(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 916 477 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
30.04.2008 Bulletin 2008/18

(21) Application number: **07118635.7**

(22) Date of filing: **17.10.2007**

(51) Int Cl.:
F23D 14/22 *(2006.01)* ***F23D 14/58*** *(2006.01)*
F23D 14/48 *(2006.01)* ***F23D 23/00*** *(2006.01)*

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC MT NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR MK RS

(30) Priority: **24.10.2006 US 585473**

(71) Applicant: **Air Products and Chemicals, Inc.**
Allentown, PA 18195-1501 (US)

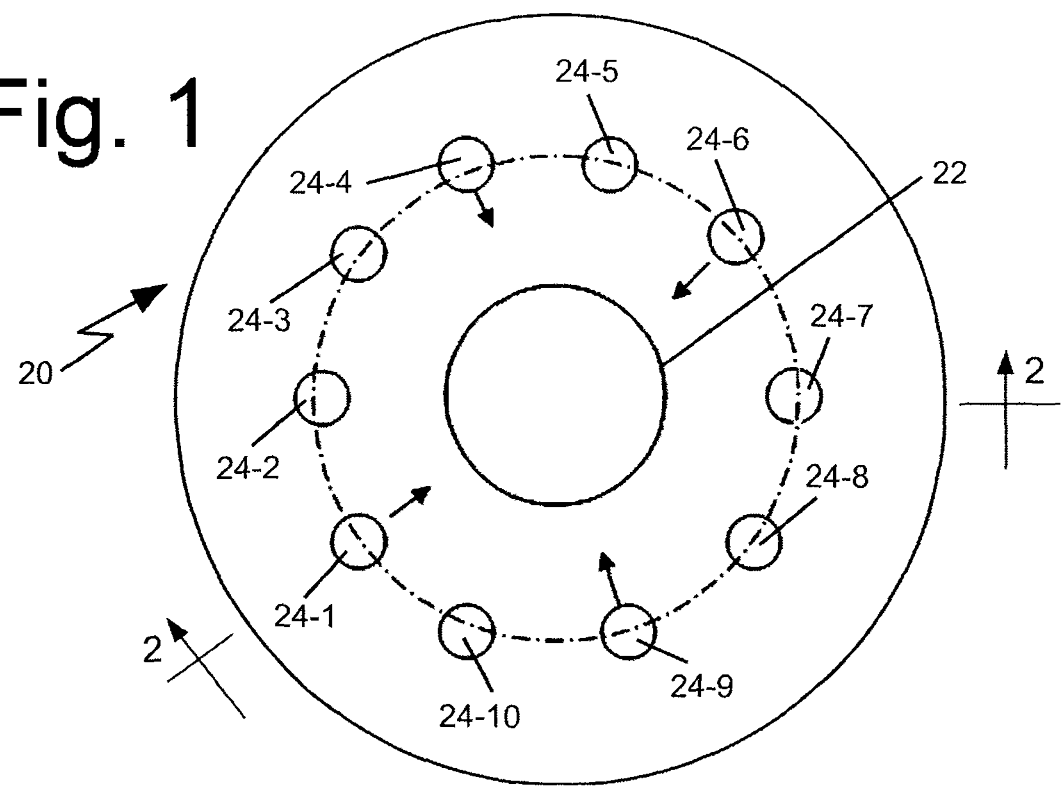
(72) Inventors:
- **Li, Xianming Jimmy**
  Orefield, PA 18069 (US)
- **Joshi, Mahendra Ladharam**
  Katy, TX 77450 (US)
- **SLAVEJKOV, Aleksandar Georgi**
  Allentown, PA 18104 (US)

(74) Representative: **Schwabe - Sandmair - Marx**
Stuntzstrasse 16
81677 München (DE)

(54) **Low nox staged fuel injection burner for creating plug flow**

(57) A burner for producing a plug-like flow and low NOx emissions. The burner has a central air jet and plural staged fuel jets surrounding the central jet. The ratio of the sum of the momentums of vector components of the staged jets along respective axes parallel to the central longitudinal axis of the central jet to the momentum of the central jet along that axis is within the range of 0.5 to 1.5 and most preferably 0.8.

Fig. 1



EP 1 916 477 A2

Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to burners for furnaces, and in particular to staged burners for creating a plug-type flow pattern with low nitrogen oxides (NOx) emissions.

[0002] Furnaces for ethylene cracking and other industrial processes, e.g., steam-methane reformers, typically make use of burners utilizing fuels such as natural gas, propane, hydrogen, refinery off-gas and other fuel gas combinations of various calorific values. For example, steam-methane reformer furnaces are used to produce hydrogen and carbon monoxide by reforming a hydrocarbon feed with steam and, at times, carbon dioxide at high temperatures. The furnace used for steam-methane reforming can be configured in several different structures. One of the most conventionally used arrangements for such reformer furnaces has vertical reformer tubes arranged in rows. The burners of the furnace can be located on the furnace's floor, its ceiling or its walls. As is known, operating a reformer tube above the desired temperature can cause large decreases in tube life. This, in turn will adversely affect the economics of the plant since the tubes are a substantial portion of the overall cost of the plant and require large expenditures of time and effort to replace one that has failed. Tube hot spots can arise from undesirable furnace flow patterns which cause flame impingement. This is particularly true in a tightly packed furnace with relatively few rows of burners and process tubes where the furnace geometry is such that the flue gas extraction system causes flue gas to cross over the process tubes. Needless to say any cross-over within the flame zone should be avoided to maintain equipment life and plant reliability. To that end, establishing an appropriate flow pattern is critical to uniform furnace heating and the concomitant reduction of process tube overheating. Thus, one important criterion for the design of burners where process tube overheating is a concern is to provide a burner that will inherently create what is commonly referred to as a plug-like flow.

[0003] Another important criterion for burner design is low NOx emissions. As is known nitrogen oxides are among the primary air pollutants emitted from combustion processes. NOx emissions have been identified as contributing to the degradation of environment, particularly degradation of air quality, formation of smog and acid rain. As a result, air quality standards are being imposed by various governmental agencies, which limit the amount of NOx gases that may be emitted into the atmosphere. One common way of reducing NOx emissions is by means of fuel/oxidant staging techniques, e.g., use of fuel staging burners making use of multiple jets outside and surrounding a central air jet. Other techniques are known for producing low NOx emissions from burners. The following are some exemplary references pertinent to the field of low NOx burners: U.S. Patent Nos 4,531,904 (Sato et al.), 4,946,382 (Kobayashi et al.) and 5,823,764 (Alberti et al.) and U.S. Published application 2006/0040223A1 (Ghani et al.). All references cited herein are incorporated herein by reference in their entireties.

[0004] While the above mentioned prior art may be suitable for their intended purposes, they nevertheless leave something to be desired from the standpoint of creating a uniform or plug-like flow with low NOx emissions.

BRIEF SUMMARY OF THE INVENTION

[0005] The subject invention constitutes a staged fuel burner for establishing a plug-like flow, and is particularly useful in furnaces, such as ethylene crackers, reformers, etc. The staged burner comprises a central nozzle and plural staged nozzles. The central nozzle has an orifice producing a jet of air directed along a central longitudinal axis. The staged nozzles surround the central nozzle and each has at least one orifice producing a staged jet Each staged jet comprises fuel, is directed along a respective longitudinal axis from the nozzle and has a vector component in a direction parallel to the central longitudinal axis. The sum of the momentums of the vector components of the staged jets parallel to the central longitudinal axis is approximately 50% to 150% (preferably 100%, and most preferably 80%) of the momentum of the central jet along the central longitudinal axis.

[0006] In accordance with another aspect of this invention there is provided a method of establishing a plug like flow of burning fuel in a furnace. The method entails providing a staged burner comprising a central nozzle and plural staged nozzles surrounding the central nozzle. The central nozzle has an orifice arranged for producing a jet of air directed along a central longitudinal axis. The staged nozzles surround the central nozzle and each has at least one orifice arranged for producing a staged jet. Each staged jet comprises fuel, is directed along a respective longitudinal axis and has a vector component in a direction parallel to the central longitudinal axis. Air is provided to the central nozzle, whereupon the central nozzle produces a jet of air directed along the central longitudinal axis. Fuel is provided to each of the staged nozzles, whereupon each staged nozzles produces a respective staged jet of fuel along a respective longitudinal axes. The sum of the momentums of the vector components of the staged jets parallel to the central longitudinal axis is approximately 50% to 150% (preferably 100%, and most preferably 80%) of the momentum of the central jet along the central longitudinal axis

BRIEF DESCRIPTION SEVERAL VIEWS OF THE DRAWING

[0007] The invention will be described in conjunction with the following drawings in which like reference numerals designate like elements and wherein:

[0008] Fig. 1 is an end view of one exemplary embodiment of a burner constructed in accordance with the subject invention;

[0009] Fig. 2 is a sectional view, not to scale, of the exemplary burner taken along line 2 - 2 of Fig. 1 ;

[0010] Fig. 3A is a sectional view, similar to Fig. 2, of another exemplary embodiment of a burner constructed in accordance with the subject invention;

[0011] Fig. 3B is a sectional view, similar to Fig. 3A, of another exemplary embodiment of a burner constructed in accordance with the subject invention;

[0012] Fig. 3C is a sectional view, similar to Fig. 3A, of another exemplary embodiment of a burner constructed in accordance with the subject invention;

[0013] Fig. 4A is a sectional view, similar to Fig. 2, of another exemplary embodiment of a burner constructed in accordance with the subject invention;

[0014] Fig. 4B is a sectional view, similar to Fig. 4A, of another exemplary embodiment of a burner constructed in accordance with the subject invention;

[0015] Fig. 4C is a sectional view, similar to Fig. 4A, of another exemplary embodiment of a burner constructed in accordance with the subject invention;

[0016] Fig. 5A is a sectional view, similar to Fig. 2, of another exemplary embodiment of a burner constructed in accordance with the subject invention;

[0017] Fig. 5B is a sectional view, similar to Fig. 5A, of another exemplary embodiment of a burner constructed in accordance with the subject invention;

[0018] Fig. 5C is a sectional view, similar to Fig. 5A, of another exemplary embodiment of a burner constructed in accordance with the subject invention;

[0019] Fig. 6A is a sectional view, similar to Fig. 2, of another exemplary embodiment of a burner constructed in accordance with the subject invention;

[0020] Fig. 6B is a sectional view, similar to Fig. 6A, of another exemplary embodiment of a burner constructed in accordance with the subject invention;

[0021] Fig. 6C is a sectional view, similar to Fig. 6A, of another exemplary embodiment of a burner constructed in accordance with the subject invention;

[0022] Fig. 7 is a sectional view, similar to Fig. 2, but showing still other exemplary embodiments of a burner constructed in accordance with the subject invention;

[0023] Figs. 8A - 8E are schematic diagrams of the arrangement and shape of several different exemplary orifices of some exemplary burners of the subject invention; and

[0024] Figs. 9A - 9I are enlarged end views of various shaped orifices that can be used with the burners of the subject invention;

DETAILED DESCRIPTION OF THE INVENTION

[0025] Referring now to Fig. 1 wherein like reference characters refer to like parts there is shown at 20 one exemplary embodiment of a staged fuel burner constructed in accordance with this invention. That burner exhibits good plug flow characteristics and low NOx emissions and is what is commonly referred to as a staged burner. To that end, the burner 20 includes a central nozzle 22 that is surrounded by a plurality of staging or staged nozzles 24. In the exemplary embodiment of Fig. 1 ten such staged nozzles 24-1 to 24-10 are provided. That arrangement is exemplary of a multitude of burners that can be constructed in accordance with this invention. In particular, burners constructed in accordance with this invention can include any number of staged nozzles surrounding the central nozzle. Each nozzle may include a single orifice or plural orifices. Moreover, the orifices may be of any shape and size, as will be seen later with reference to Figs. 8A - 8D and 9A - 9I. In the exemplary embodiment shown in Figs. 1 and 2 each nozzle includes a single, circular shaped orifice 26. Each orifice 26 is arranged to produce a stream or jet of a fluid along a longitudinal axis from the exit plane 28 of the orifice (i.e., the plane at the downstream end of the orifice). Thus, the orifice 26 of the central nozzle produces a jet of air and, if desired some fuel and/or combustion products, along the central longitudinal axis of the burner. The air, fuel and/or combustion products are provided to the central nozzle from means (not shown). The direction of this "central jet" is shown by the arrow designated as V_c in Fig. 2. It should be pointed out at this juncture that the direction of the central jet need not be parallel to the central longitudinal axis of the burner, such as shown in Fig. 2, but rather may extend at an angle thereto as shown in Figs. 6A - 6C (to be described later),

[0026] Each of the orifices 26 of each of the staged nozzles of burners constructed in accordance with this invention produces a jet of fluid (a "staged jet"), which includes fuel and may, if desired include some air and/or combustion products, along the longitudinal axis of the orifice from its respective exit plane. The fuel, air and/or combustion products are provided to the staged nozzles from means (not shown). The staged jets can all be directed in the same direction (e.g., parallel to the central longitudinal axis, at a converging angle to the central longitudinal axis or at a diverging angle to the central longitudinal axis) or can be directed in different directions to one another. For example, in the exemplary embodiment of Figs 1 and 2, four of the nozzles, namely, 24-1, 24-4, 24-6 and 24-9 are each directed at an inwardly converging angle to an axis 30 that is parallel to the longitudinal axis 32 of the central nozzle 22, while the other six nozzles 24-2, 24-3, 24-5, 24-7, 24-8 and 24-10 are each directed parallel to the longitudinal axis 32 of the central nozzle 22. In Fig. 2 the jet produced by the orifice of the nozzle 24-1 is shown by the arrow designated as V_1, and it extends at an angle θ_1 to the axis 30, while the jet produced by the orifice of the nozzle 24-7 is shown by the arrow designated as V_7 and extends parallel to the longitudinal central axis.

[0027] As best seen in Fig. 2, all of the staged nozzles 24-1 to 24-10 of the burner 20 are disposed equidistantly from one another about the central nozzle 22. Moreover, the exit plane of the orifices of the staged nozzles 24-1 to 24-10 is located rearward of the exit plane 28 of the orifice 26 making up the central nozzle 22. This arrangement is also merely exemplary of many arrangements of the position of the nozzles of burners constructed in accordance with this invention. Thus, the staged nozzles 24 need not be equidistantly spaced from one another, Moreover, the relative position of the exit plane of the orifice of the central nozzle to the orifices of the staged nozzles need not be like shown in Fig. 2, For example, as shown in Figs. 4A - 4C the exit planes of the orifices 26 of all of the burner's nozzles can be in the same plane. Alternatively, as shown in Figs. 5A - 5C the exit planes of the orifices 26 making up the staged nozzles can be located forward of the exit plane of the orifice of the central nozzle. In fact, it is contemplated that different orifices have different exit planes than other orifices. Further still, the number of staged nozzles used in any given burner is also matter of design choice, depending upon the application for the burner Thus, burners constructed in accordance with this invention may include any number of plural staged nozzles extending about the central nozzle. Further yet, the radial distance of each staged nozzle from the central longitudinal axis of the burner need not be the same. Accordingly, one or more staged nozzles 24 can be at a greater or lesser radial distance from the central longitudinal axis 32 than another staged nozzle.

[0028] Irrespective of the arrangement, number, size and direction of the nozzles/orifices, there exists a critical burner design parameter which causes a drastic change in the overall furnace flow pattern, much like laminar-to-turbulent transitions. This design parameter is the momentum ratio (hereinafter sometimes referred to as "MR") of the staged jets 24 to the central jet 22. in particular, it has been found that when a burner 20 is constructed so that the sum of the momentums of the staged jets is nearly equal to momentum of the central jet, an even or plug-like flow profile is observed. Most preferably this ratio is 0.8 (i.e., the sum of the momentums of the staged jets is 80% of the momentum of the central jet). However, it has been determined that plug-type flow can be achieved if the ratio is within the range 0.5 to 1.5 (i.e., 50% to 150%).

[0029] Turning again to Fig. 2, the momentum of the central jet produced by the nozzle 22 of the burner 20 is designated by $\dot{m}_c$, while the momentum of each of the surrounding staged jets produced by the nozzles 24-1 to 24-10 is designated by $\dot{m}_{s.i}$ where s designates that the momentum is of a staged jet and i represents the particular staging jet, e.g., in the embodiment shown in Fig. 2 i = "7" since the staging jet is that produced by the orifice making up the nozzle 24-7.

[0030] As mentioned above, the staged jets need not be all directed along axes parallel to the longitudinal axis of the central jet In fact, in the exemplary preferred embodiment, shown in Figs. 1 and 2 some staged jets, namely, the jets produced from the nozzles 24-1, 24-4, 24- 6 and 24-9, extend at an inwardly converging angle to the longitudinal axis of the central jet. The other of the staged jets, namely, the jets produced by nozzles 24-2, 24-3, 24-5, 24-7, 24-8 and 24-10, extend parallel to the longitudinal central axis of the central jet. Thus, the momentum ratio exhibited by burners constructed in accordance with this invention takes into account angularly directed jets. In particular, the momentum ratio produced by burners of this invention is the ratio of the combined momentums of the components of the staging jets that are directed parallel to the longitudinal axis of the central jet to the momentum of the central jet. As is well known, momentum is the product of mass flow and jet velocity and is a vector in the direction of the velocity. Here the jet velocity is the mean or average velocity based on the actual stream thermodynamic state (as defined by temperature, pressure, composition, etc.) at the point of exit from the orifice producing the jet and the area of the orifice through which the jet will pass, e.g., the area of the exit plane 28 of the jet's orifice 26. For staged fuel jets, this velocity can be readily determined, e.g., calculated based on the orifice area and the pressure at design rate measured during testing or in operation. For the central jet, the velocity is based on the area of the orifice and the combustion air temperature, or the burner opening into the furnace and the adiabatic flame temperature of the combustion air and the primary fuel, whichever is higher. Numerically, MR is defined by the following formula:

$$MR = \frac{\sum \dot{m}_{s,i} V_i \cos\theta_i}{\dot{m}_c V_c}$$

where *m* is mass flow rate of the identified jet, V is velocity of the identified jet at the exit plane of the orifice from which the jet projects, θ is the included angle between the central longitudinal axis and the longitudinal axes of the staged nozzles, and the subscripts *s*, *c*, *i* represent staged, central and *i*-th number of staged nozzles, because the burner includes multiple staged jets whose orifices have longitudinal axes which may extend at different angles to the central longitudinal axis of the central nozzle,

[0031] It has been observed that a smaller MR ratio means lower staged fuel fraction and the burner resembles more closely a single central jet. The flame is dominated by the center air jet, and a narrow flame ensues. When such burners are used in a typical furnace, the space between the flame produced thereby and the process tubes or the wall of the furnace will be filled by recirculating flue gas. A slight perturbation can cause the flame to touch the process tubes. In the limit, the burner is represented by a single point source. Because the point source has a high velocity, but the neighboring firing wall has zero velocity, the velocity differential and the resultant pressure difference create recirculation zones next to the jet, which become the origin of a large scale recirculation zone in the furnace.

[0032] As the MR ratio increases, more fuel is staged, and the burner gets farther away from a single central jet. When the MR ratio gets to approximately unity, the fuel (staged) jets and air (central) jet have similar momentums. The combined fuel and air jets from the burner have the best opportunity to develop a plug-type flow pattern and maintain the forward direction down the burner axis. If the MR is too large, the flame resembles a hollow jet and will collapse inward to the center and become short and bushy. Such flames tend to overheat the process tubes near the burners

[0033] A desired flame must balance the forward projecting power of a large air jet at the center and the heat release capacity of the fuel (staged) jets surrounding it. As was mentioned earlier, this balance manifests in this form as a momentum ratio close to one, with a ratio of 0.8 being optimum. Near the optimal MR ratio, the combined central air jet and staging jets attain pressure balance and produce a flame, which when used in a furnace proceeds in a straight line along the firing axis While the flow will tend to change direction and cross the process tubes, at some point (e.g., due to the flue gas extraction system) such action occurs at a sufficient distance from the burner so that the furnace gas temperature at the point where it crosses the process tubes is sufficiently low that overheating of the process tubes does not present a hazard. The plug flow in the combustion zone prevents flame impingement on the process tubes and discourages the formation of a large scale high temperature recirculation zone. As long as the combustion is complete, the combustion gases can go wherever they prefer without causing process tube overheating. The plug flow enables higher heat release intensity per cubic foot of combustion space without tube overheating. The elimination of the high temperature recirculation zone also reduces NOx emissions, since the formation of NOx is proportional to both temperature and retention time. The lower temperature also increases tube and catalyst life, and reduces soot formation in the process tubes

[0034] In Fig. 3A there is shown an alternative burner constructed in accordance with this invention. This embodiment is similar ta the embodiment of Fig. 2, except that all of the staged nozzles are directed so that their orifices 26 create staged jets extending parallel to the longitudinal axis 32 of the central nozzle 22. Thus, in the interest of brevity the common components of the embodiments of Figs. 2 and 3 will be given the same reference designations. As can be seen the burner of Fig. 3 has a central nozzle 22 that produces a central jet whose direction of flow is shown by the arrow designated as V_c while the two staged nozzles 24-1 and 24-2 shown produce respective staged jets shown by the arrows designated as V_1 and V_2, In Fig. 3B there is shown another alternative burner constructed in accordance with this invention. That burner is similar in construction to the burner shown in Fig. 3A except that its staged nozzles are directed so that the orifice of each creates a staged jet extending at an inwardly converging angle θ to an axis 30 that is parallel to the longitudinal axis 32 of the central nozzle 22. The direction of the jets from the orifices of the staged nozzles in Fig. 3B are shown by the arrows designated as V_1 and V_2. The other details of the construction of the burner of Fig. 3B are similar to the details of the burner of Fig. 3A and hence are given the same reference designations and will not be reiterated herein, In Fig. 3C there is shown another alternative burner constructed in accordance with this invention. That burner is similar in construction to the burner shown in Fig, 3A except that its staged nozzles are directed so that the orifice of each creates a staged jet extending at an outwardly diverging angle θ to an axis 30 that is parallel to the longitudinal axis of the central nozzle 22. The direction of the jets from the orifices of the staged nozzles in Fig. 3C are shown by the arrows designated as V_1 and V_2. The other details of the construction of the burner of Fig. 3C are similar to the details of the burner of Fig, 3A and hence are given the same reference designations and will not be reiterated herein.

[0035] Figs. 4A - 4C show further embodiments of burners constructed in accordance with this invention. The embodiments of Figs. 4A - 4C are similar to the embodiments of Figs. 3A - 3C, respectively, except that the exit planes of the orifices of all of the nozzles are coplanar. Thus, in the interest of brevity the common components of the embodiments of Figs, 4A, 4B and 4C and Figs. 3A, 3B and 3C, respectively, will be given the same reference designations and no further discussion of the details of the construction of the burners will be given.

[0036] Figs. 5A - 5C show further embodiments of burners constructed in accordance with this invention. The embodiments of Figs. 5A - 5C are similar to the embodiments of Figs. 3A - 3C, respectively, except that the exit planes of the orifices of the staged nozzles are coplanar and located forward of the exit plane of the orifice of the central nozzle. Thus, in the interest of brevity the common components of the embodiments of Figs. 5A, 5B and 5C and Figs. 3A, 3B and 3C, respectively, will be given the same reference designations and no further discussion of the details of the construction of the burners will be given.

[0037] Figs. 6A - 6C show further embodiments of burners constructed in accordance with this invention. The embodiments of Figs. 6A - 6C are similar to the embodiments of Figs. 4A - 4C, respectively, except that the central nozzle and its orifice extend at an angle to the central longitudinal axis 32 of the burner so that the central jet extends at that angle as shown by the arrow designated V_c. Thus, in the interest of brevity the common components of the embodiments of Figs 5A, 5B and 5C and Figs. 4A, 4B and 4C, respectively, will be given the same reference designations and no further discussion of the details of the construction of the burners will be given.

[0038] Fig. 7 shows still a further exemplary embodiment of a burner constructed in accordance with this invention. 1=ig. 7 is similar to Figs. 4B and 4C, except that its staged nozzles extend at different angles to each other In particular, one staged nozzle 24-1 extends at an inwardly converging angle θ_1 to an axis 30 that is parallel to the longitudinal axis of the central nozzle 22, while another staged nozzle 24-2 extends at an outwardly converging angle θ_2 to an axis 30 that is parallel to the longitudinal axis of the central nozzle 22.

[0039] As mentioned earlier the orifice(s) making up the central nozzle and/or any of the staged nozzles can be of any shape or size. For example, as shown in Fig. 8A the central nozzle 22 can have a single orifice 26 of circular cross section and be surrounded by four staged nozzles 24-1, 24-2, 24-3 and 24-4. Each of the staged nozzles has a single circular shaped orifice 26, whose diameter is substantially smaller than the diameter of the central orifice. Moreover, the orifices 24-1, 24-2, 24-3 and 24-4 are equidistantly spaced from each other and equidistantly spaced from the central orifice In Fig. 8B there is shown another nozzle arrangement. This arrangement is similar to the arrangement of Fig. 8A, except that the central nozzle includes a square shaped orifice 26. In Fig. 8C there is shown another nozzle arrangement. This arrangement is similar to the arrangement of Fig. 8A, except that the central nozzle includes a hexagonal shaped orifice 26. Fig, 8D shows another nozzle arrangement. This arrangement is similar to the arrangement of Fig. 8A, except that the central nozzle includes a rectangular shaped orifice 26. Figs. 9A - 9H show various other shapes for orifices that can be used in burners of this invention, such as the circular orifice of Fig. 9A, the square orifice of Fig. 9B, the hexagonal orifice of Fig. 9C, the rectangular orifice of Fig. 9D, the multi-cross slotted orifice of Fig. 9E, the cruciform orifice of Fig. 9F, and the two cross slotted orifice of Fig, 9G. Fig. 9H shows a nozzle which can be the central nozzle 22 or any or all of the staged nozzles 24, where the nozzle has three circular shaped orifices 26 arranged in a triangular array in the lower half of the nozzle. Fig. 91 shows a nozzle which can be the central nozzle 22 or any or all of the staged nozzles 24, where the nozzle has two circular shaped orifices 26 arranged in a linear array in the lower half of the nozzle. It must be pointed out at this juncture that the orifices and nozzles shown herein are merely a few examples of a myriad of shapes and sizes that can be used in burners constructed in accordance with this invention.

[0040] As should be appreciated by those skilled in the art the burners of the subject invention has particular utility for use in furnaces. However, its use is not limited to such applications. When used in furnaces the burners of the subject invention will eliminate the high temperature recirculation zone by creating a plug flow like flow pattern. With the high temperature recirculation zone eliminated, a higher firing rate can be maintained. Furthermore, the process tubes of a furnace making use of burners constructed in accordance with the subject invention will have an extended life due to the lower and even surrounding temperature. The lower temperature will also decrease the soot formation and increase catalyst life. Finally, since NOx formation is proportional to temperature, eliminating hot spots will decrease NOx emissions.

[0041] While the invention has been described in detail and with reference to specific examples thereof, it will be apparent to one skilled in the art that various changes and modifications can be made therein without departing from the spirit and scope thereof.

Claims

1. A staged fuel burner for establishing a plug-like flow in a furnace, said staged burner comprising: a central nozzle and plural staged nozzles, said central nozzle having an orifice for producing a jet comprising air directed along a central longitudinal axis, said staged nozzles surrounding said central nozzle, each of said staged nozzles having at least one orifice for producing a staged jet comprising fuel, each of said staged jets being directed along a respective longitudinal axis and having a vector component in a direction parallel to said central longitudinal axis, whereby the sum of the momentums of said vector components of said staged jets parallel to said central longitudinal axis is approximately 50% to 150% of the momentum of the central jet along said central longitudinal axis.

2. The staged fuel burner of Claim 1 wherein said sum of the momentums of said vector components of said staged jets parallel to said central longitudinal axis is approximately 80% to 100% of the momentum of the central jet along said central longitudinal axis.

3. The staged fuel burner of Claim 2 wherein said sum of the momentums of said vector components of said staged jets parallel to said central longitudinal axis is approximately 80% of the momentum of the central jet along said central longitudinal axis.

4. The staged fuel burner of Claim 1 additionally comprising means for supplying fuel to said staged nozzles and means for supplying air to said central nozzle.

5. The staged fuel burner of Claim 4 additionally comprising means for supplying air to said staged nozzles, whereupon said staged jets comprise fuel and air.

6. The staged fuel burner of Claim 4 wherein said burner additionally comprises means for supplying fuel to said central nozzle.

7. The staged fuel burner of Claim 4 wherein said burner additionally comprises means for providing combustion products to said central nozzle.

8. The staged fuel burner of Claim 1 wherein each orifice includes a respective exit plane and wherein the ratio of the sum of the momentums of the vector components of said staged jets parallel to said central longitudinal axis to the momentum of the central jet along said central longitudinal axis is a ratio (MR) defined by the formulae

$$MR = \frac{\sum \dot{m}_{s,i} V_i \cos\theta_i}{\dot{m}_c V_c}$$

where $\dot{m}$ is mass flow rate of the identified jet, V is velocity of the identified jet at the exit plane of the orifice from which the jet projects, θ is the included angle between the central longitudinal axis and the respective longitudinal axes of said staged nozzles, and the subscripts *s*, *c*, *i* represent staged, central and *i*-th number of staged nozzles.

9. The staged fuel burner of Claim 1 wherein said respective longitudinal axes of said staged jets extend parallel to said central longitudinal axis.

10. The staged fuel burner of Claim 1 wherein said longitudinal axis of at least one of said staged jets extends at an outward diverging angle to said central longitudinal axis.

11. The staged fuel burner of Claim 10 wherein said longitudinal axes of all of said staged jets extends at an outward, diverging angle to said central longitudinal axis.

12. The staged fuel burner of Claim wherein said longitudinal axis of at least one of said staged jets extends at an inward, converging angle to said central longitudinal axis.

13. The staged fuel burner of Claim 10 wherein said longitudinal axes of all of said staged jets extends at an inward, converging angle to said central longitudinal axis.

14. The staged fuel burner of Claim 1 wherein said orifices of said staged burners have a common exit plane.

15. The staged fuel burner of Claim 14 wherein said orifice of said central nozzle has an exit plane that is located forward of said common exit plane of said staged burners.

16. The staged fuel burner of Claim 14 wherein said orifice of said central nozzle has an exit plane that is located rearward of said common exit plane of said staged burners.

17. The staged fuel burner of Claim 14 wherein said orifice of said central nozzle has an exit plane that is coplanar with said common exit plane of said staged burners.

18. The staged fuel burner of Claim 1 wherein said orifices of said staging nozzles are the same size and shape.

19. The staged fuel burner of Claim 1 wherein said orifices of said staging nozzles are different sizes and/or shapes.

20. A method of establishing a plug like flow of burning fuel in a furnace comprising:

(A) providing staged burner comprising a central nozzle and plural staged nozzles surrounding said central nozzle, said central nozzle having an orifice arranged for producing a jet comprising air directed along a central longitudinal axis, said staged nozzles surrounding said central nozzle, each of said staged nozzles having at least one orifice and arranged for producing a staged jet comprising fuel, each of said staged jets being directed along a respective longitudinal axis and having a vector component in a direction parallel to said central longitudinal axis,
(B) providing a fluid comprising air to said central nozzle, whereupon said central nozzle produces a jet comprising air directed along said central longitudinal axis, and
(C) providing a fluid comprising fuel to said staged nozzles, whereupon said staged nozzles produce respective staged jets comprising fuel along said respective longitudinal axes, whereby the sum of the momentums of said vector components of said staged jets parallel to said central longitudinal axis is approximately 50% to 15a% of the momentum of the central jet along said central longitudinal axis.

21. The method Claim 20 wherein said sum of the momentums of said vector components of said staged jets parallel to said central longitudinal axis is approximately 80% to 100% of the momentum of the central jet along said longitudinal axis.

22. The method of Claim 21 wherein said sum of the momentums of said vector components of said staged jets parallel to said central longitudinal axis is approximately 80% of the momentum of the central jet along said longitudinal axis.

23. The method of Claim 20 additionally comprising supplying air to said staged nozzles, whereupon said staged jets comprise fuel and air.

24. The method of Claim 20 wherein additionally comprising supplying fuel to said central nozzle, whereupon said central jet comprises air and fuel.

25. The method of Claim 20 additionally comprising providing combustion products to said central nozzle, whereupon said central jet comprises air and combustion products.

26. The method of Claim 20 wherein each orifice includes a respective exit plane and wherein the ratio of the sum of the momentums of the vector components of said staged jets parallel to said central longitudinal axis to the momentum of said central jet along said central longitudinal axis is a ratio (MR) defined by the formula:

$$MR = \frac{\sum \dot{m}_{s,i} V_i \cos\theta_i}{\dot{m}_c V_c}$$

where $\dot{m}$ is mass flow rate of the identified jet, V is velocity of the identified jet at the exit plane of the orifice from which the jet projects, θ is the included angle between the central longitudinal axis and the respective longitudinal axes of said staged nozzles, and the subscripts *s*, *c*, *i* represent staged, central and *i*-th number of staged nozzles.

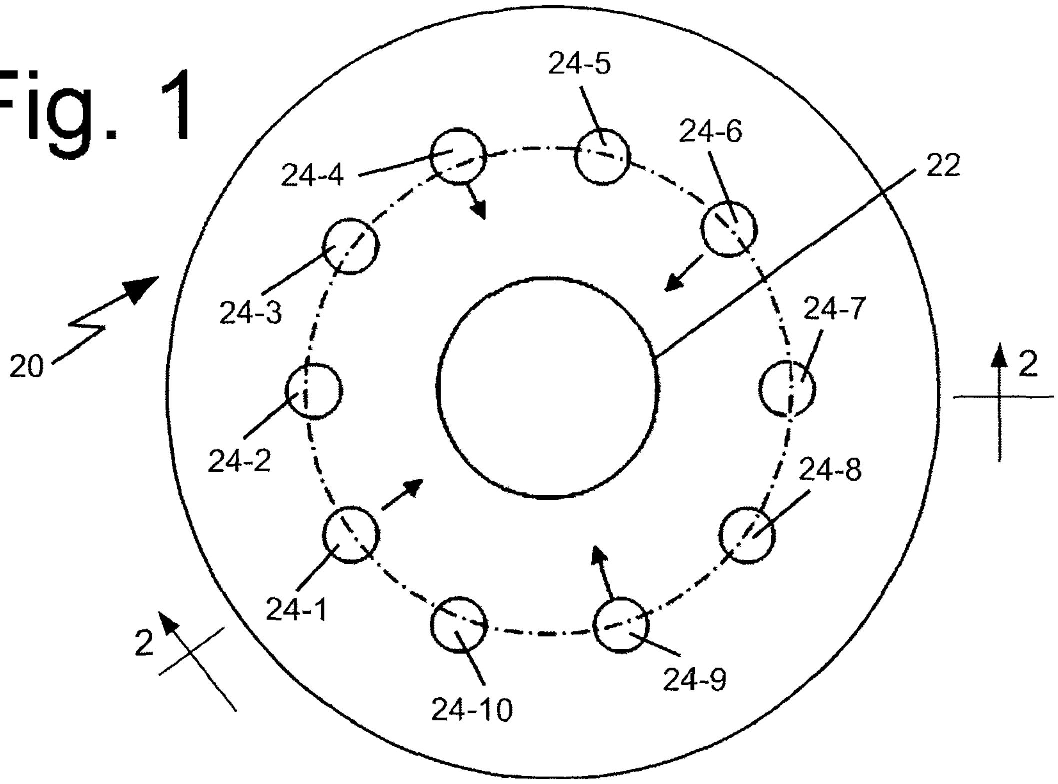

24-5
24-4
24-6
22
24-3
24-7
20
2
24-2
24-8
24-1
2
24-9
24-10

Fig. 1

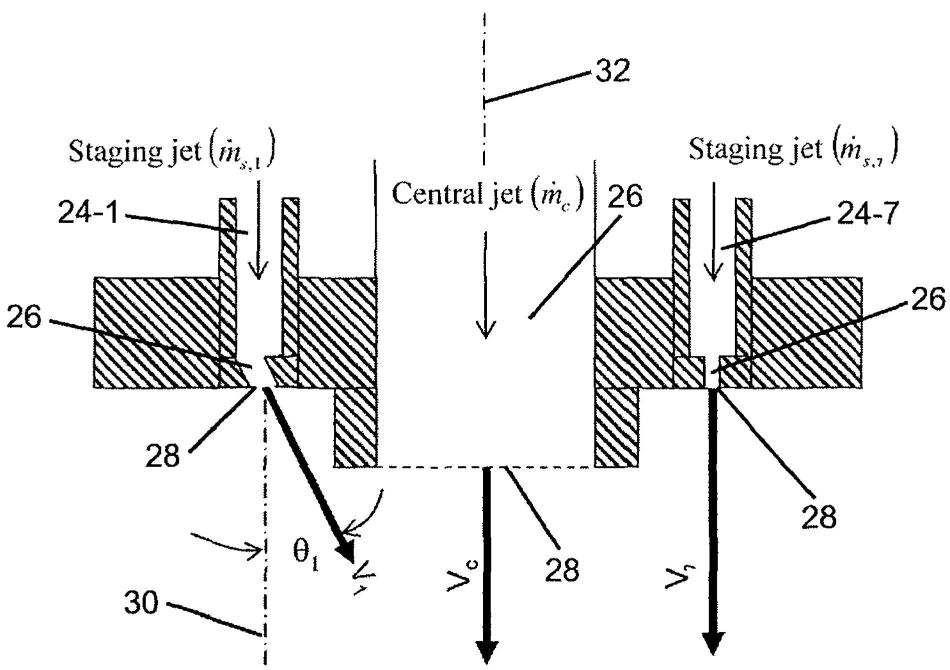

32
Staging jet ($\dot{m}_{s,1}$)
Staging jet ($\dot{m}_{s,7}$)
Central jet ($\dot{m}_c$)
26
24-1
24-7
26
26
28
28
θ_1
V_1
V_c
28
V_7
30

Fig. 2

Fig. 3A

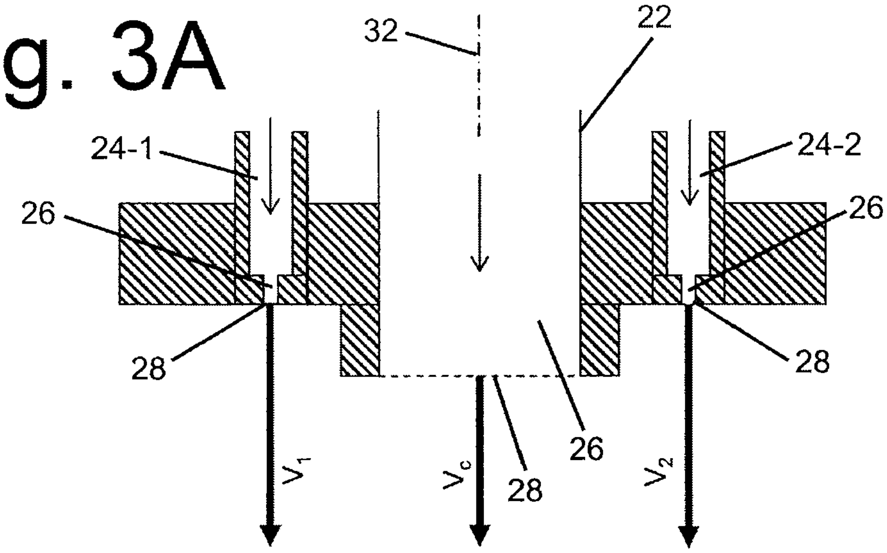


Fig. 3B

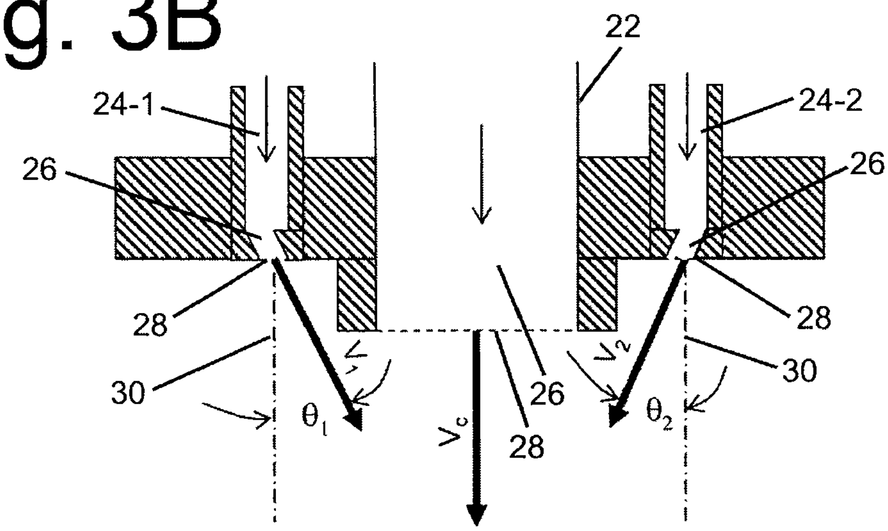


Fig. 3C

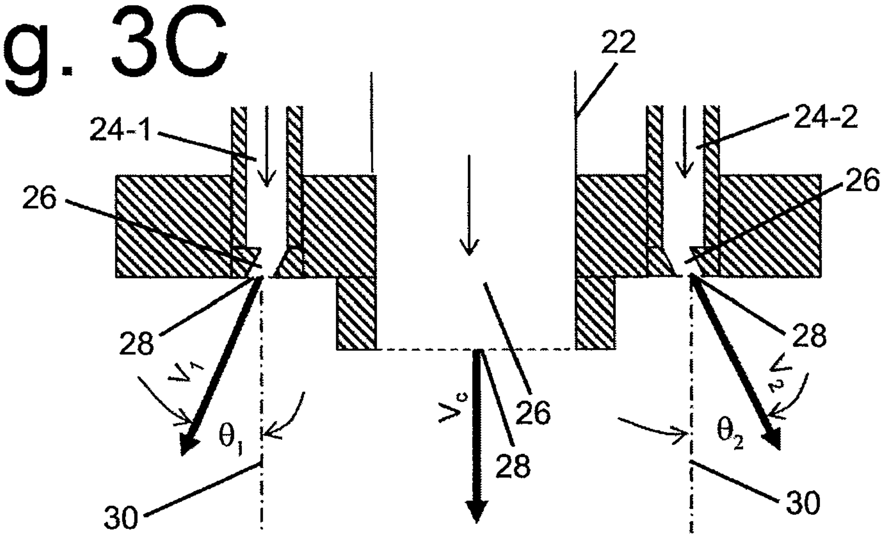


Fig. 4A

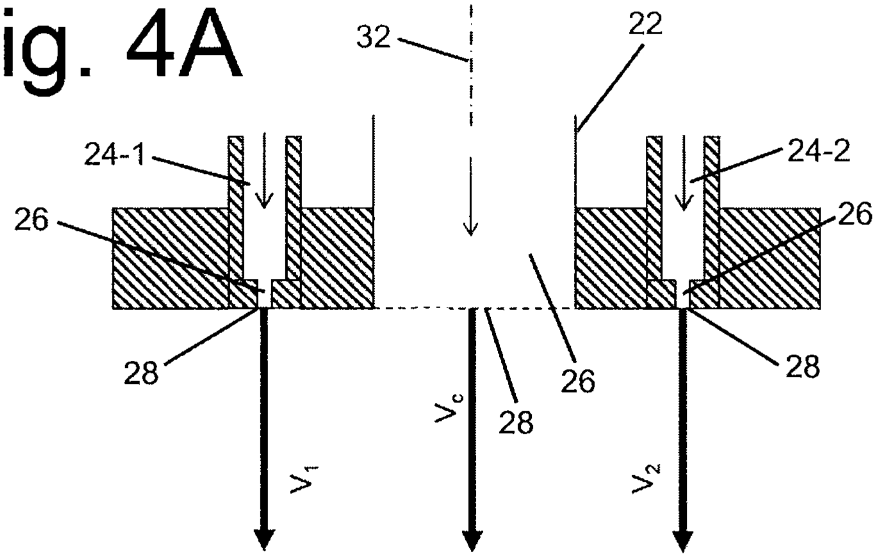


Fig. 4B

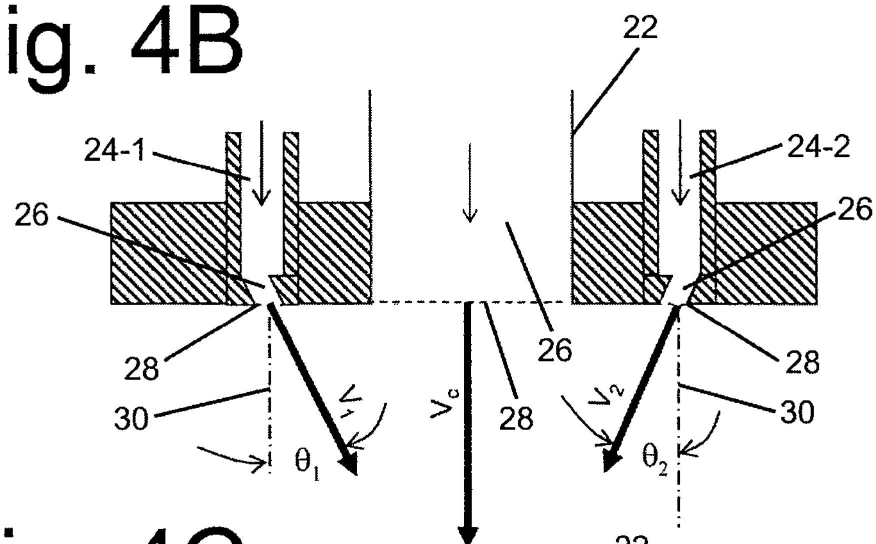


Fig. 4C

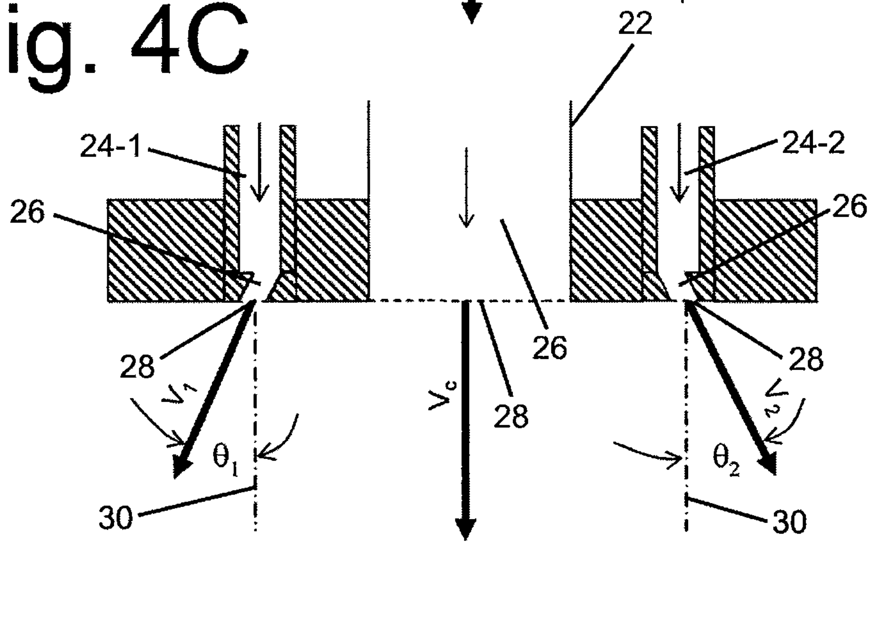


Fig. 5A

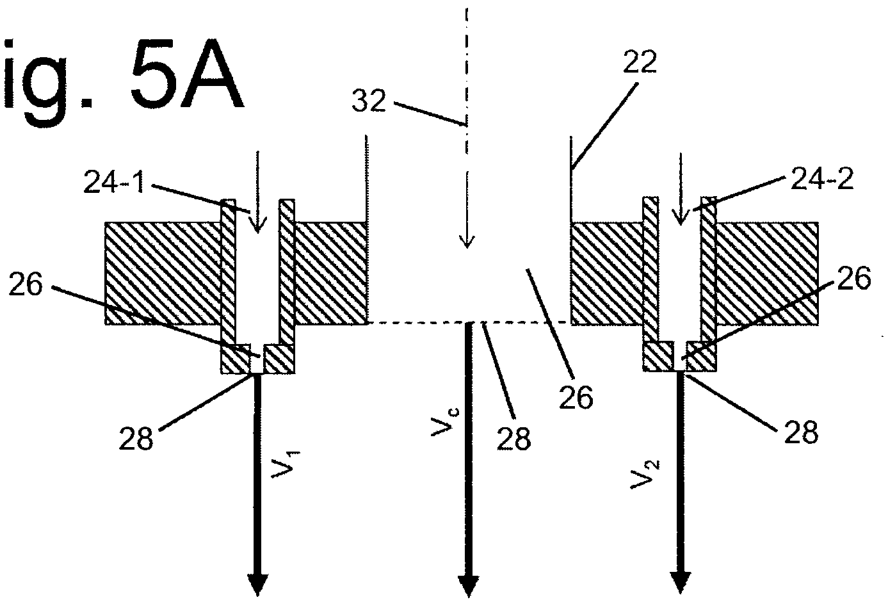


Fig. 5B

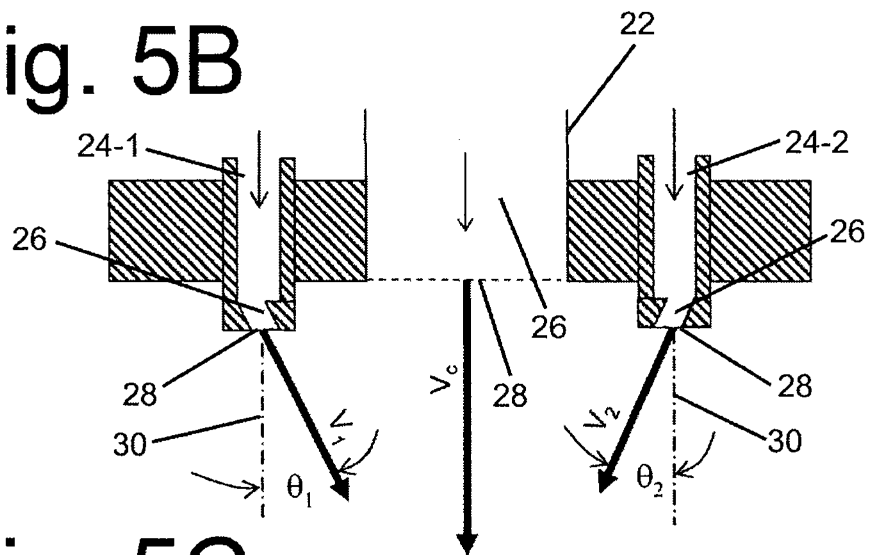


Fig. 5C

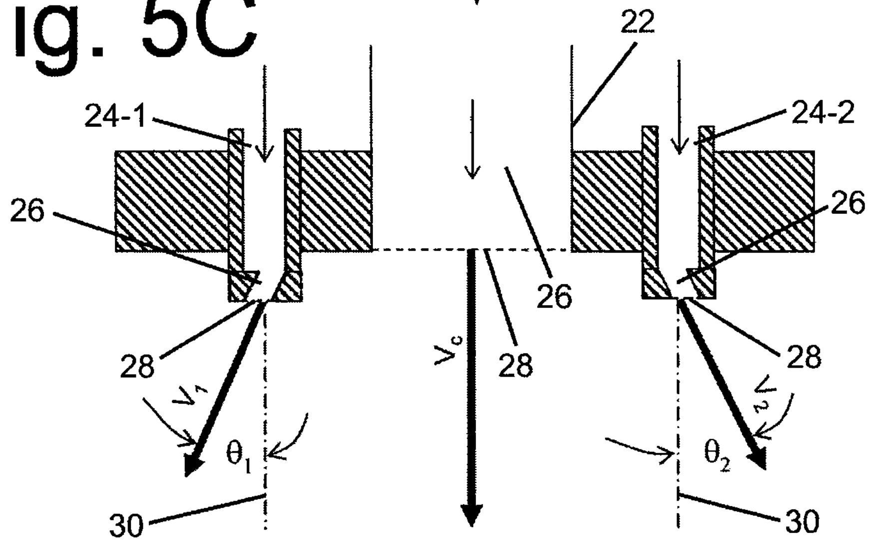


Fig. 6A

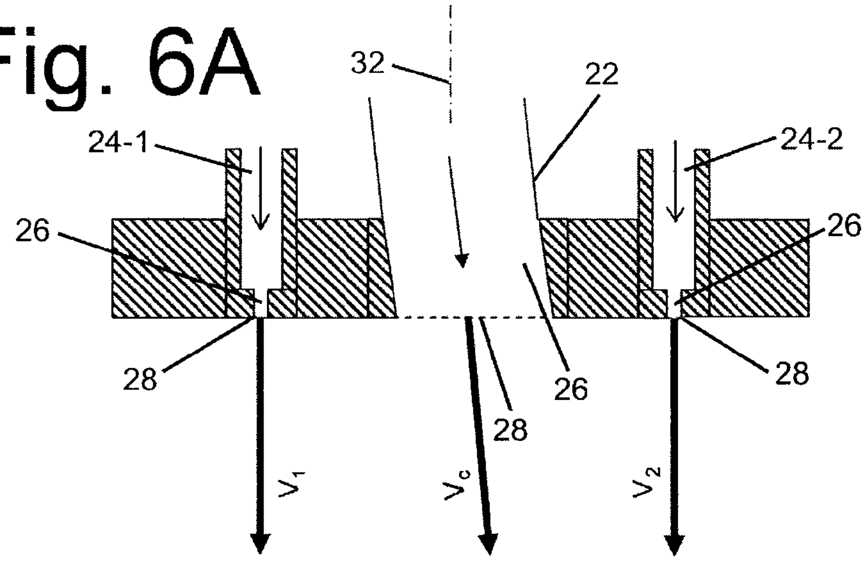


Fig. 6B

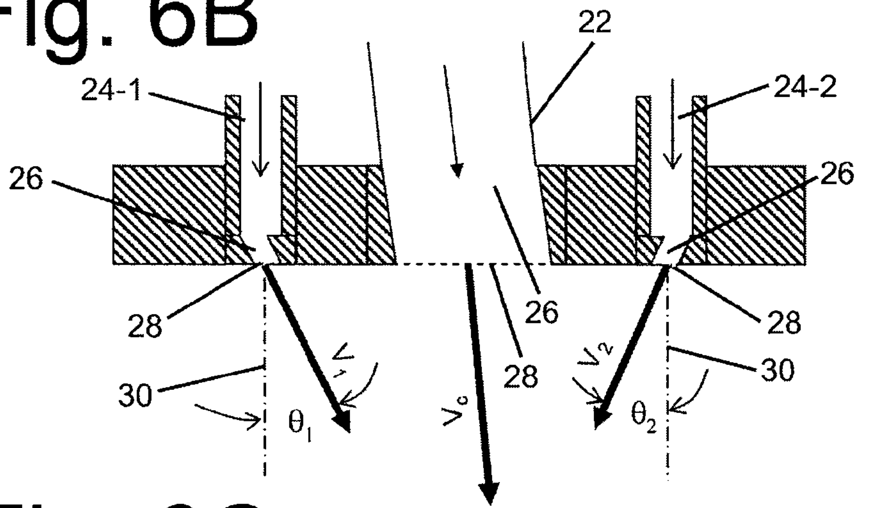


Fig. 6C

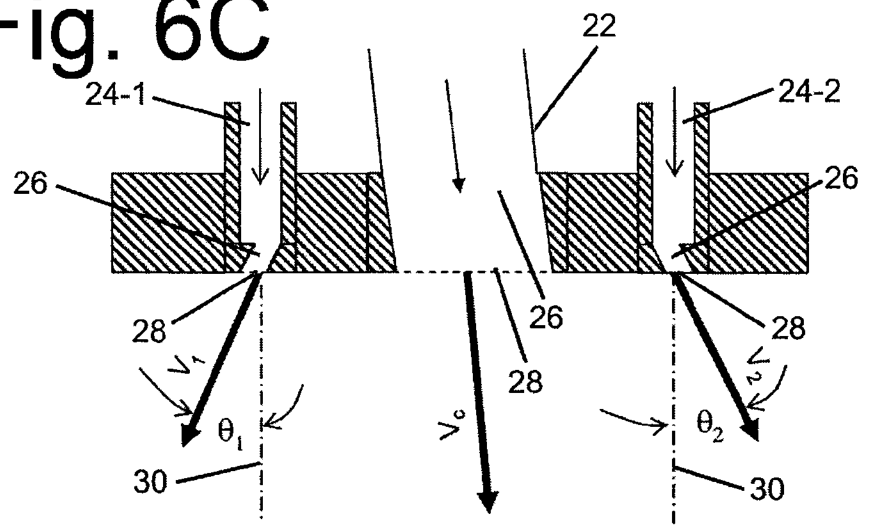


Fig. 7

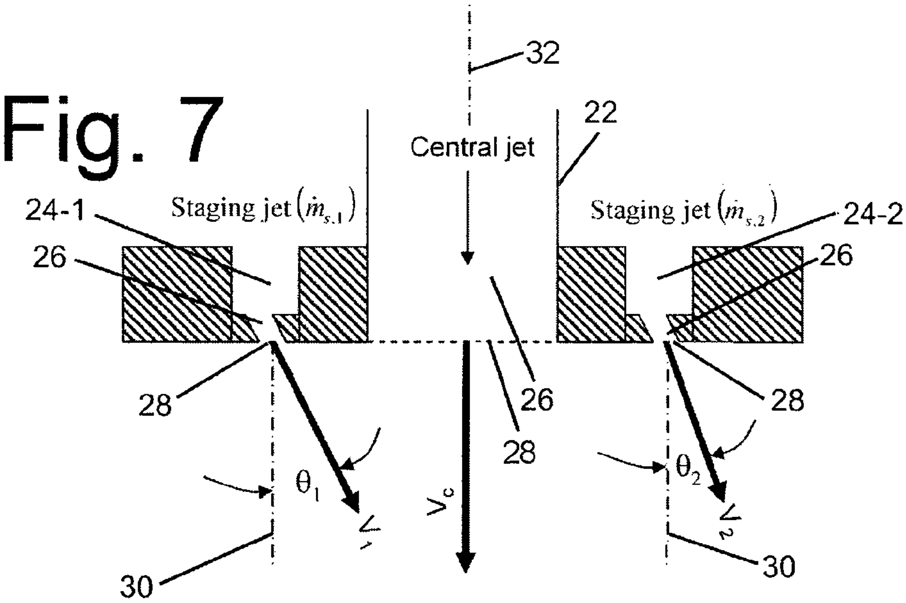


Fig. 8A

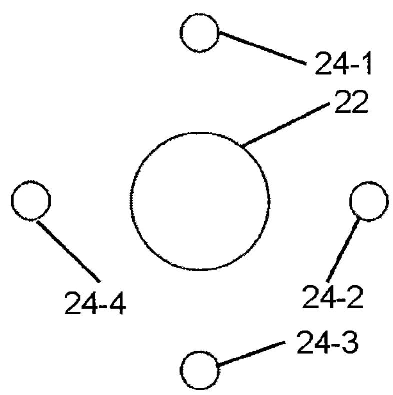


Fig. 8B

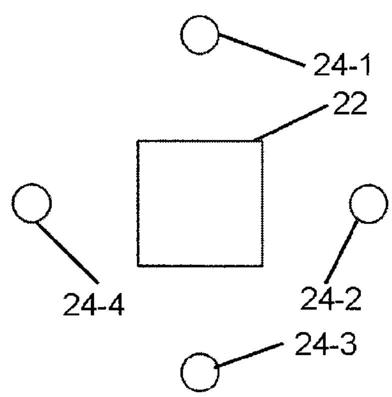


Fig. 8C

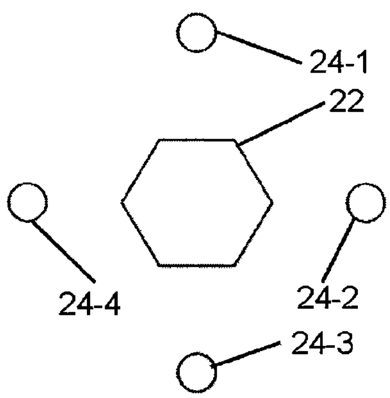


Fig. 8D

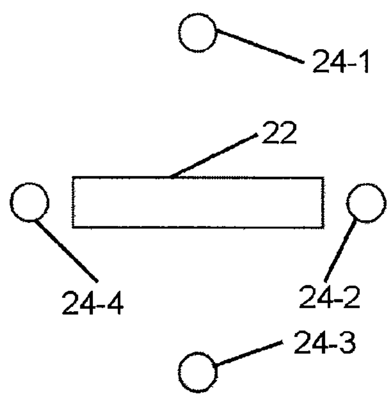


Fig. 9A

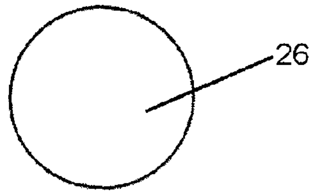


Fig. 9B

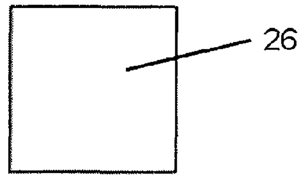


Fig. 9C

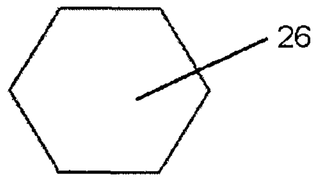


Fig. 9D

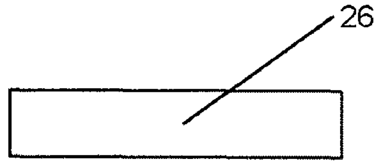


Fig. 9E

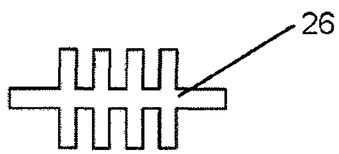


Fig. 9F

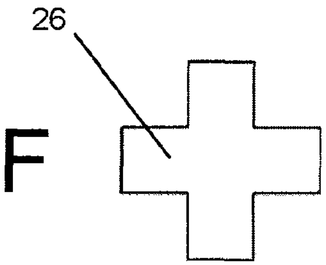


Fig. 9G

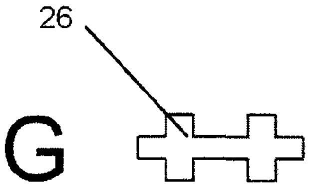


Fig. 9H

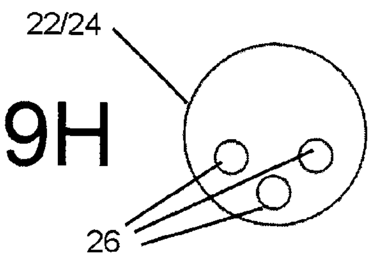
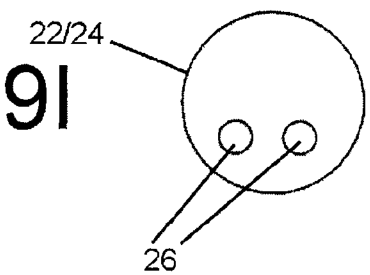


Fig. 9I



REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 4531904 A, Sato **[0003]**
- US 4946382 A, Kobayashi **[0003]**
- US 5823764 A, Alberti **[0003]**
- US 20060040223 A1, Ghani **[0003]**