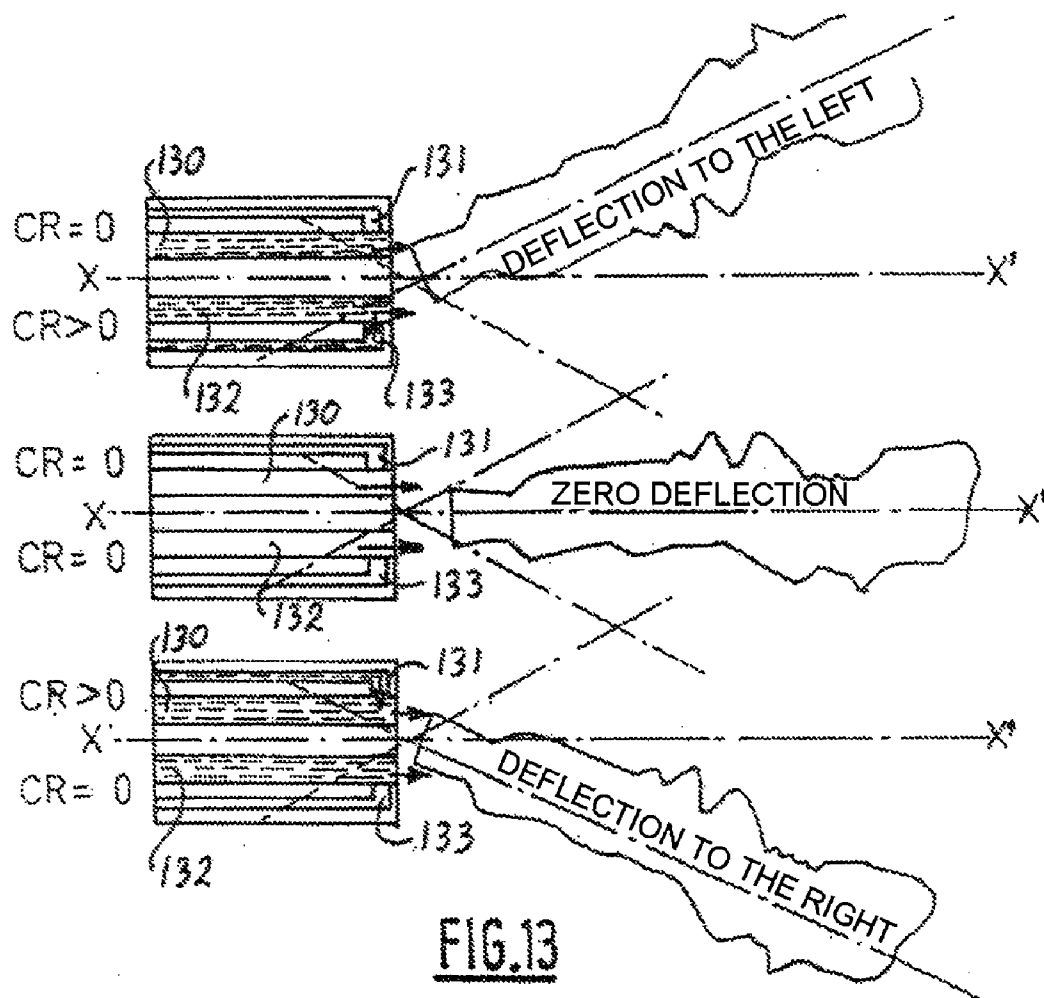


FIG.13

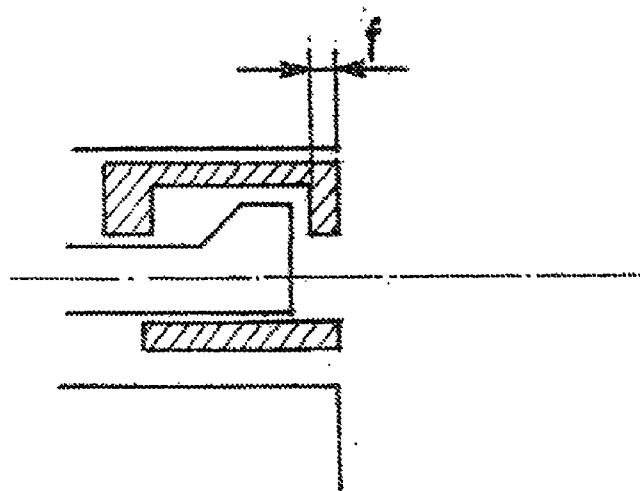


FIG.17

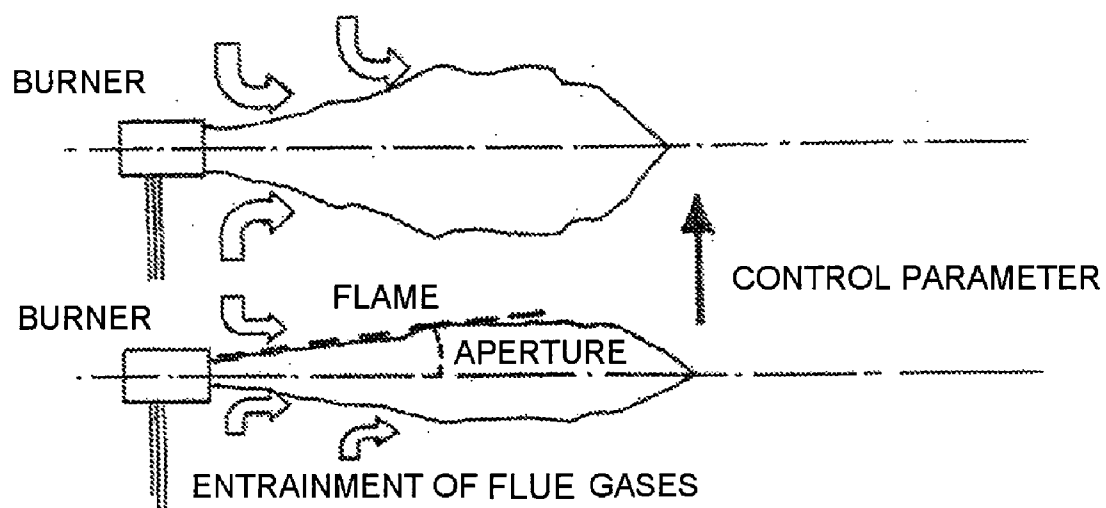


FIG.14

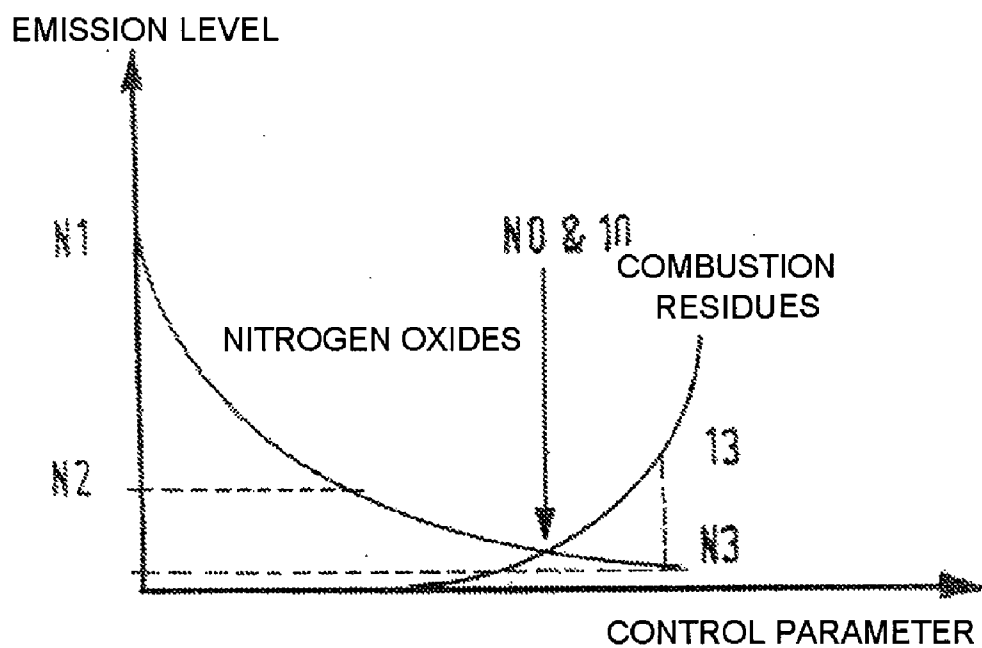


FIG.15

**BURNER THE DIRECTION AND/OR SIZE OF
THE FLAME OF WHICH CAN BE VARIED,
AND METHOD OF IMPLEMENTING IT**

[0001] The present invention relates to a burner that makes it possible to vary the direction and/or the aperture of the flame, said burner comprising at least one channel for injecting at least one main or primary jet and at least one channel for injecting an actuating or secondary jet. The primary jet is typically a jet of oxidant and/or of fuel and/or of an oxidant-fuel premix.

[0002] It also relates to the use of said burner to vary the direction and/or the aperture of a flame. It also relates to a method of heating a charge using this burner in which the direction and/or the aperture of the flame is varied.

CONTEXT OF THE INVENTION

[0003] Most ovens or industrial boilers use burners that operate in non-premixed combustion mode, that is, a mode in which the oxidant and the fuel arrive separately as far as the place of combustion. The fuel and the oxidant are then mixed, in part (locking of the flame in a refractory port or prechamber block) or in total, inside the combustion chamber. This mixing is controlled by the design and operating parameters of the burner, and determines the performance characteristics of the burner (region of operation, transfer of heat to the charge to be heated, emission of pollutants, etc.). In practice, the conditions of interaction of the various jets or flows of oxidant and fuel implemented by the burner are determined when the burner is designed. Once the burner is created, only the operating conditions can be modified. This also applies for so-called "premix" burners in which the oxidant/fuel mixture is produced in the burner upstream of the firebox. The reagents are then injected by a single tube.

[0004] The conditions of operation of the industrial combustion methods can change over time. Such is naturally the case with intermittent methods but is also the case with continuous methods for which the characteristics of the charges to be heated can vary according to production requirements. It is more generally the case for any production unit subject to aging or sensitive to the variable conditions of their environment.

[0005] To adapt the performance characteristics of the burners to variable operating conditions, the operator more often than not has only two parameters: the operating power of the burner and the oxidant excess level (overstoichiometry of oxygen).

[0006] Certain combustion technologies allow discrete and very limited numbers of operating modes. Such is, for example, the case with so-called "dual impulse" burners which use two different injection systems depending on whether the burner is to be operated with low or high impulse. These two operating modes make it possible to increase the region of operation or use of the burner or to modify the length of the flame for a given operating point.

[0007] However, the modifications of the point and/or of the operating mode are more often than not inadequate for optimizing the performance characteristics of the burners or of the methods that use these burners in all conditions. For example, the cyclic introduction into an oven for melting matter that is solid at ambient temperature will lead the operator (or the regulation system) to increase the heating power so as to obtain the fastest possible melting (in order to increase

productivity), but without in any way degrading the charge being melted (quality of the product) or overheating the oven (life span of the equipment). This trade-off between productivity and quality and/or lifetime depends in particular on the capacity of the system to transfer the energy to the charge, avoiding local overheating of the latter or of the refractories of the oven. This trade-off is reflected in a melting time below which any gain in productivity will be counterbalanced by a degradation of the quality of the product or by a reduction in the lifetime of the oven. WO-A-9744618 discloses a burner comprising a central jet of fuel surrounded first by a plurality of primary jets of oxidant, then a plurality of secondary jets of oxidant. It is thus possible in operation to modify the position of the flame.

[0008] However, the maximum deflection of the flame is in practice limited to approximately 15° from the median position to the extreme position (30° at most, in all), not allowing the incident flame to sweep a wide surface of a charge, and the construction of the corresponding burner is relatively heavy because there is a need for a plurality of orifices for the primary jets of oxidant and a plurality of orifices for the secondary jets of oxidant.

[0009] Furthermore, the properties of the flame change according to its position since the properties of the mixture vary with the angle of incidence (mixture "external" to the burner block), which induces a variation in the polluting emissions, in the quality of radiative transfer (luminosity of the flame) and in the length of the flame (position of the heat-relieving peak).

SUBJECT OF THE INVENTION

[0010] The subject of the invention is a burner allowing for a wide variation in the direction and/or the aperture of the flame, and without having to interrupt the operation of the burner or of the oven. Another aim of the invention is to allow such a variation with an optimized robust burner.

BRIEF DESCRIPTION OF THE INVENTION

[0011] The invention proposes controlling the direction and/or the aperture of a flame by the interaction of a jet of fluid (called primary jet or main jet) with at least one other jet of fluid (called secondary jet or actuating jet), the interaction between the jets occurring inside means delivering this main jet (tube, refractory port, etc.) before said main jet opens out onto said means.

[0012] The burner according to the invention comprises a passage for directing a primary jet to a main outlet aperture. The primary jet is typically a jet containing fuel, oxidant or else a fuel-oxidant premix. The burner also comprises at least one secondary duct for the injection of a secondary jet. The fluid injected by the secondary jet may or may not belong to the same category as the fluid from the primary jet. The fluid injected by the secondary jet may or may not be different from the fluid from the primary jet. The secondary jet can in particular be an inert jet such as steam or combustion products, such as recycled flue gases.

[0013] The at least one secondary duct opens out on the passage of the primary jet through a secondary aperture situated upstream of the main outlet aperture. The secondary duct is positioned relative to the passage so that, at the point of interaction (center of inertia of the imaginary surface common to both flows) between the secondary jet from this secondary duct (hereinafter called corresponding secondary jet)

and the primary jet, the angle θ between the axis of the corresponding secondary jet and the plane perpendicular to the axis of the primary jet is greater than or equal to 0° and less than 90° , preferably from 0° to 80° , also preferably from 0° to 45° . When the angle $\theta=0^\circ$, which is preferable, the axis of the corresponding secondary jet is situated in a plane perpendicular to the axis of the primary jet.

[0014] The at least one secondary aperture is spaced apart from the main aperture by a distance L less than or equal to ten times the square root of the section s of the main outlet aperture, preferably $L \leq 5\sqrt{s}$, also preferably $L \leq 3\sqrt{s}$.

[0015] Known from "Proceedings of FEDSM'02 Joint US ASME-European Fluid Engineering Division Summer Meeting of Jul. 14-18, 2002" and the article "Experimental and numerical investigations of jet active control for combustion applications" by V. Faivre and Th. Poinso, *Journal of Turbulence*, Volume 5, No. 1, March 2004, p. 25, is how to use a specific configuration of four secondary jets around a main jet to stabilize a flame thanks to the interaction between the secondary jets and the primary jet. A wider angle of dispersion is observed.

[0016] According to the invention, the burner is provided with means for controlling the impulse of the at least one secondary jet.

[0017] As explained in detail hereinbelow, the invention thus makes it possible to vary the direction and/or the aperture of the flame obtained from the burner by modifying the impulse of at least one secondary jet with said means.

[0018] Preferably, the means for controlling the impulse of the at least one secondary jet are means making it possible to control the ratio between the impulse of the secondary jet and the impulse of the primary jet. The invention thus makes it possible to produce a wide variation in direction and/or aperture of a flame without using mechanical means, potential sources of malfunction, in particular in hostile environments, such as fire boxes with high temperature and/or polluted or corrosive atmosphere.

[0019] The control means make it possible in particular to actively or dynamically control the impulse of the at least one secondary jet, that is, they make it possible to vary the pulse or pulses without interrupting the operation of the burner/without interrupting the flame. The appliance according to the invention thus allows for an equally dynamic variation of the direction and/or the aperture of the flame.

[0020] Preferably, the number of secondary jets interacting with the primary jet to obtain the desired effect on the flame will be minimized so as to limit the complexity and the cost of manufacturing the burner but also the complexity and the cost of the system for feeding and regulating the flow rates of the fluids if the secondary jets are driven independently. For example, a single-direction effect can be obtained with a single secondary jet.

[0021] Among the terms used in this description, some deserve a more precise definition in the context of the invention in order to better delimit their scope:

[0022] The direction of a jet/of a flame is defined as being a unitary vector normal to the section of passage of the fluid/of the flame and oriented in the direction of flow, that is, from upstream to downstream.

[0023] The "thickness e " means the dimension of the secondary duct in the direction of flow of the primary jet (according to the arrow in FIG. 1). In the particular case of this FIG. 1, e therefore represents the diameter of the

secondary duct **21** at the level of the secondary aperture **31** since this secondary duct **21** is cylindrical in this example.

[0024] The "aperture" of a jet/of a flame designates, for a jet/a flame opening out into a cylindrical passage such as **10** in FIG. 1, the angle between the longitudinal axis of the passage and the generatrix at the surface of the jet/of the flame leaving the passage. In the absence of interaction with a secondary jet, the generatrix is inclined by 10 to 15° approximately relative to this axis, this incline possibly reaching 70° and more according to the invention (see FIG. 9A). By extension, the term aperture will designate the angle between the direction of flow in the passage, when the latter does not have a circular section, and the generatrix.

DETAILED DESCRIPTION OF THE INVENTION

[0025] The various characteristics of the embodiments of the burner according to the invention and its use will become more clearly apparent from the detailed description that follows, reference being given to the figures which represent, diagrammatically, exemplary embodiments, given by way of non-limiting example, and more particularly:

[0026] FIG. 1: theoretical diagram of a (premix) burner according to the invention for controlling a flame by jet interaction.

[0027] FIG. 2: regulation of a burner according to the invention mounted on a fire box.

[0028] FIGS. 3A and B: burner for controlling the direction of the flame, FIG. 3A being a transverse cross-section and FIG. 3B being a longitudinal cross-section of a burner comprising four secondary jets arranged respectively at 90° to each other and directed in perpendicular incidence to the direction of the primary jet.

[0029] FIGS. 3C, D and E: use of a biscuit to transform a nozzle with parallel primary and secondary jets into a burner according to the invention.

[0030] FIGS. 4A and B: longitudinal and transverse cross-section of a burner making it possible to control the aperture of a resultant jet.

[0031] FIG. 5: use of a burner to vary a flame by means of two jets (resultant), a jet of fuel and a jet of oxidant.

[0032] FIG. 6: "tube-in-tube" type burner provided with a refractory port.

[0033] FIGS. 7A, B and C: burner with separate jets.

[0034] FIG. 8: density of the heat flux of the flame according to the distance to the point of injection, with different incidences.

[0035] FIGS. 9A and B: embodiment variants of the control of the aperture of the flame.

[0036] FIGS. 10A and B: impact of a control parameter on the deflection of the flame and the transfer of heat to a charge.

[0037] FIG. 11: aperture angle of the flame according to the impulse ratio of the jets.

[0038] FIG. 12: an exemplary application of the inventive system to the heating of a charge with change of incidence of the flame.

[0039] FIG. 13: use of the invention to heat a charge by laterally displacing the flame.

[0040] FIG. 14: application of the variable aperture of a flame to the entrainment of the gases from an oven.

[0041] FIG. 15: level of emission of a flame according to a control parameter.

[0042] FIG. 16: protection of the end of a burner by a refractory port.

[0043] FIG. 17: protection of the end of the burner by a sleeve brick.

[0044] Hereinafter, the same reference numerals are used, on the one hand, to designate the primary jet and the passage in which it flows and, on the other hand, to designate the secondary jet or actuating jet and the corresponding secondary duct in which this secondary jet flows.

[0045] FIG. 1 represents a theoretical diagram of the method of controlling a flame in a burner according to the invention.

[0046] The burner comprises a passage 10 which makes it possible to direct the primary jet to a main outlet aperture 11.

[0047] The primary jet is directed by the passage 10 and interacts with the secondary jet obtained from the secondary duct 21 so as to create downstream of the outlet aperture 11 a flame 1 of direction and/or aperture different from the direction and/or aperture of the flame in the absence of secondary jet.

[0048] At least one secondary duct 21 for injecting a secondary jet opens out onto the passage 10 through a secondary aperture 31. This secondary duct 21 is positioned relative to the passage 10 so that, at the point of interaction between the corresponding secondary jet and the primary jet, the angle θ between the axis of the secondary jet 21 and the plane perpendicular to the axis of the primary jet 10 is greater than or equal to 0° and less than 90° ($\theta=0^\circ$ in FIG. 1).

[0049] The secondary aperture 31 is spaced apart from the main aperture 11 by a distance L, L being less than or equal to $10 \times \sqrt{s}$ (s =section of the main aperture 11). The distance L makes it possible to influence the impact of the secondary jets on the primary jet with respective identical impulses. For example, to maximize the directional effect, efforts will be made to minimize this distance. As a general rule, for oxygen burners and developed powers of the order of a megawatt, the length L is less than or equal to 20 cm, more preferably less than or equal to 10 cm.

[0050] The burner comprises means for controlling the impulse of the secondary jets. These means can usefully be chosen from the devices for controlling mass flow, for controlling head loss, for controlling passage section, but also devices for controlling temperature, for controlling the chemical composition of the fluid or for controlling pressure.

[0051] These means are preferably means that make it possible to control the ratio between the pulse of the secondary jet and the pulse of the primary jet.

[0052] The control means make it possible to activate and deactivate one or more of the secondary jets (flow or absence of flow of the secondary jet concerned) so as to dynamically vary the direction and/or the aperture of the flame.

[0053] The control means preferably also make it possible to dynamically increase and reduce the impulse (non-zero) of one or more of the secondary jets or to increase and reduce the ratio between the impulse of a secondary jet and the impulse of the primary jet.

[0054] The burner can be fed with fuel and with oxidant via an oxidant injection channel and at least one fuel injection channel, arranged concentrically, or even via an oxidant injection channel and at least one fuel injection channel that are separate from each other and preferably parallel to each other.

[0055] The burner advantageously comprises a block of material 5, such as a block of refractory material, in which at

least a part of the passage 10 is situated, the main outlet aperture 11 being situated on one of the faces or surfaces of the block: front face 6.

[0056] In FIG. 1, the secondary jet is conveyed by a secondary duct 21 which passes through the block 5, this secondary jet preferably opening out substantially perpendicularly to the primary jet.

[0057] The interaction between the primary jet and the secondary jet takes place at a distance L from the front face 6 of the block onto which opens out the passage 10 of the primary jet, this distance L possibly varying as indicated previously.

[0058] According to one embodiment that makes it possible to vary the direction of the flame illustrated in FIGS. 3A and 3B, the burner comprises at least one secondary duct 321, 322, 323 and 324 which is positioned relative to the passage 310 of the primary jet so that, at the level of the corresponding secondary aperture 331, 332, 333 and 334 (that is, the secondary aperture through which the secondary duct concerned opens out onto the passage), the axis of the primary jet and the axis of the corresponding secondary jet are secant or quasi-secant.

[0059] Such an arrangement between the passage and the secondary duct makes it possible to vary the angle between the axis of the flame and the axis of the primary jet upstream of the secondary aperture by changing the impulse of at least one corresponding secondary jet.

[0060] If, in the absence of actuating jet, the flame obtained from the main outlet aperture 311 is perpendicular to the plane of FIG. 3A, the injection of a jet through the secondary duct 323 allows for a deflection of the flame to the right in FIG. 3A, that is, in the same direction as the direction of flow of the jet from 323. If, simultaneously, there is injection of a secondary jet through the secondary duct 324, depending on the relative motion quantities of the jets from 323 and 324, it is possible to obtain a flame deflected in a direction (projected in the plane of FIG. 3A) that can vary continually between the directions of the jets from 323 and 324 (to the right and downward in FIG. 3A).

[0061] The burner preferably comprises at least two secondary ducts that are positioned relative to the passage 310 so that, on the one hand, the two corresponding secondary apertures are situated on one and the same transverse section of the passage 310 and, on the other hand, at the level of these two secondary apertures, the axes of the corresponding secondary jets are secant or quasi-secant with the axis of the primary jet. In this case, the two corresponding secondary apertures can, usefully, be situated either side of the axis of the primary jet (to the right and to the left for the apertures 331 and 333; downward and upward for the apertures 332 and 334), the two secondary apertures and the axis of the primary jet preferably being situated in a single plane (horizontal for the apertures 331 and 333; vertical for the apertures 332 and 334).

[0062] According to another useful configuration, at the level of the two corresponding secondary apertures, the plane defined by the axis of the primary jet and one of the two corresponding secondary apertures is perpendicular to the plane defined by the axis of the primary jet and the other of the two corresponding apertures. For example, the horizontal plane defined by the axis of the passage 310 and the secondary aperture 331 is perpendicular to the vertical plane defined by this axis and the secondary aperture 332.

[0063] It is also possible to combine these two embodiments. In this case, as illustrated in FIGS. 3A and 3B, the burner comprises at least four secondary ducts 321, 322, 323 and 324 which are positioned relative to the passage 310 in such a way that:

[0064] (1) the four corresponding secondary apertures 331, 332, 333, 334 are situated on one and the same transverse section of the passage 310, and

[0065] (2) two of these corresponding secondary apertures 331 and 333 define a first plane with the axis of the primary jet and are situated either side of this axis, the other two secondary apertures 332 and 334 defining a second plane with the axis of the primary jet, the first plane preferably being perpendicular to the second plane.

[0066] This arrangement makes it possible to vary the direction of the flame in the first plane and in the second plane (for example in the horizontal plane and in the vertical plane) and as selected to one or other of the four secondary apertures situated in each plane (for example, to the left and to the right in the horizontal plane, and upward and downward in the vertical plane) and, as explained hereinabove, toward any intermediate direction.

[0067] At the level of the four corresponding secondary apertures 331 to 334, the axes of the four corresponding secondary jets are preferably in one and the same plane perpendicular to the axis of the primary jet 310.

[0068] The invention also makes it possible to produce an interaction between the primary jet and one or more secondary jets so as to generate, maintain or reinforce a rotation of the jet of fluid resulting from this interaction and therefore of the flame around its axis. Such an interaction makes it possible to vary the aperture of the flame.

[0069] As illustrated in FIGS. 4A and 4B, the burner can be provided with at least one secondary duct 421 to 424 which is positioned relative to the passage 410 of the primary jet so that, at the level of the corresponding secondary aperture 431 to 434, the axis of the corresponding secondary jet 421 to 424 is not coplanar or substantially coplanar with the axis of the primary jet 410, this at least one secondary duct 421 to 424 preferably opening out tangentially onto the passage 410 of the primary jet. In this way, the interaction between the primary jet and the secondary jet confers a rotation impulse on the primary jet.

[0070] The burner can, usefully, comprise two secondary ducts 421 and 422 positioned relative to the passage 410 of the primary jet so that, at the level of the two corresponding secondary apertures 431, 432, the axes of the two corresponding secondary jets 421 and 422 are not coplanar with the axis of the primary jet 410, the two secondary jets being oriented in one and the same direction of rotation about the axis of the primary jet. The two secondary jets thus contribute to the rotation impulse conferred on the flame.

[0071] The two secondary apertures are advantageously situated on the same transverse section of the passage 410/in one and the same plane perpendicular to the axis of the primary jet. They can be situated either side of the axis of the primary jet (apertures 431 and 433 or 432 and 434). They can also be situated so that the plane defined by the axis of the primary jet and one of the two secondary apertures 431 is perpendicular to the plane defined by the axis of the primary jet and the other of the two secondary apertures 432.

[0072] According to one embodiment, the burner comprises at least four secondary ducts 421 to 424 which are positioned relative to the passage 410 of the primary jet so

that, at the level of the corresponding secondary apertures 431 to 434, the axes of the corresponding secondary jets are not substantially coplanar with the axis of the primary jet. Two of the corresponding secondary apertures 431 and 433 are substantially coplanar with the axis of the primary jet 410 in a first plane and situated either side of the axis of the primary jet. The other two corresponding secondary apertures 432 and 434 are substantially coplanar with the axis of the primary jet 410 in a second plane and also situated either side of the primary axis, the four corresponding secondary jets being oriented in one and the same direction of rotation about the axis of the primary jet. The first and the second planes can in particular be perpendicular to each other. It is also preferable for the four corresponding secondary apertures to be on one and the same transverse section of the passage 410.

[0073] To confer a rotation impulse on the primary jet, and thus to change the aperture of the flame, it is preferable to ensure that, at the level of the secondary aperture where the primary jet and the corresponding secondary jet interact, on the one hand, the axis of the secondary jet belongs to the plane perpendicular at this position to the axis of the primary jet and, on the other hand, the angle between the axis of the secondary jet and the tangent to the secondary aperture (or more precisely, to the imaginary surface of the passage of the primary jet at the level of the secondary aperture) in this plane is between 0 and 90°, preferably between 0 and 45°.

[0074] FIGS. 4a and b show an exemplary embodiment for controlling the aperture of a flame. The primary jet (which flows from left to right in the passage 410 in FIG. 4A) meets the secondary jets from the secondary ducts 421, 422, 423 and 424 (represented in FIG. 4b which is a transverse cross-section on the plane AA of FIG. 4a). These secondary jets impact on the primary jet tangentially to the passage 410, thus making it possible, depending on the impulses of these different jets, to "open" the flame more or less. This aperture effect is mainly due to the fact that the secondary jets and the primary jet have axes that do not intersect, although the jets have a physical interaction between them. This entrains a rotation of the resultant jet and therefore of the flame on its axis.

[0075] It is also possible to combine in a single burner the embodiment that makes it possible to vary the direction of the flame according to any one of the methods of implementation described hereinabove with any one of the embodiments described hereinabove making it possible to generate, maintain or reinforce a rotation of the resultant jet and thus vary the aperture of the flame.

[0076] To obtain both a directional and rotational effect, the teachings of the preceding paragraphs will therefore be combined. To obtain a dynamic variation of the directional and rotational effects, it is possible, for example, to provide several secondary jet injection systems.

[0077] By providing the separate secondary ducts with means of regulating the impulse of the secondary jet, such as feed valves, it is thus possible to change, continuously or discontinuously, the form and the direction of the resultant jet simply by actuating said regulation means (valves).

[0078] To enable the secondary jet to act as effectively as possible on the primary jet, the actuating jet should be injected substantially perpendicularly to the direction of the main jet.

[0079] For optimum operation, the burner can comprise at least one secondary duct 21 positioned relative to the passage 10 of the primary jet so that, at the level of the corresponding

secondary aperture **31**, this duct presents a thickness e and a height l , such that $l \geq 0.5 \times e$ and preferably: $0.5 \times e \leq l \leq 5.0 \times e$ (see FIG. 1). A minimum height greater than or equal to $0.5 \times e$ makes it possible to produce an optimal interaction between the corresponding secondary jet and the primary jet.

[0080] For example, in order to practically produce a secondary jet such that, at the point of interaction between this secondary jet and the primary jet, the angle θ between the axis of the secondary jet and the plane perpendicular to the axis of the primary jet is 0° , it will be preferable, before the corresponding secondary aperture, for the secondary duct to have a direction substantially perpendicular to the axis of the primary jet over a length l which will preferably be between 0.5 and 5 times the thickness e (dimension in the direction of flow of the main fluid) of said duct (e is the diameter of the duct when the latter is cylindrical). Obviously, it is also possible for this length l to be greater than $5e$, but this then adds no additional effect of significant impact of the secondary jet on the primary jet. For example, for a burner with an injection of gaseous hydrocarbons in ambient conditions and an injection of oxygen, at least $l=5$ mm is obtained for a 100 kW burner and $l=50$ mm is obtained for a 10 mW burner.

[0081] The burner can include a refractory port or a combustion prechamber (for example made of ceramic) positioned at the end of the passage, at least one secondary duct being at least partially arranged inside the refractory port/the prechamber.

[0082] The passage of the primary jet can consist, in total or for at least part, of a primary duct for the injection of the primary jet. This primary duct opens out onto a primary aperture.

[0083] This primary aperture can coincide with the main outlet aperture of the passage.

[0084] When, as illustrated in FIGS. 3c, d and e and in FIG. 6, the primary duct **308**, **608** ends before the main outlet aperture **311**, **611**, the primary aperture **309**, **609** is positioned upstream of the main aperture **311**, **611**. In this case, at least one secondary aperture **334**, **632**, **634** can be situated between the primary aperture **309**, **609** of the primary duct **308**, **608** and the main aperture **311**, **611** of the passage.

[0085] FIG. 6 more particularly represents an exemplary embodiment of the invention in a burner of tube-in-tube type that has a prechamber attached to the burner inside a ceramic refractory port in which the flame is stabilized (such as, for example, described in the patent applications No. U.S. Pat. No. 5,772,427 and U.S. Pat. No. 5,620,316 in the name of the Applicant and marketed by the Applicant) under the trade name ALGLASS. In the figure, the refractory port block **605** comprises a cavity **671** (or prechamber) into which the bi-tube opens out.

[0086] The passage **610** of the primary jet thus consists of a primary duct **608** opening out through a primary aperture **609** onto the cavity **671**, a cavity that opens out through the main outlet aperture **611** situated on the front face of the refractory port downstream of the primary aperture **609**.

[0087] In the refractory port (block) **605** of the burner there are a plurality of secondary ducts **622**, **624** opening out substantially perpendicular to the axis of symmetry X-X of the burner onto the passage **610**, and more particularly onto the cavity, respectively through the secondary apertures **632** and **634** situated at a distance L from the main outlet aperture **611**.

[0088] The bi-tube proper schematically comprises a central tube for injecting fuel (preferably), surrounded by a con-

centric tube into which is injected the oxidant, the two fluids being mixed in the cavity **671**.

[0089] In this exemplary embodiment, there is, upstream of the secondary apertures **632**, **634**, a mixing of the oxidants and fuels (and possibly of combustion products) injected co-axially by the tubes. The direction and/or the aperture of the flame are then regulated by the action, and more particularly by the controlled impulse, of at least one actuating jet **622**, **624**.

[0090] For optimum operation of the burner according to the invention, the passage of the primary jet will present, at the level of the at least one secondary aperture, a non-obstructed, or at least substantially non-obstructed, fluidic passage in the extension of the at least one corresponding secondary duct, in order to allow an effective interaction between the at least one corresponding secondary jet and the primary jet. Typically, the transverse section of the passage of the primary jet will define a non-obstructed, or at least substantially non-obstructed, fluidic passage at the level of the at least one secondary aperture. This is illustrated in FIG. 6 where the central tube directing the fuel ends at the level of the primary aperture and therefore well before the secondary apertures.

[0091] FIGS. 3c, d and e show another embodiment of the burner, in which the primary duct **308** ends before the main outlet aperture **311**.

[0092] FIG. 3c represents an embodiment variant similar to FIG. 3B, but with an embodiment in which there are two parallel channels (primary duct **308** and secondary duct **324**) in a nozzle **345**, the two channels **308** and **324** opening out onto the front face of the nozzle. On this front face, a biscuit **342** is applied which makes it possible to orient the secondary jet from the secondary duct **324** to the primary jet leaving the primary duct **308**, and more particularly perpendicularly or substantially perpendicularly to the primary jet. In this way, it is possible to deflect the flame, for example in the direction indicated by the arrow **344** in FIG. 3c. (The direction **344** of the flame will depend on the ratio of the impulses of the primary and secondary jets.) It is thus possible, by varying the impulse of the secondary jet using the control means, to obtain a variable flame direction that makes it possible to sweep an entire surface, such as the surface of a liquid bath to be heated, with the flame.

[0093] FIG. 3d is an exploded view of the nozzle **345** onto which is fixed the biscuit **342** (by means not represented in this figure), here in the form of a hollow lateral cylindrical part **350** which bears on the end of the nozzle **345**, whereas the aperture **346** in this biscuit is positioned at the point where the primary duct **308** opens out.

[0094] FIG. 3e represents the bottom (inside) of this biscuit **342** whose internal face **349** comprises a cavity **347** in which the secondary jet from the secondary duct **324** will be spread then encounter, substantially perpendicularly, the primary jet from the primary duct **308** through the intermediary of the slot **348** above the main outlet aperture **346**. The flame **344** (FIG. 3c) from this aperture **346** will thus be deflected downward (compared to FIGS. 3c, d and e).

[0095] It should be noted that the possibility of using a biscuit to confer the desired orientation on one or more secondary jets before their respective points of interaction with the primary jet is not limited to the secondary jets oriented so as to vary the direction of the flame, but also applies to the secondary jets described hereinabove that make it possible to vary the aperture of the flame.

[0096] The invention also relates to a method for dynamically or actively controlling the performance characteristics of a combustion system or of a burner using one or more secondary jets, impacting on a primary jet in order to modify the flow of the jet and to produce a flame whose direction and/or aperture can be modified according to the characteristics (in particular direction and quantity of motion) of the primary and/or secondary jets. This method can be used to regulate, in closed or open loop mode, the performance characteristics of a combustion system implementing injections of fluid jets (liquid, gaseous or solid dispersion).

[0097] FIG. 2 represents a method of regulating the performance characteristics of a burner 210 according to the invention, mounted on a fire box 212.

[0098] The sensors 214, 216 and 217 respectively measure quantities characterizing the combustion products, the combustion or fire box operating conditions and the operation of the burner. These measurements are transmitted using the lines 218, 219 and 220 to the controller 215. The latter, according to set-points given for these characteristic quantities, determines the operating parameters of the secondary jets so as to maintain the characteristic quantities at their set-point values and transmits using the line 221 these parameters to the control units 211 of the burner.

[0099] The burner according to the invention advantageously comprises means for controlling the impulses of the primary and/or secondary jets, or even means for controlling the ratio of the impulses of the primary jet and of the secondary jet or jets. This ratio is a function of the ratio of the section of the passage of the primary jet and of the sections of the secondary ducts, of the ratio of the flow rates in the secondary ducts to the flow rate of the resultant jet feeding the flame and of the ratio of the specific gravities of the fluids of the primary jet and of the secondary jet or jets. (In the following paragraphs, when considering the variation of one of these ratios, the other two are considered constant.)

[0100] Given constant respective flow rates, the corresponding secondary jet has an increasing impact on the primary jet as the value of the ratio of the section of the passage and of the section of a secondary duct at the level of the corresponding secondary aperture increases. A section ratio will preferably be chosen that is between 5 and 50, and more preferably between 15 and 30.

[0101] The ratio of the flow rate of all of the secondary jets to the total flow rate will vary typically between 0 (absence of secondary jets) and 0.5, and preferably between 0 and 0.3; more preferably, between 0 and 0.15; bearing in mind that the deflection and/or the aperture of the flame increases as this flow rate ratio increases.

[0102] The ratio of the specific gravity of each fluid constituting the secondary jets to the specific gravity of the fluid of the primary jet makes it possible to control the impact of the secondary jets. The effect of the secondary jet on the primary jet, at a constant flow rate, will increase as the value of this ratio decreases. For practical reasons, the same fluid will often be used in the secondary jets and in the primary jet (ratio equal to unity). To increase (at constant mass flow rate) the effects of the secondary jets, a fluid of lower density than that of the fluid in the primary jet will be used. The nature of the fluid in the secondary jets will be chosen as a function of the target application. A mixture of air and of helium (lower density) can, for example, be used to control the deflection of a jet of air, or, by controlling the main fuel jet and/or oxidant jet with a secondary jet of steam, it is possible to increase the

entrainment of the combustion products in a flame fuelled by propane. As a general rule, the ratio of the specific gravities (or of the densities) of the densest fluid to the least dense fluid can vary between 1 and 20, preferably between 1 and 10, more preferably between 1 and 5.

[0103] The geometry of the injection section of the passage and/or of the secondary ducts, can be of various forms and in particular circular, square, rectangular, triangular, oblong, multi-lobed, etc. The geometry of these injection sections influences the development of the instabilities of the resultant jet/of the flame. For example, a jet leaving an injector of triangular form will be more unstable than that obtained from an injector of circular form, this instability favoring the mixing of the resultant jet with the surrounding medium. Similarly, an injector of oblong form will favor, in a field close to the injector, the non-symmetrical development of the jet, unlike an injector of circular or square form.

[0104] Regarding the physical/chemical properties of the fluid used to produce the secondary jets, these can be chosen to control certain properties of the resultant flow. For example, it is possible to modify the reactivity of a mixture of main jets for fuel (for example natural gas) and oxidant (for example air), through the use of oxygen (or other oxidant), and/or of hydrogen (or other fuel).

[0105] If the end of the passage of the primary jet, just before the point of interaction of the primary and secondary jets, is provided with a nozzle comprising a convergent/divergent lead (also called Laval nozzle in the literature), it is possible at the outlet of the divergent lead to obtain (in a manner known per se in the literature) a primary jet of fluid and a resultant jet, for example a jet of oxygen, supersonic which can then be of variable direction (possibly of variable aperture, but generally losing its supersonic speed, which makes it possible to alternate subsonic and supersonic speeds in certain methods). The Laval nozzle can also be positioned on the resultant jet before the main outlet aperture.

[0106] According to a variant of the method, at least two secondary jets are used, so as to obtain a variation of the direction of the flame in a plane (for example, to the left and right, or upward and downward). It is also possible to use at least two secondary jets so as to obtain a variation of the direction of the flame in at least two secant planes. These two variants, alone or in combination, make it possible to sweep at least a part of a surface, such as the surface of a charge.

[0107] By using a secondary jet whose axis is not secant or quasi-secant with the axis of the primary jet, the aperture of the flame above the charge can be varied, on its own or in combination with a sweep.

[0108] Means are preferably provided to control the quantity of motion of the primary jet and/or of the at least one secondary jet.

[0109] It should be noted that, although in the foregoing the burner and the method have been illustrated hereinabove by referring to an embodiment with a single primary jet that is made to interact with one or more secondary jets, it is obvious that the present invention also covers such a burner to create one or more flames with an aperture and/or direction that are variable from a multitude of primary jets that interact with one or more secondary jets.

[0110] FIG. 5 illustrates how the burner according to the invention makes it possible to produce a variable flame from two primary jets: a primary jet of fuel and a primary jet of oxidant. Each primary jet interacts with one or more secondary jets. The two resultant jets obtained from the burner, and

therefore also the flame, having a variable direction and/or aperture thanks to this interaction.

[0111] FIG. 5a diagrammatically shows the resultant jet of fuel **61** topped by the resultant jet of oxidant **62**, in the situation where none of these jets is controlled by an interaction with one or more secondary jets. FIG. 5b shows the same resultant jets, but in a situation where the latter are controlled or deflected in opposition (convergent jets). The jet **60** is deflected downward by the secondary jet **62** whereas the jet **61** is deflected upward by the secondary jet **63**, directed from bottom to top (unlike **61**). FIG. 5c shows the resultants in a situation where these jets are controlled or deflected in the same direction (upward in the figure): the secondary jets **63** and **65** act from bottom to top respectively on the main jets **61** and **60**, which generates resultant jets both directed upward. These three examples make it possible to obtain flames of very different direction and morphology (length, flattening, etc.). The flame **64** will be very wide in the median horizontal plane of the two jets, whereas the flame **67** will be strongly deflected upward.

[0112] According to the invention, at the point of interaction between the secondary jet and the primary jet, the axis of the secondary jet forms with the plane perpendicular to the axis of the primary jet an angle that is less than 90° , and preferably equal to 0° . However, as illustrated in FIGS. 3C and D, for reasons of bulk, the channels feeding these jets are more often than not substantially parallel. To reorient the secondary flow at the level of the area of interaction of the two flows, it is possible to fix at the end of a burner with parallel channels an end piece hereinbelow named injection biscuit, the function of which is to transform the direction of the secondary jet initially parallel to the primary jet, into a secondary jet impacting on the primary jet, the axis of said secondary jet preferably being situated in a plane perpendicular to the axis of the primary jet.

[0113] However, the use of the burner for very high-temperature methods ($T > 1000^\circ \text{C.}$) can lead to an overheating and a degradation of the injection biscuit. To overcome this kind of problem, efforts will be made in the dimensioning of the injection biscuit to reduce the front surface of the burner subject to the radiation in the high-temperature enclosure. For this, efforts will be made to limit the ratio l/e .

[0114] It is also possible to use one of the two solutions illustrated in FIGS. 16 and 17. The first solution (FIG. 16) consists in placing the burner **500** in a refractory piece **501** whose geometry and relative burner/refractory port position will protect the first from an excessive radiation. The position or the set-back of the burner in the refractory port must be sufficient to protect it from the radiation, but must not in any way limit the directional amplitude of the flame. For this, the geometry of the refractory port can be modified by eliminating a part of the latter along the broken line **160** in FIG. 16 at the angle α . Preferably, the ratio R/d will be within the range 0.3 to 3, whereas the angle α will lie within the range $[0^\circ, 60^\circ]$.

[0115] The second solution consists in adding a refractory piece of sleeve brick type directly to the nose of the burner (where the main outlet aperture is located) as illustrated in FIG. 17. This solution makes it possible to do away with the presence of a refractory port of complex geometry. The dimensions of the sleeve brick are such that it does not limit the directional amplitude of the injector. This means in particular that the thickness f of the sleeve brick is low (less than the diameter of the main jet) or even that the material used to

produce this sleeve brick has a very low thermal conductivity. Alumina will be chosen, for example.

[0116] The invention also relates to a method for heating a charge using a burner, in which the direction (and/or the aperture) of the flame is varied relative to the charge. As already mentioned hereinabove, the invention makes it possible in particular to use one or at least two secondary jets, so as to obtain a variation of the direction of the flame in a plane (for example, to the left and right, or upward and downward). It is also possible to use at least two secondary jets so as to obtain a variation of the direction of the flame in at least two secant planes. These two variants, alone or in combination, make it possible to sweep at least a part of the surface of the charge.

[0117] According to one embodiment, the heating of the charge is such that, in a first phase, the flame is directed toward the charge, and in that, in a second phase, the flame is directed substantially parallel to the charge. In particular, during the first phase, the injection angle of the flame can be between approximately 90° and 5° , typically between approximately 90° and 10° . During the second phase, the injection angle of the flame is typically between approximately 5° and 0° .

[0118] Preferably, the injection angle of the flame during the first phase is between 5° and 75° , more preferably from 25° to 45° .

[0119] FIG. 8 shows three profiles of heat flux transferred by a flame to a charge according to the angle of incidence of the flame on the charge as a function of the distance to the point of injection of the flame reagents. A very strong increase is observed in the heat flux transferred to the charge with the increase of the incidence of the flame. For a zero incidence ($\alpha = 0$ —see FIG. 12), the heat flux is substantially constant over the entire length of the flame; for an incidence of 15° , the transferred flux increases very quickly, then a little less quickly from the point A, whereas for a flame incidence of 30° , the transferred flux increases extremely rapidly as far as the point B, then less rapidly roughly to the point A, from which the transfer decreases.

[0120] FIGS. 9A and B represent the aperture angle of the flame according to the ratio of the flow rate of the secondary jets (actuators) to the flow rate of the primary jet (main jet).

[0121] In FIG. 9A, the curves C1 and C2 respectively represent the aperture angle as a function of the ratio of the actuator/main jet flow rates. C1 relates to a configuration CONF1 in which the actuators are perpendicular to the main jet and open out at a distance h from the main outlet aperture and C2 corresponds to a configuration identical to CONF1, but with a distance $2 \times h$ instead of h between the secondary apertures and the main outlet aperture. These two curves show that the aperture of the flame is greater when the impact between the actuators and the main jet is closer to the main outlet aperture.

[0122] FIG. 9b illustrates the variations of the aperture angle according to the ratio of the flow rates of the actuators and of the main jet: the curve C3 corresponds to the configuration CONF3 with actuators impacting on the main jet at 90° (that is, on a plane perpendicular to the axis of the main jet: $\theta = 0^\circ$), at a distance $2 \times h$ from the main outlet aperture (similar to CONF2), whereas the curve C4 corresponds to the configuration CONF4 identical to CONF3, apart from the angle of incidence α of the actuators which is 45° relative to the axis of the main jet (that is, the angle θ between the axis of the actuators and the plane perpendicular to the axis of the main

jet= $90^\circ - \alpha = 45^\circ$). It will be noted that when the actuating jets are perpendicular to the main jet (CONF3: $\theta = 0^\circ$), there is obtained, all other things being equal, an aperture of the flame that is greater than when the angle of incidence α of the actuating jets is lower (here 45°) (CONF4: $\theta = 45^\circ$). FIG. 9 represents the deflection angle (in degrees) as a function of the ratio of the flow rate of the actuating jets and of the flow rate of the main jet, expressed as a percentage. FIG. 10A gives four curves, all other things being equal, for which the flow rate of the main jet is respectively 200 l/min, 150 l/min, 100 l/min and 50 l/min. It will be noted that these four curves are almost the same, which clearly shows that the deflection of the flame is not a function of the flow rate of the main jet.

[0123] FIG. 10B represents the transfer of heat to a charge: heat flux delivered by a burner according to the invention, in which the ratio of the flow rate of the actuating jets to the flow rate of the main jet (here also represented as a percentage of the flow rate of the main jet) is varied, both for the jet of fuel and for the jet of oxidant (burner with separate injection). Each jet initially injected parallel above the charge is progressively deflected toward the charge, which increases the heat transfer to the charge.

[0124] FIG. 11 represents a curve of the aperture angle of the flame as a function of the jet impulse ratio.

[0125] This curve brings together all the trial data obtained for controlling the aperture. The measured aperture angle is posted according to the physical parameter J which is the ratio of the specific impulses of the actuating jets and of the main jet. This ratio is expressed as the product of the ratio of the densities (actuating fluid to main fluid) and of the ratio of the square of the velocity of the actuating jets and of the square of the velocity of the main jet). The main fluid is the same for all the trials, whereas different fluids have been used for the actuators. These fluids differ mainly by their density (from greatest density to lowest density: CO_2 , air, air-helium mix). It is observed that all the trial points (regardless of the flow rates and the fluids used) are aligned on a straight line. This shows that the physical parameter that controls the aperture is indeed the ratio of the specific impulses defined hereinabove.

EXAMPLES

[0126] The following examples will provide a better understanding of the invention and how it can be used. FIG. 7 shows an example of a burner with separate injections of different fluids in more detail.

[0127] The burner with separate injections 101 comprises a top row of injectors of oxygen 112 in the form of jets and of injectors of natural gas (fuel) 124 in the form of jets, all of the injectors being located in the refractory mass 121 (FIG. 7C).

[0128] The normally metallic part 102 of the burner 101 is situated in the right-hand part of FIG. 7A and is prolonged by the tubes 107 and 109 for injecting oxygen gas, on the one hand, 207 and 209 for injecting natural gas, on the other hand, on the left in FIG. 7A.

[0129] In this figure, there are provided two independent supplies of oxygen (or any oxidant) 104 and 106 respectively feeding the boxes 103 and 105 respectively linked to the tubes 109 and 107, the oxygen flowing through the tubes 110 and 108.

[0130] The end 111 of the tubes is enlarged in FIG. 7B, to help explain the interaction of the main 108 and actuating 110 jets. At the end of the tubes 107 and 109, there is a channel 127 prolonging the channel 110 carrying the flow of the actuating jet. The wall 109 is prolonged by the walls 113, inclined

upward, 114, horizontal and 115 vertical (in the figure), whereas a central volume 126 makes it possible to delimit a channel 127 first inclined upward, horizontal then vertical (that is, at 90° relative to the gaseous flow channel 108 and opening out into the latter through the aperture 120). The vertical part of the channel 127 has a height L, defined hereinabove, that makes it possible to ensure the orthogonality of the jets 110 and 108 at the level of 120 (obviously, if an angle of intersection of the different jets of 90° is chosen, the channel 127 will have the required inclination and its length L remaining within the limits set out hereinabove). The metal part of the burner ends in a wall 123, vertical in the present case, edging the channel 127, with the metal part being exposed to the thermal radiation of the fire box in use. To ensure the longevity of this end of the injection tubes, it is possible to provide a protection element, for example made of alumina, that is resistant to high temperatures, which, for example, fits onto this metal end to protect it and has an aperture equal to the aperture 112 (FIG. 7C).

[0131] The fuel feed system 204, 206, 203, 205 is similar to the oxidant feed system described hereinabove with a main channel 207, an actuating channel 209 delimiting main fuel jets 208 and fuel actuators 210, all being housed in a cylindrical aperture 222 of the refractory port 221 (similar to 122 for the oxidant). The ends 124 and 125 are similar to 123 and 112. The same fuel actuating jet injection system is provided at the end of 207 and 209 as represented in FIG. 7B, dimensioned according to the characteristics of the fuel.

[0132] In general, however, preference shall be given to providing only a single actuating jet for each injector on the fluid having the highest impulse (generally the oxidant in the case of a burner), the duly deflected jet itself resulting in the deflection of the other jet outside the burner. In such a case, of course, the jet (or row of jets) of highest impulse will generally be above the jet of lower impulse, so that, without action on the part of the actuating jet on the jet of highest impulse, the burner delivers a flame oriented generally horizontally, whereas when the actuating jet (acting from top to bottom on the main jet of highest quantity of motion) acts on the main jet, the latter is directed, as explained hereinabove, downward (progressively, according to the ratio of the impulses) and drives with it the second jet of lower impulse (in this case the fuel), forming a flame that can thus pass from a horizontal position to an inclined position toward the charge to be heated, situated under the flame of the burner. By adding an actuating jet either side of the main jet at 90° (or any other angle between 0° and 180°) to said actuating jet illustrated in FIG. 7a (that is, on a horizontal at the level of 123 in FIG. 7c, perpendicular to A-A), this then makes it possible to displace the flame over the charge to be heated from left to right or from right to left, so substantially covering the whole surface to be heated. According to the invention, the actuating jet forms with the main jet an angle that is greater than zero. For reasons of bulk, the two channels conducting these jets are fed more often than not by a coaxial feed system (parallel channels—see FIG. 7).

[0133] The invention will be illustrated hereinafter in the case of a burner that is useful for heating any charge that can be a metal charge or any other charge that needs to be melted and/or brought to a high temperature, then maintained at the latter, for example a charge of ferrous or non-ferrous metal, of solid materials for the production of glass, for the production of cement or, on the contrary, a charge that must be dried from a liquid bath.

[0134] It is in particular possible to use the invention on a tool for treating steel in an electric arc oven, for example in the following way: this type of tool generally comprises a flame (usually subsonic) that is used to heat the metal, melt it, in particular at the start of a smelting. This flame, as explained in the present application, can be of variable direction by equipping each main jet (oxidant, fuel, premix) or at least one main jet with an actuating jet which varies its direction and/or its aperture, so as to be able to displace this flame over the charge without requiring heavy mechanical means which change the direction of the body of the burner. These tools are often also provided with lances for injecting powdered coal, generally injected using vector gas in a lance. By providing this lance with a duct for injecting a secondary jet, for example a gas identical to the gas “thrusting” the powdered coal, it is thus possible to vary the direction (also the aperture of the jet as for any fluid) of the jet of powdered coal (or of sprayed liquid fuel oil) in order to favor a rapid meeting of the jet of sprayed fuel with the flame or, on the other hand, distance this jet from the flame.

[0135] The examples hereinbelow relate to the control of the transfer of heat by a burner according to the invention to a charge, for example metal, in a charge smelting method.

[0136] An oven for smelting aluminum is generally equipped with one or more burners on one or more of the lateral walls surrounding the smelting basin of the oven, arranged above the float line of the metal when the latter is completely melted (liquid). The axis of the flame, when the latter is horizontal, is situated at a height of between 10 and 100 cm relative to this float line, preferably between 40 and 80 cm.

Example 1

Case of Solid Material in the Oven

[0137] Burners according to the invention are used for the incidence of the flame to be variable. (The term “incidence” should be understood to mean the angle of the flame relative to the horizontal). When the incidence is zero, the flame is horizontal. When the incidence is non-zero, the flame is inclined under the horizontal and directed toward the hearth of the smelting basin of the oven.

[0138] The burners inject each jet of fluid into the chamber of the oven, but this type of injector can be used only for fluid (oxidant or fuel) of higher impulse when the latter can interact with that of lesser impulse so as to obtain the desired deflection of the flame, typically, the oxidant in the case of an air/gaseous fuel burner, or oxygen/gaseous fuel burner.

[0139] In the first part of the aluminum smelting cycle, when the metal is mostly present in the solid state, the direction of the flame is adjusted for the latter to have a non-zero incidence (axis of the flame between 5° and 75°, preferably between 25° and 45°). This adjustment makes it possible to considerably increase the thermal transfer from the burner and therefore reduce the smelting time (as explained using FIG. 10).

[0140] When most of the blocks of solid metal are molten, the direction of the flame is adjusted so as to have a zero incidence angle. The flame is therefore parallel to the float line of the liquid metal. This adjustment makes it possible to continue to transfer energy to the charge and complete the smelting of the metal or refine it by limiting the heating of the already molten metal and, consequently, its oxidation by the flame or the combustion products.

[0141] Between the extreme positions of the flame described hereinabove (clear incidence or zero incidence), it is also possible during the first part of the cycle to adopt an intermediate, static setting, where the incidence of the flame is between 5° and 30°, preferably between 10° and 25°, to obtain a trade-off between coverage of the charge of the oven by the flame (projected surface of the flame on the bath) and intensity of the thermal transfer. FIG. 12 illustrates the extreme positions of the flame relative to the charge.

[0142] FIG. 12a is a top view of an aluminum smelting oven equipped with two burners according to the invention producing two flames positioned above the metal bath. The flue of the oven is used to evacuate the flue gases produced by the flames.

[0143] FIGS. 12b and 12c represent a side view of the same oven, at the level of the flame.

[0144] In FIG. 12b, the flame is inclined by an angle α relative to the horizontal, preferably when there is solid metal still present in the metal bath, whereas in FIG. 12c, the flame is positioned at zero incidence ($\alpha=0$).

[0145] Between the extreme positions of the flame (clear incidence and zero incidence), it is also possible, during the first part of the cycle, to periodically vary the angle of incidence of the flame. For example, the operator of the oven can vary the incidence between 0° and 45° then return to 0°.

[0146] Preferably, the burner will be driven with a control module making it possible to periodically modulate the control ratio of the burner, that is, the ratio of the impulses of the main and actuating jets and consequently the incidence of the flame on the bath. The control signal from the control module can be sinusoidal, triangular, square, etc., with a frequency variable from 0.05 Hz to 100 Hz, preferably triangular at a frequency of 0.1 to 10 Hz. By periodically varying the position of the flame, the transfer of heat inside the oven is made uniform and thus the solid elements are melted more rapidly.

Example 2

Creating a Uniform Transfer of Energy to the Charge

[0147] Burners according to the invention are used for the orientation of the flame in a horizontal plane to be able to be modified on demand according to the control ratio of each burner as illustrated in FIG. 13.

[0148] Each fluid jet is injected into the chamber of the oven through a burner according to the invention, but for jets situated in one and the same horizontal plane or in horizontal planes that are very close together (no more than one to two jet diameters apart), it is possible to use these injectors only for the peripheral jets when the latter can interact with the other jets to be deflected.

[0149] The variation of the horizontal orientation can be achieved in both left and right directions either by equipping each main jet with two lateral actuating jets, or by equipping each peripheral main jet with a single actuating jet, capable of actuating the main jet in the horizontal direction but in directions opposite to each other. It is also possible to offset the main injector so that, at a zero control ratio, the flame is naturally deflected (to the right or to the left) relative to the axis X-X' of the burner in FIG. 13, and then vary the orientation of the flame by progressively increasing the control ratio of the control system (that is, obtain a jet on the axis X-X' with a non-zero control ratio).

[0150] The use of one or more burners with variable flame orientation makes it possible to increase the coverage of the charge by displacement of the flame in a horizontal plane.

[0151] (The expression "control ratio" used hereinabove is defined as being the ratio of the flow rates of the actuating jet and of the main jet, given that the impulse of a fluid jet can be controlled simply by varying the aperture of a valve, the increase in the aperture of a valve being proportional to the increase in the flow rate of the jet, all other things being equal).

[0152] When the control ratios of the burner or burners are zero, the orientation of the flame is situated in the natural axis of the burner and the flame covers a portion of the charge. When one of the control ratios is non-zero, the position of the flame is deflected and the flame covers another portion of the charge.

[0153] FIG. 13 illustrates an example of horizontal displacement of a flame above a charge; each main jet 130, 132 (oxidant or fuel) is provided with an actuating jet 131, 133; in FIG. 13a, the control ratio CR of the jet 130 is zero, that is, no fluid is injected into the channel 131; the control ratio CR of the jet 132 is, on the other hand, positive, which means that, because 133 acts from bottom to top in FIG. 13a, the actuating jet 133 deflects the main jet 132 upward in the figure, that is, to the left relative to the axis X-X' of the burner.

[0154] In FIG. 13b, the control ratios of the two main jets 130 and 132 are zero (CR=0), so there are no actuating jets in action and the flame is propagated on the axis X-X'.

[0155] In FIG. 13c, unlike FIG. 13a, the control ratio CR of the jet 130 and of the jet 132 is positive which brings about a deflection of the flame downward in the figure (to the right looking from above), the main jet 132 and the actuating jet 133 having a zero control ratio (no jet 133).

[0156] Thus, each burner can cover a greater portion of charge favoring the uniformity of the thermal transfer and making it possible to limit the possible formation of hot points if refractory materials are included in the bath (for example, alumina-based residues, recycled or in formation by oxidation of the metal during smelting), and to favor overall the thermal transfer making it possible to accelerate the smelting process at constant power, or to reduce the energy consumption with constant smelting time.

Example 3

Flame with Variable Incidence on Charge and Laterally Sweeping the Charge

Example 4

Closed Loop Regulation

[0157] This exemplary embodiment of the invention making it possible to control both horizontal and vertical displacement of the flame according, for example, to different operating parameters of the oven, given by different types of sensors installed on the oven, and in particular sensors of heat flux, temperature, or, possibly, chemical composition (for example TDL-type laser diode).

[0158] A regulation loop whose sensor is a measuring device making it possible to obtain an image of the thermal transfer to the charge or of the oxidation of the aluminum bath, this information making it possible to reduce or increase the transfer to the charge by acting on the flow rate from the actuating jet, as explained hereinabove.

[0159] A loop for regulating the flame position based on the measurement of the temperature of the bath, when at least a portion of the bath is present in the liquid state. As long as the bath temperature is less than a value T_c, between 650 and 750° C. for example for aluminum, the flame must remain at non-zero incidence on the bath to maximize the transfer of heat. As the value T_c is approached, the flame is gradually observed to separate from the bath, all the more so when the target value is reached, in order to limit the risks of oxidation of the charge. The incidence of the flame is then regulated to maintain the temperature at its target value.

[0160] A loop for regulating the position of the flame based on the measurement of the heat flow rate:

[0161] This heat flow rate can, if necessary, be assessed through a difference in temperatures read between two thermocouples immersed in the bath at two different depths but on the same generatrix perpendicular to the hearth of the oven.

[0162] The heat flow rate can also be deduced from the thermal transfers calculated through the hearth of the oven, still by measuring the difference in temperature within it. Given the greater resistivity of the hearth, consisting of refractory materials, it is easier to obtain a significant temperature gradient.

[0163] The heat flow rate can also be followed thanks to a flow meter positioned, for example, at the roof of the smelting chamber. In practice, all other things being equal, any reduction in the flow rate perceived by the roof and observed by the flow meter will correspond at least partially to an increase in the heat flux transmitted to the charge (there is less interest in the absolute value of the heat flow rate transmitted to the charge (or of the losses at the walls) than in the trend over time of the signal that corresponds to it).

[0164] The smelting of the charge will begin with a flame with clear incidence on the charge, this incidence being retained while the flux transferred to the charge remains high. When this flux reduces, revealing an increase in the temperature of the charge and a reduction in its heat absorption capability, the flame is raised progressively to separate it from the bath, in order to limit the risks of oxidation or of overheating of the charge.

[0165] A loop for regulating the position of the flame based on the measurement of the composition of the flue gases on leaving the oven or inside the oven, for example before the flue gas manifold of the oven, above the bath, between the incident flame and the aluminum bath, etc. for the detection of one or more species revealing the oxidation of the aluminum bath such as CO:

[0166] a. The composition of the flue gases can be measured in a manner that is known per se by extraction then analysis (conventional analyzers, TDL or other) or in situ by absorption (laser diode or other means) or by electrochemical probe.

[0167] b. The smelting begins with a flame with clear incidence on the charge, and this incidence is retained as long as the tracer or tracers of the oxidation of the charge are stable and in small quantity. When the concentration of the tracer or tracers of oxidation increases, the flame is progressively raised to separate it from the bath, in order to limit the concentration of the tracer or tracers, and therefore the oxidation of the

charge, by acting on the main jet through the intermediary of the actuating jet as explained hereinabove.

[0168] c. Furthermore, the position of the flame can be adjusted to reach a set-point value then maintain a precise set-point of concentration of oxidation tracer. It is possible in fact to set a concentration threshold not to be exceeded and permanently adjust the incidence of the flame to achieve it.

[0169] It should be noted in all cases that when the charge consists at least partly of cold solid, the flame can be oriented clearly regarding incidence on the charge since, as long as the temperatures remain modest, for example below 600° C. for aluminum, the rate of oxidation remains low. When the charge has become mainly liquid, the regulation used becomes important to avoid the rise in temperature of the metal and the oxidation of the latter. For an application of the invention to the heating of a material other than aluminum, for example for heating a bath of glass, etc., the same regulation principles apply, for temperatures and criteria that are different from one material to another, but that are themselves well known to those skilled in the art.

Example 5

Control of Emissions

[0170] All the primary techniques for reducing emissions of nitrogen oxides from the burners or from industrial hearths use the local properties of the flows of the fluids or of the flame to limit their formation. In particular, they aim to reduce the temperature or the concentrations of the reagents (fuel, oxygen) or the residence times of the reagents in the flame and/or in the combustion products. One of these techniques consists in sufficiently entraining flue gases in the reagents or in the flame in order to reduce the temperatures or the concentration of the reagents, or to reduce the residence time. For this, the burner is dimensioned so as to obtain jets of fuel and/or of oxidant at high velocity (strong impulse) and sufficiently distant to obtain the maximum rate of entrainment or of recirculation of flue gases that is compatible with a good stabilization of the flame. The stabilization limit is detected on appearance of combustion residues in the combustion products such as carbon monoxide for hydrocarbons. In certain conditions, it is possible to obtain a “flameless” combustion regime that is particularly favorable to reducing emissions.

[0171] The limitation of this technique and of the combustion technologies that use it is that the rate of entrainment of the flue gases is set by the dimensions of the burner and the operating conditions. Consequently, the performance characteristics in terms of emissions can be very significantly degraded immediately there is a departure from these conditions, but also when the fuel is changed or when the flows specific to the oven or to the hearth contribute significantly to the properties of the flames.

[0172] The invention makes it possible to adapt in operation the properties of the flames and in particular the recirculation rate of flue gases, which makes it possible to minimize in all circumstances the emissions of pollutants and, ultimately, to optimize the performance characteristics of the burners.

Example 6

Premix Burner Comprising an Injector Placed in a Hearth

[0173] Actuating jets as described hereinabove are used to modify in operation the aperture angle of the main jet of fluid

(or of several jets). In this case, the main jet is a gaseous premix of fuel and oxidant. The aperture of the jet measures the level of entrainment of the ambient medium by the latter, it can be measured by the angle between the axis of the jet and the straight line tangential to the boundary between the jet and the ambient medium. (This boundary can be defined as the place in the jet where the concentration of the injected fluid becomes zero).

[0174] The aperture of the jet is controlled by the ratio between the flow rate of the actuating jet and the overall flow rate of the resultant jet. When this control ratio is zero, an emission level N1 is measured (FIG. 15). This control ratio is in fact the ratio of the impulses of the jets as explained hereinabove.

[0175] The control parameter is then increased so as to increase the entrainment of flue gases in the jet and so dilute the injected fuel mixture. This dilution will lead on the one hand to a reduction in temperature and on the other hand to a reduction in the concentration of the reagents in the flame. The emissions of NOx will therefore decrease to reach a level N2 (FIG. 15). If the value of the control parameter is increased further, the temperature and the concentrations of the reagents become too low to ensure a good stabilization of the flame: combustion residues are then seen to appear in the combustion products. The emissions of nitrogen oxides are then at a level N3 and the emissions of combustion residues at a level I3 that is too high. The control parameter is then reduced to obtain the optimum level for emissions N0 and I0 (intersection of the NOx and combustion residue curves in FIG. 15). This optimum can be obtained manually (passive control) or preferably by an active control device. This device incorporates sensors for measuring the emissions of nitrogen oxides and of combustion residues, a logic controller using the control logic explained hereinabove and the units for controlling the flow rates of the main jet and of the actuating jet or jets at least one injector. The logic controller will determine the value of the control parameter that minimizes the emissions of nitrogen oxides and combustion residues. The active control becomes essential when the number of the parameters to be optimized is greater than or equal to 2. For example, it is possible at the same time to want to minimize the emissions of pollutants by increasing the rate of dilution of the flame by the flue gases and maximize the transfer to the charge by inclination of the flame toward the charge.

Example 6

Burner with Non Pre-Mixed Combustion

[0176] If the combustion technology is of the non-pre-mixed type, then the control can be exercised immaterially on the fuel, the oxidant or even both in a manner similar to example 5.

[0177] If necessary, the effects of aperture (entrainment of the ambient medium) and of deflection of the jets (divergent fuel and oxidant jets) will be combined and in particular to increase the impact of the dilution of the flame and maximize the reduction in emissions.

1-21. (canceled)

22. A burner comprising:

a passage for directing a primary jet of oxidant or of fuel, or of an oxidant-fuel premix to a main outlet aperture, at least one secondary duct for the injection of a secondary jet,

in which:

the at least one secondary duct opens out onto the passage through a secondary aperture situated upstream of the main aperture and is positioned relative to the passage so that, at the point of interaction between the corresponding secondary jet and the primary jet, the angle between the axis of the corresponding secondary jet and the plane perpendicular to the axis of the primary jet is greater than or equal to 0° and less than 90° , preferably from 0° to 80° , even more preferably from 0° to 45° , and in that

the at least one secondary aperture is spaced apart from the main aperture by a distance L less than or equal to ten times the square root of the section of the primary aperture, preferably $L \leq 5\sqrt{s}$, also preferably $L \leq 3\sqrt{s}$,

characterized in that:

the burner comprises means of regulating the impulse of each corresponding secondary jet,

said burner making it possible to vary the direction and/or the aperture of the flame by changing the impulse of at least one corresponding secondary jet.

23. The burner of claim 22, wherein the regulation means controls the ratio between the impulse of each corresponding secondary jet and the impulse of the primary jet.

24. The burner of claim 22, comprising at least one secondary duct positioned relative to the passage so that, at the level of the corresponding secondary aperture, the axes of the primary jet and of said secondary jet are secant or quasi-secant in order to be able to vary the angle of the flame at the outlet from the burner relative to the axis of the primary jet upstream of the corresponding secondary aperture.

25. The burner of claim 24, comprising at least two secondary ducts positioned relative to the passage so that the two corresponding secondary apertures are situated in one and the same plane perpendicular to the axis of the primary jet and that, at the level of these two corresponding secondary apertures, the axes of the corresponding secondary jets are secant or quasi-secant with the axis of the primary fluid jet.

26. The burner of claim 25, wherein the two corresponding secondary apertures are coplanar with the axis of the primary jet at the level of the two secondary apertures and situated either side of this axis of the primary jet.

27. The burner of claim 25, wherein the plane defined by the axis of the primary jet at the level of the two corresponding secondary apertures and one of the two corresponding secondary apertures is perpendicular to the plane defined by the axis of the primary jet and the other of the two corresponding secondary apertures.

28. The burner of claim 25, comprising at least four secondary ducts positioned relative to the passage so that the four corresponding secondary apertures are in one and the same plane perpendicular to the axis of the primary jet and that, at the level of these four secondary apertures, the axes of the corresponding secondary jets are secant or quasi-secant with the axis of the primary jet, two of these corresponding secondary apertures being coplanar with the axis of the primary jet on a first plane and situated either side of this axis, the other

two corresponding secondary apertures being coplanar with the axis of the primary jet in a second plane and situated either side of this axis.

29. The burner of claim 22, wherein at least one secondary duct is positioned relative to the passage so that, at the level of the corresponding secondary aperture the axis of the corresponding secondary jet of fluid is not substantially coplanar with the axis of the primary jet of fluid, so as to be able to generate, maintain or reinforce a rotation of the resultant jet of fluid around its axis, and thus vary the aperture of the flame at the outlet of the burner.

30. The burner of claim 29, comprising at least two secondary ducts positioned relative to the passage in such a way that the axes of the corresponding secondary jets are not substantially coplanar with the axis of the primary jet and that the corresponding secondary jets are oriented in the same direction of rotation about the axis of the primary jet.

31. The burner of claim 30, wherein the two corresponding secondary apertures are situated either side of the axis of the primary jet.

32. The burner of claim 22, wherein at least one secondary duct is positioned relative to the passage so that, at the level of the corresponding secondary aperture, the secondary duct presents a thickness e and a height l , the height l being greater than or equal to 0.5 times the thickness e , preferably between $0.5 \times e$ and $5 \times e$.

33. The burner of claim 22, comprising means for controlling the ratio of the impulses of the primary fluid jet and of the secondary fluid jet.

34. The burner of claim 22, comprising a block of material in which at least one part of the passage is situated, the main aperture being situated on one of the faces or surfaces of the block.

35. The burner of claim 22, comprising means for controlling the impulses of the primary and/or secondary jets.

36. The burner of claim 22, comprising a refractory port positioned at the end of the passage and at least one secondary duct opening out onto the passage through a secondary aperture situated in the refractory port.

37. A method for heating a charge by means of a flame, said flame being produced by using a burner of claim 22.

38. The method of claim 37, wherein the direction and/or the aperture of the flame is varied by making a primary jet interact with at least one secondary jet.

39. The method of claim 38, wherein the primary jet is a jet containing oxidant or fuel or a premix of oxidant and of fuel.

40. The method of claim 37, wherein the direction of the flame is varied in order to sweep at least a part of the surface of the charge.

41. The method of claim 40, wherein the direction of the flame is varied in at least two secant planes in order to sweep at least a part of the surface of the charge.

42. The method of claim 37, wherein, in a first phase, the flame is directed toward the load and in that, in a second phase, the flame is directed substantially parallel to the charge.

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