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(54) A BURNER AND A METHOD FOR FORMING A FLAME IN A FURNACE BY A BURNER

(57) The invention relates to a burner (1) for forming a flame (F) in a furnace (3) by means of gaseous fuel (G) and combustion air (I), simultaneously recirculating flue gases (S) in the furnace (3), wherein the burner (1) comprises

- a burner frame (1a) and a combustion head (2) connected to the same by its cylindrical body (20), wherein the end portion (21) of the combustion head (2) facing the furnace (3) extends at its first end to the furnace (3), and the second end of the end portion (21) is connected to said cylindrical body (20),

- a primary gas pipe (10) for supplying gaseous fuel (G; G1) to the furnace (3), wherein the primary gas pipe (10) extends inside the combustion head (2) in its longitudinal direction, particularly inside (T) of the end portion (21) of the combustion head, and the orifice of the primary gas pipe (10) opens into or close to the furnace (3), and a primary air supply pipe (14) also extends inside the combustion head (2) and surrounds said primary gas pipe (10), and the orifice of the supply pipe (14) opens into the furnace (3) or to the orifice (21) of the end portion (21) of the combustion head (2),

- a flow duct for main combustion air (Imain) extending inside the combustion head and surrounding said primary air supply pipe (14) at least inside (T) of the end portion (21), and

- a set of main gas rods (6), comprising a set of elongated primary gas rods (6¹, 6²... 6ⁿ) extending in the longitudinal direction of the combustion head, for supplying the furnace (3) with fuel, wherein the main gas rods (6¹, 6²... 6ⁿ) are arranged at least partly outside the cylindrical body (20) of the combustion head (2), extending close to

the joint (L) between the cylindrical body (20) and the end portion (21) so that they are surround said body (20) at regular intervals around the circumference of the body (20), and wherein in connection with the main gas rods (6¹, 6²... 6ⁿ), at the end portion (21) of the combustion head, several ejector ducts (8; 81) are provided for recirculating flue gas (S) from the furnace (3) into the gaseous fuel (G; G2) coming from the main gas rods, and for conveying the produced flue gas-flue mixture (S+G2) further to the furnace (3).

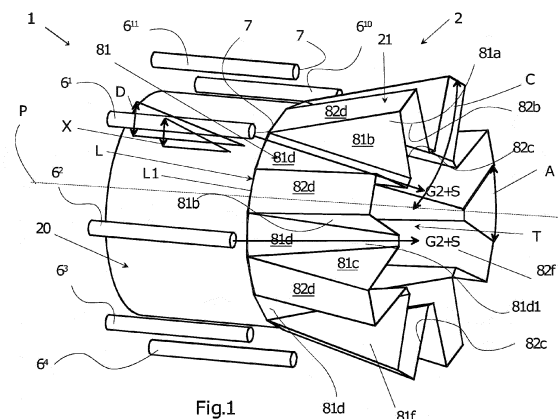


Fig.1

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Description

[0001] The invention relates to a burner according to the preamble of claim 1 for forming a flame in a furnace by means of gaseous fuel and combustion air, simultaneously recirculating flue gases in the furnace.

[0002] The invention also relates to a method according to the preamble of claim 21 for forming a flame in a furnace by a burner according to claim 1.

[0003] The invention further relates to a burner-boiler assembly, wherein the burner frame of a burner as defined in claim 1 is installed in a boiler.

[0004] The invention relates to a burner whose operation is based on internal recirculation of flue gas. The internal recirculation of flue gas is a process in which flue gases from combustion are recirculated back to the foot of the flame. The purpose of internal recirculation of flue gas in a furnace is to reduce nitrogen oxides generated from combustion and to enhance cooling of the combustion head.

[0005] The applicant's own published application FI 20215192 discloses a burner in which internal recirculation of flue gases in a furnace is used to reduce nitrogen oxides generated from combustion. However, the burner comprises some drawbacks. For example, the distribution of main combustion air for staging of combustion is implemented by a deflector plate which may cause interference in the flame formation.

[0006] The aim of the invention is to reduce or at least alleviate problems present in said prior art and to further reduce the amount of nitrogen oxides resulting from the use of the burner by more efficient internal recirculation of flue gases.

[0007] The above presented aims are achieved by a burner according to claim 1 for forming a flame in a furnace by means of gaseous fuel and combustion air, simultaneously recirculating flue gases, and by a corresponding method for forming a flame in a furnace by a burner as defined in claim 1.

[0008] More precisely, the invention relates to a burner according to claim 1 for forming a flame in a furnace by means of gaseous fuel and combustion air, simultaneously recirculating flue gases in the furnace. The burner comprises - a burner frame and a combustion head connected by its cylindrical body to the burner frame, wherein the first end of the end portion of the combustion head, facing the furnace, extends into the furnace, and the second end of the end portion is connected to said cylindrical body,

- a primary gas pipe for supplying gaseous fuel to the furnace, the primary gas pipe extending inside the combustion head in its longitudinal direction, particularly inside of the end portion of the combustion head, and the orifice of the primary gas pipe opening into or to the vicinity of the furnace, and a primary air supply pipe also extends inside the combustion head, surrounding said primary gas pipe, and the orifice of the supply pipe opening into the furnace or to the orifice of the end portion of the combustion head,
- a flow duct for main combustion air (Imain) extending inside the combustion head and surrounding said primary air supply pipe at least inside of the end portion, and
- a set of main gas rods, comprising a set of elongated primary gas rods extending in the longitudinal direction of the combustion head, for supplying the furnace with fuel, wherein the main gas rods are arranged at least partly outside the cylindrical body of the combustion head, extending close to the joint between the cylindrical body and the end portion so that they surround said body at regular intervals around the circumference of the body.

[0009] Furthermore, in connection with the primary gas rods, in the end portion of the combustion head, a number of ejector ducts are provided for recirculating flue gas from the furnace to the gaseous fuel from the main gas rods, and for conveying the produced mixture of flue gas and fuel further to the furnace.

[0010] The end portion of the combustion head has the shape of a truncated cone and comprises ejector ducts and air ducts alternating in the direction of the circumference of said end portion, the free ends of the ducts opening in the direction of the furnace, and the top end of the duct groove of each ejector duct being also open in the direction of the furnace, and the lower end of the duct groove of each air duct being also open in the direction of the central axis of the combustion head, wherein the end portion having the shape of a truncated cone expands at an angle of 3 to 30 degrees, seen from the direction of the joint between the cylindrical body of the combustion head and the end portion of the combustion head.

[0011] In the method according to the invention, the flame is formed in the furnace by a burner as defined in claim 1, by means of gaseous fuel and combustion air, simultaneously recirculating flue gases. Thus, for forming a primary flame, primary gas is supplied to the primary gas pipe via the part of said primary gas pipe on the side of the burner frame, and primary air is also supplied by means of the primary air supply pipe extending inside the combustion head and leading to the furnace, and

- for forming a main flame, a flow of main combustion air is conveyed from the inside of the combustion head to the

furnace, and a flow of main gas is conveyed via the main gas rods, wherein the main gas is conveyed into each main gas rod via its part on the side of the burner frame, wherein flue gas from the furnace is mixed into the flow of main gas by means of ejector ducts at the orifice of the end portion of the combustion head. The flame produced in the furnace, formed by the primary flame and the main flame, and the distribution of fuel, combustion air and internally recirculated flue gas at the orifice of the combustion head, achieved by the shape of the combustion head, result in an inert return flow of flue gases having low contents of oxygen and unburned fuel components.

[0012] If natural gas is used as the fuel, the inert return flows arriving at the area of the combustion head contain less than 5000 ppm of carbon monoxide and less than 5000 ppm of methane. The oxygen content of the return flow depends on the total air factor. The oxygen content is lower than 5 wt% on average, the total air factor λ being 1.15.

[0013] The invention also relates to a burner-boiler assembly, wherein the frame of a burner as defined in claim 1 is installed in a boiler so that the combustion head of the burner extends into the furnace. Thus, the power density (kW/m²) of the burner, that is, the fuel power (kW) of the burner in relation to the cross-sectional area (m²) of the furnace is not more than 10,000 kW/m².

[0014] The present invention is based on the idea that the orifice of the combustion head, having the shape and structure of a truncated cone at the end portion of the burner, provides secondary and tertiary flows of main combustion air as well as alternation of ejector ducts and air ducts at the orifice of the burner in its circumferential direction. This, in turn, results in efficient staging of combustion and in a main flame where the burning of main gas is such that the return flows of flue gas are as inert as possible, and also the amount of nitrogen oxides generated during combustion of the main gas is as small as possible. When return flows of flue gas are efficiently mixed with the main gas via ejector ducts at the orifice of the combustion head, it is possible to efficiently reduce the amount of nitrogen oxides during combustion and to decrease the temperature of the combustion head.

[0015] By the design of the combustion head and by the internal recirculation of flue gases, it is possible to achieve, particularly with natural gas, a nitrogen oxides emission level even lower than 2.5 ppm (per standard cubic metre, dry, referred to 3% residual oxygen) without external recirculation of flue gas.

[0016] Inert return flow of flue gases refers to a flue gas composition having such low fuel contents that they do not provide significant combustion power, and the oxygen content of the flue gas composition being as low as possible.

[0017] The return flow of flue gases refers to a flue gas flow outside the diameter of the approximately cylindrical combustion head, wherein the velocity component of the flue gas flow in the axial direction of the combustion head extends in a direction opposite to the velocity component of the fluid flow (air flow + gas flow) from the combustion head in the axial direction of the combustion head.

[0018] The orifice of the combustion head having the shape of a truncated cone, and the alternation of ejector ducts and air ducts at the end portion of the combustion head and particularly on the circumference of the orifice of the combustion head, in turn, result in the distribution of air, intended for combustion of main gas, into flows of secondary air and tertiary air. By staging the flows of secondary and tertiary air, it is possible to optimize the temperature of the flame and to provide a desired burning rate in various use conditions and furnaces.

[0019] Primary air is introduced with primary gas via primary nozzles into the furnace, and in dual-fuel burners, liquid fuel is supplied to the burner via an oil inlet. With primary air and primary gas, a primary flame is produced, intended to enable steady burning.

[0020] In an embodiment of the invention, the burner further comprises an air ejector connected to the flow duct for main combustion air and arranged to absorb flue gas from the furnace.

[0021] Preferably, the orifices of the flue gas duct of the air ejector are arranged evenly within the end portion of the combustion head over the entire flow area (B) of main combustion air, and the structure of each air ejector is arranged so that the respective air ejector is capable of absorbing at least 0.3% of flue gas per mbar of static pressure loss produced by the ejector into the main combustion air (I_{main}), calculated from the total amount (wt-%/wt-%) of main combustion air passed through the ejector within a given period of time.

[0022] Flue gases can be conveyed from the furnace to the air ejector via openings in a row of openings arranged in the area of the body of the combustion head defined by the set of main gas rods. These openings in the body of the combustion head encircle the body of the combustion head at regular intervals and open into the flue gas duct of the air ejector.

[0023] With such an air ejector, a mixing ratio between flue gas and air is achieved which secures a maximum temperature lower than 500°C for the air-flue gas mixture downstream of the air ejector. In preferred embodiments of the invention, the maximum temperature of the air-flue gas mixture inside the combustion head is lower than 300°C.

[0024] An air ejector of the above described type, connected to the main air duct, boosts the recirculation of flue gases further, enabling a further reduction in the nitrogen oxide level and good cooling of the combustion head. As to the more detailed structure of the air ejectors, reference is made to prior art, such as the applicant's own published application FI 20215192.

[0025] In the following, the invention and the advantages achieved by it will be described in more detail with reference to the appended drawings.

Figure 1 shows a schematic perspective view of the combustion head of a burner according to the invention.

Figure 2A shows a schematic view of the longitudinal section of the frame of a burner according to the invention, and the combustion head connected to it.

Figure 2B shows a schematic view of a combustion head according to an embodiment of the invention from above.

Figure 2C shows a schematic view of the combustion head of Fig. 2B from the front.

Figure 3 shows a schematic view of a flame formed by combustion air and gaseous fuel discharged from the orifice of the combustion head.

[0026] In the following, the aspects of the invention illustrated by each of the Figures 1 to 3, and the structural and functional properties of the burner shown in the figures, will first be briefly discussed.

[0027] Figures 1 and 2A show a burner 1 according to the invention for forming a flame F in a furnace 3 by means of gaseous fuel G and combustion air (I). For forming the flame, flue gases S, which are as inert as possible, are recirculated within the furnace 3.

[0028] Figure 1 shows the combustion head 2 of the burner, comprising the body 20 of the combustion head 2, to which the end portion 21 of the combustion head 2, having the shape of a truncated cone, is connected.

[0029] Figure 2A shows a furnace 3, in which the burner 1 is mounted in an intermediate wall 31. The burner frame 1a is shown on the left side of the intermediate wall 31, and the body 20 of the combustion head is shown on the right side of the intermediate wall 31.

[0030] Figure 2A shows a view of a longitudinal section of the burner in the furnace 3, illustrating the burner frame 1a of the burner 1 and the combustion head 2 connected to it and extending into the furnace 3. The combustion head 2 comprises a cylindrical body 20 to which a end portion 21 having the shape of a truncated cone is connected and extends into the furnace 3. The part of the end portion 21 on the side of the furnace 3 constitutes an orifice 25 which opens into the furnace 3. The conical end portion 21 is connected to the cylindrical body 20 at a joint L extending around the body 20.

[0031] The combustion head 2 is provided with a set 6 of main gas rods comprising a number of elongated main gas rods 6¹, 6²...6ⁿ, for supplying the furnace 3 with fuel.

[0032] In Fig. 2A, that part of the main gas rods 6, into which main gas G₂ is fed, is marked as part 6a of the main gas rods 6, extending on the side of the burner frame 1a. Correspondingly, that part of the main gas rods 6 which protrudes into the furnace 3 is marked as part 6b of the main gas rods 6, extending on the side of the furnace 3. The main gas rods 6 extend in the longitudinal direction of the burner. Figure 1 shows how the main gas rods 6¹, 6²... 6ⁿ extend at least partly outside the body 20 of the combustion head 2 and are connected to the cylindrical body 20 of the burner so that they extend around said body 20 at regular mutual distances in the direction of the circumference of the body 20.

[0033] The set of main gas rods 6 extend into the furnace 3 through an intermediate wall 31 separating the furnace 3 and the burner body 20, and the part 6b of each main gas rod 6¹, 6²... 6ⁿ on the side of the furnace 3 extends in the longitudinal direction of the body 20 of the combustion head 2 (= in the direction of the central line P of the combustion head 2) to a distance from said intermediate wall 31. Preferably, the main gas rods 6 extend close to the joint L between the cylindrical body 20 and the end portion 21.

[0034] In connection with the main gas rods 6¹, 6²... 6ⁿ in the end portion 21 of the combustion head 2, several ejector ducts 8; 81 are provided for recirculating flue gas S from the furnace 3 to the gaseous fuel G; G₂ coming from the main gas rods 6, and for conveying the resulting flue gas-fuel mixture S+G₂ further to the furnace 3.

[0035] The end portion 21 of the combustion head 2 of the burner 1 has the shape of a truncated cone and comprises ejector ducts 81, opening in the direction of the furnace 3, and air ducts 82, opening in the direction of the inside T of the end portion 21 of the combustion head, alternating in the direction of the circumference of said end portion 21 (cf. particularly Fig. 1).

[0036] The end portion 21 in the shape of a truncated cone expands at an angle of 3 to 30 degrees, seen from the joint L between the cylindrical body 20 of the combustion head 2 and the end portion 21 of the combustion head 2. This expansion of the end portion of the combustion head is illustrated by an angle C measured as the distance, in the axial direction of the end portion of the combustion head, from the central line P of the combustion head to the bottom of the air duct 81. At the joint L, the distance from the central line P of the combustion head to the groove bottom 82d of the air duct is 3 to 30% smaller than the same distance between the central line of the combustion head and the groove bottom, measured at the orifice 25 of the end portion 21.

[0037] Each ejector duct 81 is also open at the top of the duct groove 81f facing the furnace 3, and each air duct 82 is also open at the bottom of the duct groove 82f towards the central axis P of the combustion head, i.e. towards the inside T of the end portion.

[0038] Preferably, one main gas ejector duct 81 is provided for each main gas rod 6.

[0039] As shown in the sectional view of Fig. 2A, the burner 1 also comprises a primary gas pipe 10 for supplying the furnace 3 with gaseous fuel G; G1. The primary gas pipe 10 extends inside the combustion head 2, in its longitudinal direction, particularly inside T of the end portion 21 of the combustion head 2. The orifice of the primary gas pipe 10 opens into the furnace 3 or close to it, such as into the orifice 25 of the end portion. An inlet pipe 14 for primary air also extends

inside the combustion head 2, surrounding said primary gas pipe 10. The orifice of the primary air inlet pipe 14 opens into the furnace 3 or into the orifice 25 of the end portion 21 of the combustion head 2.

[0040] The flow duct for main combustion air (Imain) in the burner 2 extends inside the combustion head 2 and surrounds said primary air inlet pipe 14 at least inside T of the end portion 21.

[0041] In a preferred embodiment of the invention, a primary flame F1 can be produced by supplying liquid fuel for the primary flame along a channel extending inside the primary pipe 14. This supply of liquid fuel is indicated by the marking "oil" in the cross-sectional figure 2A.

[0042] Main gas G2 is supplied to the ejector ducts 81 along the main gas rods 6. Separate gas inlets and controls are provided for primary gas GA and main gas G2 each, so that the ratio between these gases can be optimized for each application to achieve good flame stability and the highest possible efficiency of the ejector ducts 81.

[0043] Figure 2A also shows a stabilizer 9 for the purpose of forming the primary flame close to the combustion head and keeping it burning in all operating conditions. This enables safe and steady combustion.

[0044] A primary gas nozzle 11 and an oil nozzle 12 may be positioned upstream and/or downstream of the stabilizer.

[0045] Figures 2B and 2C show more detailed views of the structure of the ejector ducts 81 and air ducts 82 alternating in the direction of the circumference of the end portion 21 of the combustion head 2.

[0046] Figure 2B shows an embodiment of the invention depicting the combustion head 2 from above. Figure 2B shows four main gas rods 6; 6¹, 6², 6³ and 6⁴ of the set of main gas rods 6 (in total, 8 rods are provided in the combustion head 2 shown in Fig. 2). These main gas rods 6; 6¹, 6², 6³ and 6⁴ extend on the shell 20d of the body 20, from the intermediate wall 31 in the direction of the central line 9 of the combustion head to the joint L between the body 20 and the end portion 21. An ejector duct 81 of the end portion 21 extends from an end of each main gas rod 6; 6¹, 6², 6³ and 6⁴, while an air duct 82 is provided on either side of the ejector duct 81.

[0047] Figure 2C, in turn, illustrates the combustion head 2 directly from the front, i.e. from the direction of the orifice 25. Figure 2 shows eight main gas rods 6; 6¹, 6²... 6⁸. These main gas rods 6; 6¹, 6²... 6⁸ extend on the shell 20d of the body 20 of the combustion head 2, to the joint L between the body 20 and the end portion 21, as shown in Fig. 2C.

[0048] An ejector duct 81 of the end portion 21 extends from the end of each main gas rod 6; 6¹, 6², 6³ and 6⁸, while air ducts 82 are provided on either side, opening in the direction of the central line P of the combustion head, i.e. to the inside T of the end portion 21.

[0049] As shown in said Figs. 2B to 2C, and partly in Fig. 1 as well, each ejector duct 81 at the end portion 21 of the combustion head 2 comprises a groove bottom 81d in the longitudinal direction of the combustion head 2, with a groove wall 81b or 81c extending, on either side, upwards from the groove bottom 81d, i.e. away from the longitudinal central axis P of the combustion head 2. The duct groove 81f of the ejector duct 81, left between these groove walls 81b, 81c, is open at its top facing the furnace 3.

[0050] Figure 1 shows how each ejector duct 81 extends approximately in parallel with the main gas rod 6 ending at the upstream end of the respective ejector duct, i.e. on the side of the intermediate wall. However, the groove bottom 81d of the ejector duct 81 at the end portion 21 of the combustion head 2 is tilted at an angle X of about 3 to 20 degrees downwards, i.e. in the direction of the longitudinal central axis P of the combustion head 2, when said groove bottom 81d is seen from the joint L between the cylindrical body 20 of the combustion head and the end portion 21 of the combustion head 2, extending around the combustion head 2. The main gas jet from the main gas rod 6 is directed to the ejector duct 81 at an angle D which is either the same as or different from the tilt angle X of the groove bottom 81d.

[0051] When the ejector duct 81 is seen from the joint L1 between the ejector duct 81 and the body 20 towards the free end 81d1 of the groove bottom 81d of said ejector duct 81, facing the furnace 3, the groove bottom 81d of the ejector duct 81 at the end portion 21 of the combustion head 2 tapers or has a constant width.

[0052] Moreover, when the ejector duct 81 is seen from the joint L1 between the cylindrical body 20 of the combustion head 2 and the ejector duct, the groove bottom 81d of the ejector duct 81 at the end portion 21 of the combustion head 2 is, at the joint L1 between said ejector duct 81 and the cylindrical body 20 of the combustion head 2, flush with the shell 20d of the cylindrical body 20.

[0053] The groove walls 81b, 81c of the ejector duct 81 at the end portion 21 of the combustion head 2 extend from the groove bottom 81d of the ejector duct 81 obliquely upward, i.e. away from the central line of the combustion head, towards the furnace 3. Planes extending via the groove walls 81b, 81c of the ejector duct 81 are placed at an angle A of 1 to 30 degrees to each other.

[0054] The width of the duct groove 81f of the ejector duct 81 at the end portion 21 of the combustion head 2, measured at the joint L1 between the groove bottom 81d of said ejector duct 81 and the cylindrical body 20, is 0.2 to 1 times the length of the circumference of the shell 20d of the cylindrical body 20, divided by the number n of ejector ducts 81 at the end portion 21 of the combustion head 2.

[0055] The length of the duct groove 81f of each ejector duct 81 is 3 to 15 times the width of the same duct groove 81f of the ejector duct 81, when said width of the duct groove 81f is measured at the joint L1 between the groove bottom 81d of said ejector duct 81 and the cylindrical body 20.

[0056] Herein above, ejector ducts 81 at the end portion of the combustion head 2 have been discussed. An air duct 82 is provided on either side of each ejector duct 81. The groove walls 81b, 81c of each ejector duct 81 at the end portion 21 of the combustion head 2 simultaneously constitute the groove walls 82b, 82c of the two adjacent air ducts 82. In the following, the structure and function of these air ducts will be discussed in more detail with reference to particularly Figs. 1, 2B and 2C.

[0057] Each air duct 82 at the end portion 21 of the combustion head 2 comprises a groove bottom 82d in the longitudinal direction of the combustion head 2, with a groove wall 82b, 82c extending, on either side, downward from said groove bottom 82d. The duct groove 82f of the air duct 82 left between the groove walls 82b, 82c is open towards the inside T of the end portion 21 of the combustion head 2, encircling the central axis P of the combustion head 2 at the end portion 21.

[0058] The groove bottom 82d of each air duct 82 at the end portion 21 of the combustion head 2 extends at an angle of 3 to 30 degrees upward, i.e. away from the longitudinal central axis P of the combustion head, when said groove bottom 82d of the air duct 82 is seen from the joint L between the cylindrical body 20 and the end portion 21, encircling the combustion head 2. The inside T of the end portion 21 encircling the longitudinal central line P; P2 of the combustion head 2 expands so that the distance S between the groove bottom 82d of each air duct 82 at the end portion 21 of the combustion head 2 and the longitudinal central line P of the combustion head 2 is 3 to 30% greater at the end of the groove bottom 82d of said air duct 82 on the side of the furnace than at the joint L1 between the groove bottom 82d of the same air duct 82 and the cylindrical body 20 of the combustion head 2.

[0059] The burner 1 may also comprise an air ejector 9 in connection with the flow duct for main combustion air I_{main} at the body 20 of the combustion head 2, provided for absorbing flue gases from the furnace 3. The air ejectors 9 at the body 20 of the combustion head 2 and the ejector ducts 82 at the end portion 21 of the combustion head 2 are arranged in relation to each other in such a way that the location for feeding flue gas S into the ejector ducts 82 is upstream of the openings for the air ejectors 9 in the body 20, seen from the direction of the orifice 25 of the end portion 21 of the combustion head 2.

[0060] Flue gases S can be conveyed to the air ejector 9 via a flue gas duct, from that longitudinal area B of the body 20 of the combustion head 2 where the main gas rods 6 extend outside the body 20 of the combustion head 2 in the furnace 3. Each air ejector 9 is arranged to absorb at least 1% of flue gas per mbar of static pressure loss generated by the ejector into the main combustion air (I_{main}), calculated from the total content of main combustion air (wt-%/wt-%).

[0061] Moreover, the amount of flue gas to be absorbed by the air ejector 9 into the main combustion air is adjusted so that the maximum temperature of the air-flue gas mixture in the flow direction of said air-flue gas mixture (I+S) downstream of the air ejector 9 is lower than 500°C, preferably lower than 300°C.

[0062] At least one opening is provided for each air ejector 9 in the frame, and the openings for the air ejectors 9 of the set of air ejectors, provided in the frame and connected to the flue gas ducts, constitute a row of 6 to 60 openings encircling the combustion head 2 at the same distance from the vertical plane extending via the orifice 25 of the combustion head 2.

[0063] Each air ejector 9 comprises one or more partly hollow blades, including an entry-side blade arranged to accelerate the flow of combustion air I steadily on said entry-side blade.

[0064] In the following, Figs. 2A and 3 will be discussed to illustrate the operation of the burner and the formation of a flame F and return flows.

[0065] Figure 3 illustrates the formation of a flame produced by the burner according to the invention, and return flows of flue gases. In the method according to the invention, a burner 1 according to the invention is used to form a primary flame F1 and a main flame F2 by means of gaseous fuel (G) and combustion air (I), whereby flue gases S are simultaneously recirculated.

[0066] By adjusting the ratios between secondary air I_s and tertiary air I_t as well as between primary gas and main gas to be suitable, a uniform flame can be formed. A uniform flame is shown in Fig. 3. Figure 3 shows how the main flame F2 and the primary flame F1 merge to form a flame F, and return flows P are formed during burning, which are inert return flows P_I at the combustion head.

[0067] Via the set of main gas rods 6, a first amount of gaseous fuel can be supplied to the furnace 3, for forming the main flame F2 by means of secondary air I_s and tertiary air I_t; and via the primary gas pipe 10, a second amount of gaseous fuel can be supplied to the furnace 3 for forming the primary flame F1. The amount of primary gas to be supplied for forming the primary flame F1 and the amount of main gas to be supplied for forming the main flame are adjusted mutually so that the main flame F2 and the primary flame F1 will merge.

[0068] This provides efficient staging of combustion and a main flame F2 in which the burning of main gas is such that the return flows P of flue gas are return flows P_I as inert as possible. Furthermore, the formation of nitrogen oxides is as minimal as possible during the burning of the main gas itself. By the design of the combustion head and by the internal recirculation of flue gases, it is possible to achieve, particularly with natural gas, a nitrogen oxides emission level even lower than 2.5 ppm (per standard cubic metre, dry, referred to 3% residual oxygen) without external recirculation of flue gas.

[0069] For forming the primary flame F1, the primary gas pipe 10 is supplied with primary gas G1 via the part 10a of said primary gas pipe 10 on the side of the burner frame 1a. Moreover, primary air I_p is also supplied via a primary air inlet pipe

14 extending inside the combustion head 2 and leading to the furnace 3. The primary flame F1 can also be produced by supplying liquid fuel.

[0070] For forming the main flame F2, a flow of main combustion air (I_{main}) is conveyed from the inside of the combustion head 2 to the furnace 3, as well as a flow of main gas G2 via the main gas rods $6^1, 6^2 \dots 6^n$. The main combustion air (I_{main}) flows inside of the body 20 of the combustion head 2 and the end portion 21 but outside of the primary air inlet pipe 14.

[0071] Main gas G2 is introduced into each main gas rod $6^1, 6^2 \dots 6^n$ via its part 6a on the side of the burner frame 1a, wherein flue gas S is mixed with the flow of main gas G2 by main gas ejectors 8. The flame (F; $F1 + F2$) formed by the primary flame F1 and the main flame F2 in the furnace causes a flue gas return flow $PI (S_{inert})$ which is as inert as possible. In the case of burning natural gas, the flue gas return flow $PI (S_{inert})$ contains less than 5000 ppm of carbon monoxide and less than 5000 ppm of methane when entering the area of the combustion head. The oxygen content of the return flow depends on the total air factor. Average oxygen content is less than 5 wt-% when the total air factor λ is 1.15.

[0072] As mentioned, the flow of main gas G2 can be conveyed via the main gas rods $6^1, 6^2 \dots 6^n$ from the inside of the combustion head 2 to the furnace 3. Thus, flue gases S can be conveyed by main gas ejectors 8 from the furnace 3 into the main gas G2 flowing in each main gas rod $6^1, 6^2 \dots$ of the set of main gas rods 6, one ejector duct 81 being provided for each main gas rod $6^1, 6^2 \dots$. The flue gases S are conveyed into the main gas G2 flowing in the main gas rod part 61 of each main gas rod $6^1, 6^2 \dots$ on the side of the burner frame 1a by an ejector duct 81 arranged in connection with (downstream of) each main gas rod. Flue gases S from the furnace 3 as well as main gas G2 flowing in the main gas rod 62 enter into each ejector duct 81.

[0073] The flow area B of main combustion air (I_{main}) inside the body 20 of the combustion head 2 comprises an area left between the primary air inlet pipe 14 and the body 20 of the combustion head 2.

[0074] By the structure and dimensions of the ejector ducts 81 and air ducts 82 at the end portion 21 as well as by the conical shape of said end portion 21, the flow of main combustion air (I_{main}) is divided at the end portion 21 of the combustion head 2 into a flow of secondary air I_s and a flow of tertiary air I_t (cf. Fig. 2A).

[0075] In the furnace 3, the flue gases S flow to the root of the flame F, from where they are conveyed by the ejector ducts 81 to the gaseous fuel G; G2 flowing in the second part 6b of the main gas rods 6.

[0076] As illustrated in Fig. 2A, the main combustion air I_{main} is divided into tertiary air I_t and secondary air I_s at the end portion of the combustion head. Tertiary air constitutes 5 to 50 vol-%, preferably 5 to 40 vol-% of the main combustion air I_{main} supplied to the furnace 3, and secondary air I_s constitutes 50 to 95 %, preferably 60 to 95 vol-% of the main combustion air (I_{main}) supplied to the furnace 3.

[0077] The burner may comprise an air ejector 9, as shown in Fig. 2A. A set of air ejectors comprises several elongated air ejectors 9. The entire air mass of the main combustion air (I_{main}) is forced through the set of air ejectors. Each air ejector 9 comprises a flue gas duct with two orifices of the flue gas duct opening from the body 20 of the combustion head 2 to the furnace 3, the orifices of the flue gas duct being oriented in opposite directions, seen from the inside of the flue gas duct.

[0078] Each air ejector 9 comprises one or more partly hollow blades. An air ejector 9 consisting of one or more blades comprises an entry-side blade arranged to steadily accelerate the flow of the main combustion air (I_{main}) on said entry-side blade. This entry-side blade extends into the flue gas duct, and downstream of the flue gas duct the same or a different blade extends as an exit-side blade arranged to steadily decelerate the flow of air-flue gas mixture S, I on said exit-side blade.

[0079] The static pressure of main combustion air (I_{main}) decreases when it flows along the entry-side blade towards the flue gas duct. Static pressure of the combustion air-flue gas mixture I+S, in turn, increases as the mixture flows along the exit-side blade, away from the flue gas duct. In the area B of the body 20, at least one opening, preferably two openings are provided for each air ejector 9 in the set of air ejectors. The openings provided in the frame and connected to the flue gas ducts of the air ejectors 9 of the set of air ejectors constitute a row of 6 to 60 openings encircling the combustion head 2 at the same distance from the vertical plane extending via the orifice 25 of the combustion head 2.

[0080] Before the division of the main combustion air at the end portion 21 into tertiary air I_t and secondary air I_s , flue gas S (combustion gas) from the furnace 3 can thus be mixed with the main combustion air (I_{main}) by the air ejectors 9. Thus, flue gases S are conveyable from the furnace 3 to each air ejector 9 of the set of air ejectors by openings in a row of openings in the area B of the body 20 of the combustion head 2 defined at least partly by the set of main gas rods 6, the openings of the body opening into a flue gas duct / flue gas ducts of the air ejector(s) 9, conveying the flue gases S steadily to the main combustion air (I_{main}) within the whole flow area B of the main combustion air (I_{main}).

[0081] The air ejector 9 has such properties that it is capable of absorbing at least 0.3% of flue gas per mbar of static pressure loss generated by the ejector into the main combustion air (I_{main}), calculated from the total content of main combustion air (wt-%/wt-%). Preferably, the air ejectors 9 are arranged to absorb at least 0.3%, preferably at least 1% of flue gas per mbar of static pressure loss produced by the ejector 9 into the main combustion air (I_{main}), calculated from the total content of main combustion air (wt-%/wt-%) passing through the entire set of air ejectors. As to the more detailed structure of these air ejectors, reference is made to prior art, such as the applicant's own published application FI 20215192..

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List of reference numerals

	Burner	1
	Burner frame	1a
5	Combustion head	2
	body	20
	shell	20d
	end portion	21
	orifice	25
10	Furnace	3
	Intermediate wall, flange of furnace	31
	Main gas inlet	4
	Primary air inlet	5
15	Set of main gas rods	6
	main gas rod	6 ¹ , 6 ² , ..6"
	Main gas nozzle	7
	Main gas ejectors	8
	ejector duct	8a
20	free end	81a
	groove wall	81b, 81c
	groove bottom	81d
	duct groove	81f
25	Air duct (for main gas)	82
	free end	82a
	groove wall	82b, 82c
	groove bottom	82d
	duct groove	82f
30	Air ejector	9
	Primary gas pipe	10
	Primary gas nozzle	11
	Oil nozzle	12
35	Primary air supply pipe	14
	Combustion head body area	A
	Within the body of the combustion head,	
	Area of main combustion air flow in air ejector	B
	Primary flame	F1
40	Main flame	F2
	Gas	G
	Primary gas	G1
	Main gas	G2
45	Main gas + flue gas mixture	G2+S
	Combustion air	I
	Primary air	Ip
	Main combustion air	I _{main}
	Secondary air	Is
50	Tertiary air	It
	Central axis	P
	Flue gas	S
	Inside of end portion	T

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Claims

1. A burner (1) for forming a flame (F) into a furnace (3) by means of gaseous fuel (G) and combustion air (I), simultaneously recirculating flue gases (S) in the furnace (3), wherein the burner (1) comprises

- a burner frame (1a) and a combustion head (2) connected by its cylindrical body (20) to the burner frame (1a), wherein an end portion (21) of the combustion head (2) facing the furnace (3) extends at its first end to the furnace (3), and a second end of the end portion (21) is connected to said cylindrical body (20),
 - a primary gas pipe (10) for supplying gaseous fuel (G; G1) to the furnace (3), wherein the primary gas pipe (10) extends inside the combustion head (2) in its longitudinal direction, particularly inside (T) of the end portion (21) of the combustion head, and an orifice of the primary gas pipe (10) opens into or close to the furnace (3), and a primary air supply pipe (14) also extends inside the combustion head (2) and surrounds said primary gas pipe (10), and an orifice of the supply pipe (14) opens into the furnace (3) or to the orifice (21) of the end portion (21) of the combustion head (2),
 - a flow duct for main combustion air (I_{main}) extending inside the combustion head and surrounding said primary air supply pipe (14) at least inside (T) of the end portion (21), and
 - a set of main gas rods (6), comprising a set of elongated primary gas rods (6¹, 6²... 6ⁿ) extending in the longitudinal direction of the combustion head, for supplying the furnace (3) with fuel, wherein the main gas rods (6¹, 6²... 6ⁿ) are arranged at least partly outside the cylindrical body (20) of the combustion head (2), extending close to a joint (L) between the cylindrical body (20) and the end portion (21) so that they are surrounding said body (20) at regular intervals around a circumference of the body (20),

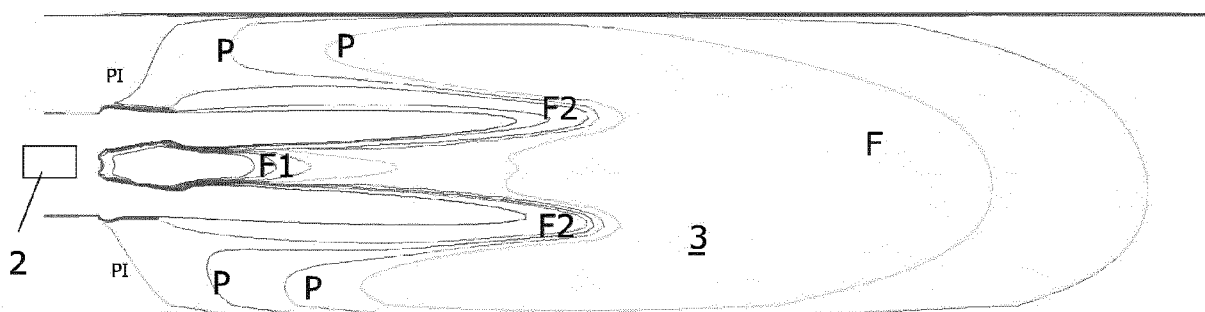
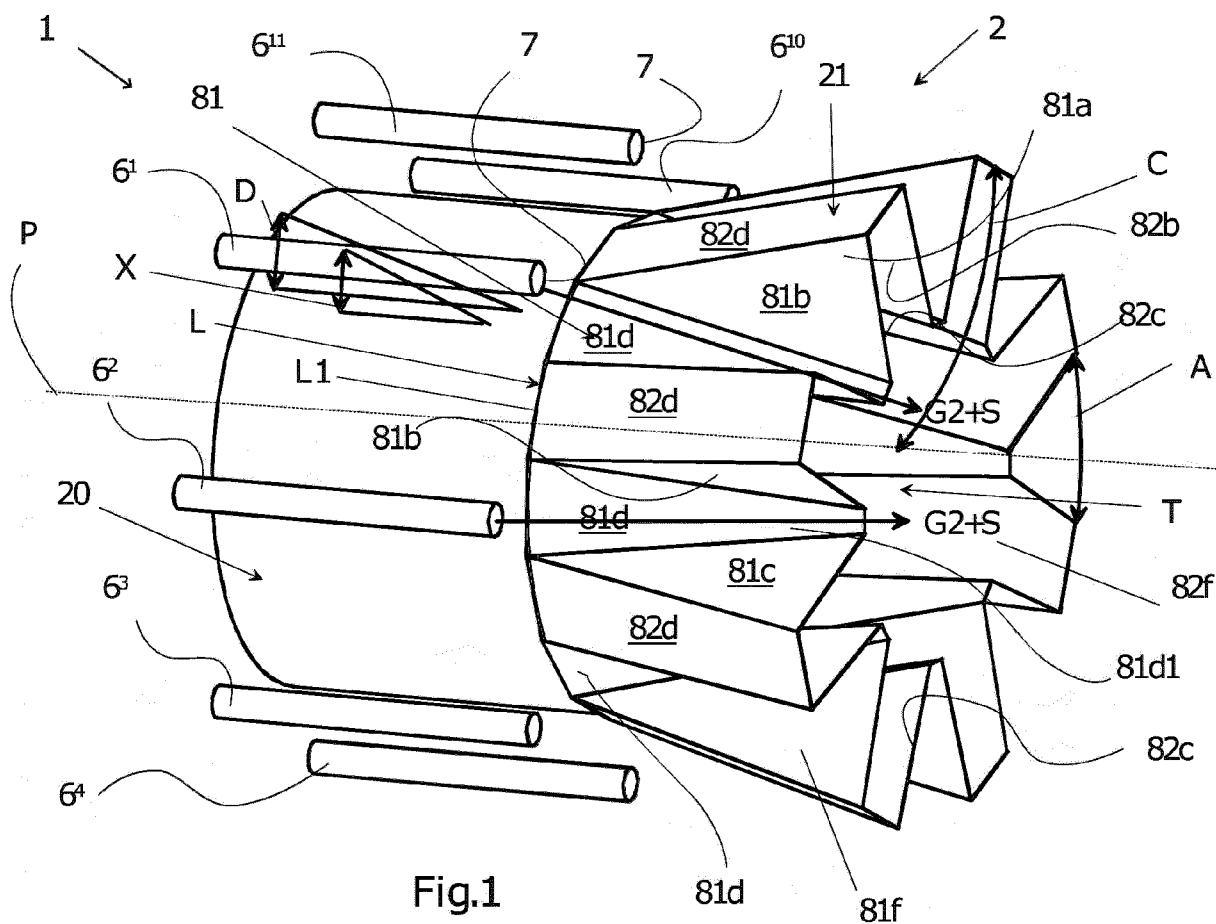
and wherein in connection with the main gas rods (6¹, 6²... 6ⁿ), at the end portion (21) of the combustion head, several ejector ducts (8; 81) are provided for recirculating flue gas (S) from the furnace (3) into the gaseous fuel (G; G2) coming from the main gas rods, and for conveying the produced flue gas-flue mixture (S+G2) further to the furnace (3),
characterized in that the end portion (21) of the combustion head (2) has the shape of a truncated cone and comprises ejector ducts (81) and air ducts (82) alternating in a direction of a circumference of said end portion (21), free ends (81a, 82a) of the ducts (81, 82) opening in the direction of the furnace (3), and a top end of a duct groove (81f) of each ejector duct (81) being also open in the direction of the furnace (3), and a lower end of the duct groove (82f) of each air duct (82) being also open in the direction of the central axis (P) of the combustion head (2), wherein the end portion (21) having the shape of the truncated cone expands at an angle of 3 to 30 degrees, seen from the direction of the joint (L) between the cylindrical body (20) of the combustion head (2) and the end portion (21) of the combustion head (2).

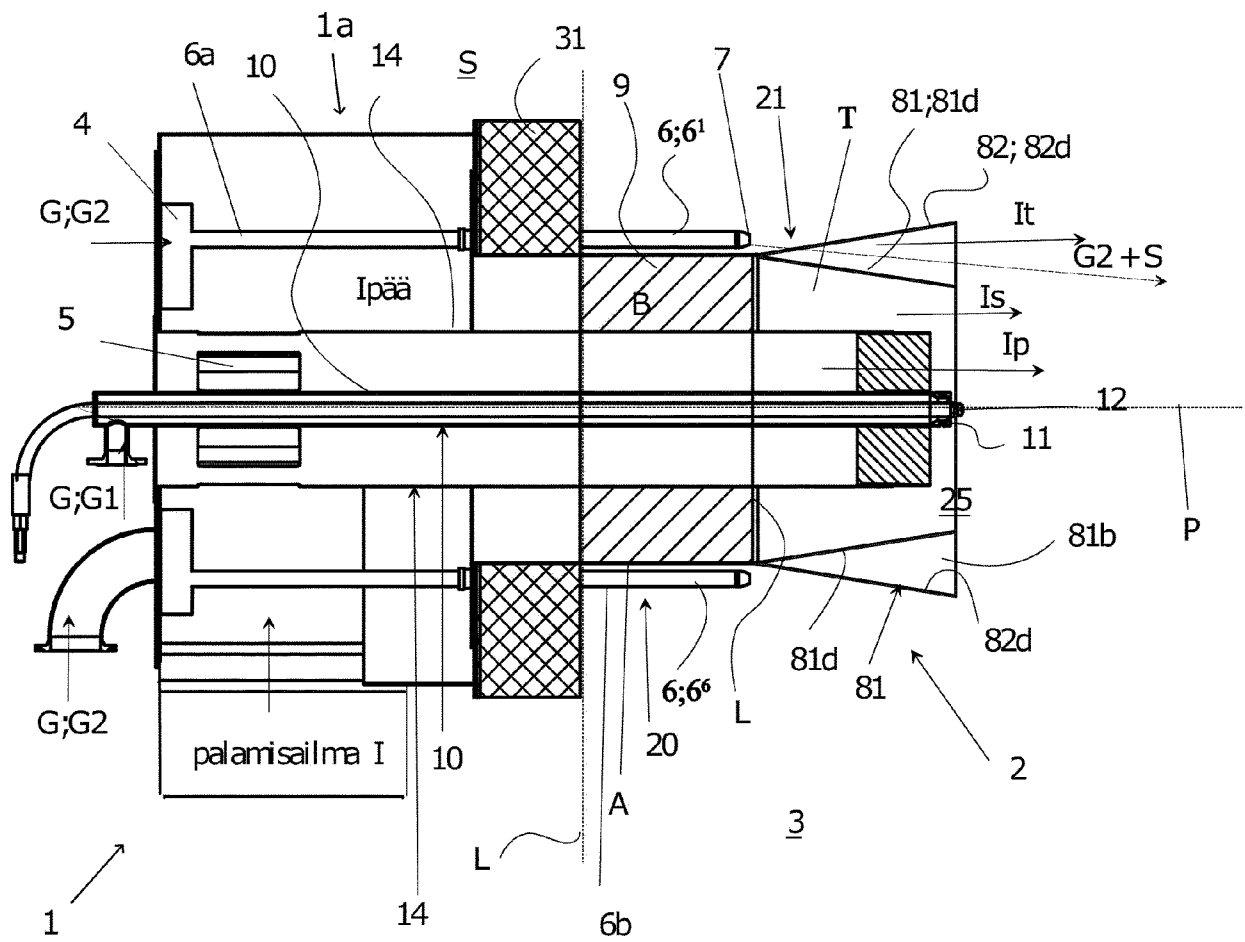
2. The burner (1) according to claim 1, **characterized in that** the ejector duct (81) at the end portion (21) of the combustion head (2) comprises a groove bottom (81d) in the longitudinal direction of the combustion head (2), wherein a groove wall (81b, 81c) extends on either side upward from the groove bottom (81d), and the duct groove (81f) of the ejector duct (81) left between the groove walls (81b, 81c) is open at its top facing the furnace (3).
3. The burner (1) according to claim 2, **characterized in that** the bottom groove (81d) of the ejector duct (81) at the end portion (21) of the combustion head (2) extends at an angle of 3 to 20 degrees downward, i.e. towards the longitudinal central axis (P) of the combustion head (2), when said groove bottom (81d) is seen from the joint (L) between the cylindrical body (20) of the combustion head and the end portion (21) of the combustion head (2), encircling the combustion head (2).
4. The burner (1) according to claim 2 or 3, **characterized in that** the groove bottom of the ejector duct (81) at the end portion (21) of the combustion head (2) tapers or has a constant width in the direction from the joint (L) between the cylindrical body (20) of the combustion head (2) and the groove bottom (81d) of the ejector duct (81) at the end portion (21) of the combustion head (2) towards the free end (81d1) of the groove bottom (81d) of said ejector duct (81) facing the furnace (3).
5. The burner (1) according to claim 3 or 4, **characterized in that** the groove bottom (81d) of the ejector duct (81) at the end portion (21) of the combustion head (2) is, at the joint (L1) between said ejector duct (81) and the cylindrical body (20) of the combustion head (2), flush with the shell (20d) of the cylindrical body (20).
6. The burner (1) according to any of the claims 2 to 5, **characterized in that** the groove walls (81b, 81c) of the ejector duct (81) at the end portion (21) of the combustion head (2) extend from the groove bottom (81d) of the ejector duct (81) obliquely upward, i.e. away from the central line of the combustion head, towards the furnace (3), so that the planes

extending via these groove walls (81b, 81c) are placed at an angle A of 1 to 30 degrees to each other.

7. The burner (1) according to any of the claims 2 to 6, **characterized in that** the width of the duct groove (81f) of the ejector duct (81) at the end portion (21) of the combustion head (2), measured at the joint (L1) between the groove bottom (81d) of said ejector duct (81) and the cylindrical body (20), is 0.2 to 1 times the length of the circumference of the shell (20d) of the cylindrical body (20), divided by the number (n) of ejector ducts (81) at the end portion (21) of the combustion head (2).
8. The burner (1) according to any of the claims 2 to 7, **characterized in that** the length of the duct groove (81f) of each ejector duct (81) is 3 to 15 times the width of the same duct groove (81f) of the ejector duct (81) measured at the joint (L1) between the groove bottom (81d) of said ejector duct (81) and the cylindrical body (20).
9. The burner (1) according to claim 1, **characterized in that** each air duct (82) at the end portion (21) of the combustion head (2) comprises a groove bottom (82d) in the longitudinal direction of the combustion head (2), with a groove wall (82b, 82c) extending on either side downward from said groove bottom (82d), i.e. in the direction of the central line (P) of the combustion head, wherein the duct groove (82f) of the air duct (82) left between the groove walls (82b, 82c) is open towards the inside (T) of the end portion (21) of the combustion head (2), encircling the central axis (P) of the combustion head (2) at the end portion (21).
10. The burner (1) according to any of the claims 2 to 9, **characterized in that** the groove walls (81b, 81c) of each ejector duct (81) at the end portion (21) of the combustion head (2) simultaneously constitute the groove walls (82b, 82c) of the two adjacent air ducts (82).
11. The burner (1) according to claim 9 or 10, **characterized in that** the groove bottom (82d) of each air duct (82) at the end portion (21) of the combustion head (2) extends at an angle of 3 to 30 degrees upward, i.e. away from the longitudinal central axis (P) of the combustion head, when said groove bottom (82d) of the air duct (82) is seen from the joint (L) between the cylindrical body (20) and the body (21), encircling the combustion head (2).
12. The burner (1) according to any of the claims 9 to 11, **characterized in that** the inside (T) of the end portion (21) encircling the longitudinal central line (P) of the combustion head (2) expands so that the distance (S) between the groove bottom (82d) of each air duct (82) at the end portion (21) of the combustion head (2) and the longitudinal central line (P) of the combustion head (2) is 3 to 30% greater at the end of the groove bottom (82d) of said air duct (82) on the side of the furnace than at the joint (L1) between the groove bottom (82d) of the same air duct (82) and the cylindrical body (20).
13. The burner (1) according to claim 1, **characterized in that** the main gas rods (6) extend through the flange (31) between the furnace (3) and the burner frame into the furnace (3), and extend in the longitudinal direction of the cylindrical body (20) of the combustion head (2) to a distance from said flange (31), close to the joint (L1) between the body (20) of the combustion head and the bottom (81d) of the ejector duct (81) at the end portion (21) of the combustion head (2).
14. The burner (1) according to claim 1, **characterized in that** the burner (1) further comprises air ejectors (9) provided in connection with the flow duct for main combustion air (Imain) in the body (20) of the combustion head (2), arranged to absorb flue gas from the furnace (3).
15. The burner (1) according to claim 14, **characterized in that** the air ejectors (9) in the body (20) of the combustion head (2) and the ejector ducts (81) at the end portion (21) of the combustion head (2) are arranged, with respect to each other, in such a way that the location for supplying flue gas (S) to the ejector ducts (82) is upstream of the openings leading to the air ejectors (9) in the body (20), seen from the direction of the orifice (25) of the end portion (21) of the combustion head (2).
16. The burner (1) according to claim 15, **characterized in that** flue gases (S) can be conveyed to each air ejector (9) via the flue gas duct of the air ejector (9), from that area (B) in the longitudinal direction of the body (20) of the combustion head (2) where the main gas rods (6) extend in the furnace (3), outside the body (20) of the combustion head (2).
17. The burner (1) according to claim 14, **characterized in that** each air ejector (9) is arranged to absorb at least 1% of flue gas per mbar of static pressure loss produced by the ejector into the main combustion air (Imain), calculated from the total content (wt-%/wt-%) of main combustion air.

18. The burner (1) according to any of the claims 14 to 17, **characterized in that** the content of flue gas to be absorbed into the main combustion air by each air ejector (9) is further adjusted so that the maximum temperature of the air-flue gas mixture downstream of the air ejector (30), in the flow direction of the air-flue gas mixture (I+S), is lower than 500°C, preferably lower than lower than 300°C.
19. The burner (1) according to any of the claims 14 to 18, **characterized in that** at least one opening is provided for each air ejector (9) in the body, and the openings provided for the air ejectors (9) in the assembly of air ejectors in the body and connected to the flue gas ducts constitute a row of 6 to 60 openings encircling the body (20) of the combustion head (2) at the same distance from the vertical plane extending via the orifice (25) of the combustion head (2).
20. The burner (1) according to claim 14, **characterized in that** each air ejector (9) comprises one or more partly hollow blade, including an entry-side blade arranged to accelerate the flow of combustion air (I) steadily on said entry-side blade, wherein this entry-side blade extends into the flue gas duct of the air ejector (9), and downstream of the flue gas duct the same or a different blade extends as an exit-side blade arranged to steadily decelerate the flow of air-flue gas mixture (S,I) on said exit-side blade.
21. A method for forming a flame (F; F1, F2) into a furnace (3) by a burner (1) defined in claim 1, by means of gaseous fuel (G) and combustion air (I), simultaneously recirculating flue gases (S); wherein
for forming a primary flame (F1), primary gas is supplied into a primary gas pipe (10) via a part (10a) of said primary gas pipe (10) on the side of the burner frame (1a), and primary air (Ip) is also supplied by means of a primary air supply pipe (14) extending inside the combustion head (2) and into the furnace (3),
and
- for forming a main flame (F2), a flow of main combustion air (Imain; Is+It) is conveyed from inside of the combustion head (2) to the furnace (3), and a flow of main gas (G2) is conveyed via main gas rods (6¹, 6²..6ⁿ), whereby the main gas (G2) is conveyed into each main gas rod (6¹, 6²..6ⁿ) via its part (6a) on the side of the burner frame (1a), wherein flue gas (S) from the furnace (3) is mixed into the flow of main gas (G2) by means of ejector ducts (81) at the orifice of the end portion of the combustion head (2), **characterized in that** the flame (F; F1+F2) produced in the furnace, formed by the primary flame (F1) and the main flame (F2), and the distribution of fuel, combustion air and internally recirculated flue gas at the opening of the combustion head, obtained by the shape of the combustion head, results in an inert return flow (PI) of flue gases with low contents of oxygen and unburned fuel components.
22. The method according to claim 21, wherein the main gas (G2) is methane and wherein the inert return flow (PI) of flue gases returning back to the area of the combustion head (2) in the furnace contains less than 5000 ppm of carbon monoxide, less than 5000 ppm of methane, and has an average oxygen content lower than 5 wt-% when the total air factor λ is 1.15.
23. The method according to claim 21, **characterized in that** the inert flue gas (PI) is conveyed to ejector ducts (81) in connection with main gas rods (6).
24. The method according to claim 21, **characterized in that** main gas jets from the main gas rods (6) are directed from the main gas rods (6) to the ejector ducts (81) at an angle (D) downward, *i.e.* directed at an angle towards the longitudinal axis of the combustion head, when said ejector duct (81) is seen from the joint between the cylindrical body (21a) and the orifice (21b), the angle (D) being in the same direction as or in a different direction from the tilt angle (B) of the groove bottom (81d) of the ejector duct (81).
25. The method according to claim 21, **characterized in that** the flow of main combustion air (Imain; Is+It) is directed to the flow duct for main combustion air (Imain) which surrounds the primary air supply pipe (14) and is divided into a tertiary air flow (It) flowing in air ducts (82) within said end portion (21) and a secondary air flow (Is) flowing outside the air ducts.
26. The method according to claim 25, **characterized in that** the secondary air flow (Is) passes through the inside (T) of the end portion (21) of the combustion head (2).
27. A burner-boiler assembly, wherein a frame of the burner as defined in claim 1 is mounted in a boiler so that the combustion head (2) of the burner extends into the furnace, **characterized in that** power density of the burner relative to a cross-sectional area of the furnace is at most 10,000 kW/m².





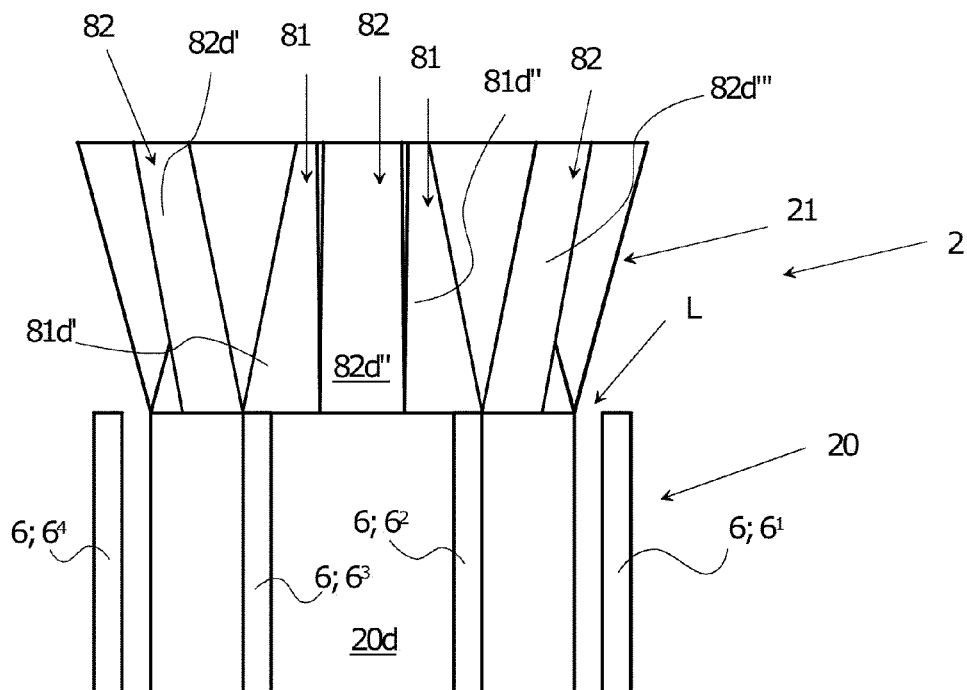


Fig.2B

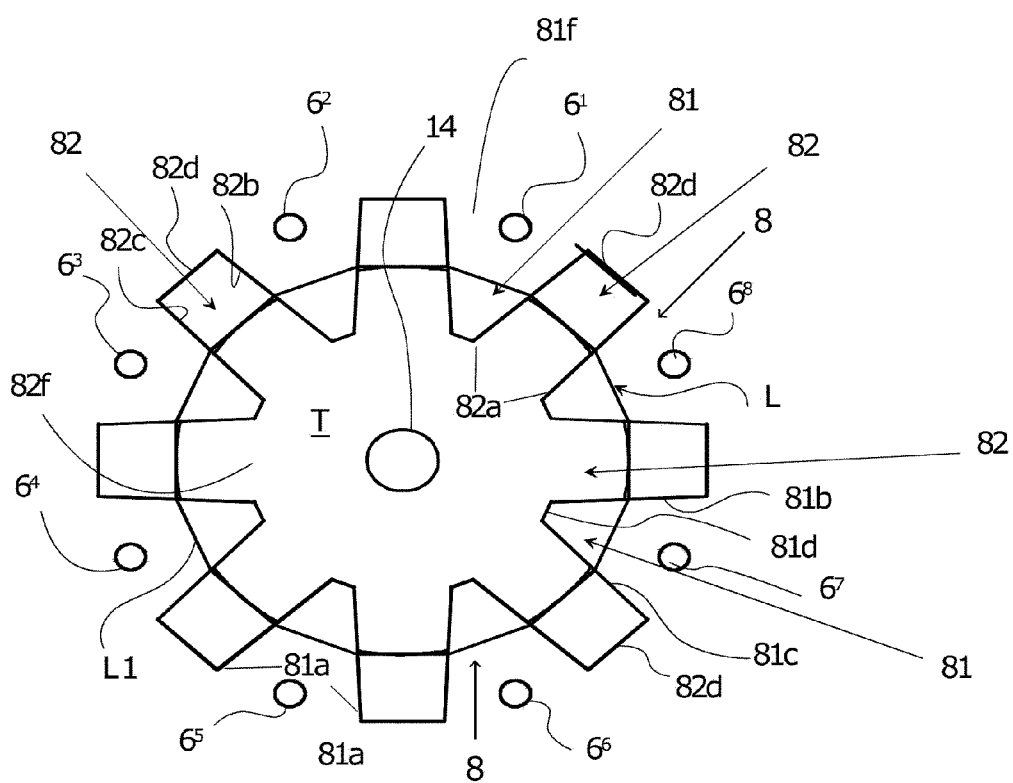


Fig.2C



EUROPEAN SEARCH REPORT

Application Number

EP 24 18 6813

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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A	EP 1 074 790 A1 (ENTPR GENERALE [FR]) 7 February 2001 (2001-02-07) * the whole document *	1-27	
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			F23C F23D
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
Munich		26 November 2024	Theis, Gilbert
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26-11-2024

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