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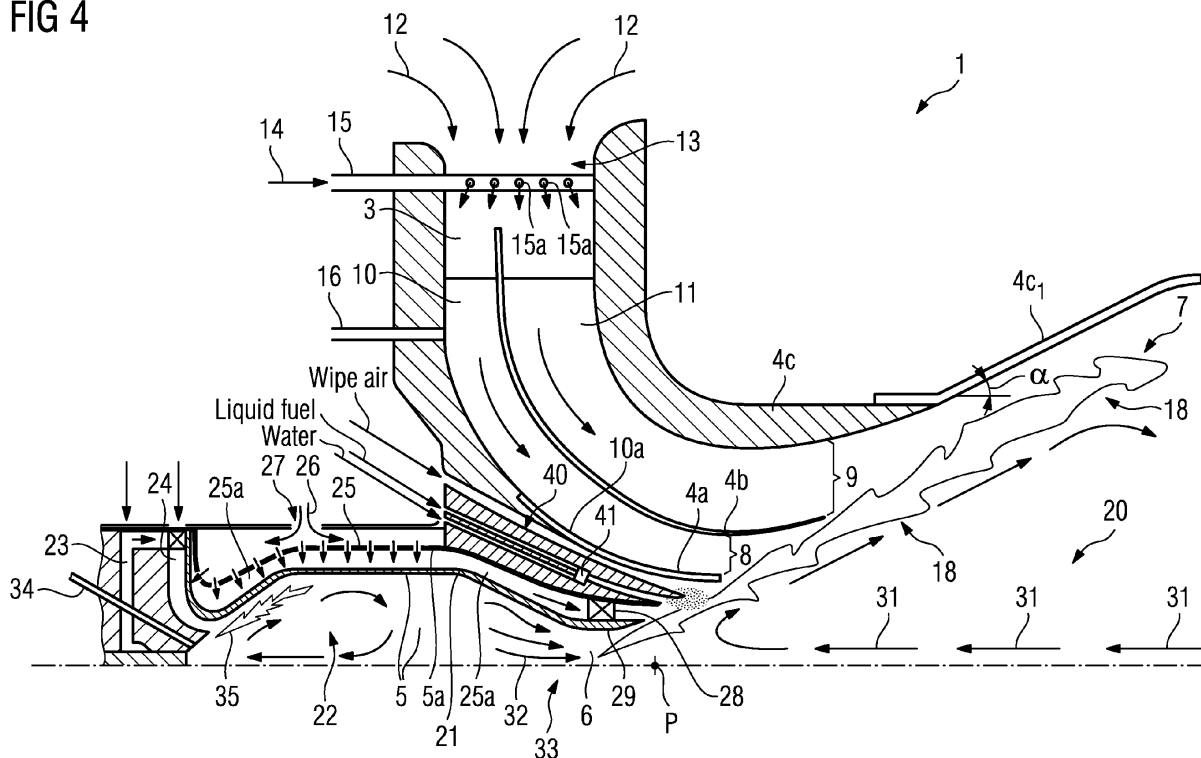
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(54) **Burner with low NO_x emissions**

(57) A burner (1) for a gas turbine engine, having at the upstream end of the burner a heat source X for supplying heat and a high concentration of free radicals arranged to support a rapid and stable combustion of a main flame burning in a lean premixed air/fuel swirl in a combustion room defined by a quarl arrangement (4a-4c) axially aligned with the heat source (5) and positioned downstream an exit (6) of said heat source (5), and wherein a recirculation zone (20) of the main flame

(7) directs a flow of free radicals back to a forward stagnation point (P) at the exit (6) of the heat source (5). The burner is provided with a fuel distributor (40) at the exit of the heat source (5), said fuel distributor (40) being supplied with liquid fuel and water and provided with mixing means (41, 141) for mixing said liquid fuel and said water for forming a fuel/water emulsion, and said fuel distributor (40) having means for directing said fuel/water emulsion to the upstream end of the main flame (7) for reducing the temperature of the main flame (7).

FIG 4



Description

TECHNICAL FIELD

[0001] The present invention refers to a burner preferably for use in gas turbine engines, and more particularly to a burner adapted to stabilize engine lean partially premixed (LPP) combustion process and engine turn-down requirements, and further to a burner that use a pilot combustor to provide combustion products (radicals and heat) to stabilize a main lean partially premixed combustion process. Particularly, the present invention is directed to a device and a method for reducing the temperature of a main flame in the combustion process for the reduction of NO_x emissions in the exhaust gases from the combustion.

TECHNICAL BACKGROUND

[0002] Gas turbine engines are employed in a variety of applications including electric power generation, military and commercial aviation, pipeline transmission and marine transportation. In a gas turbine engine which operates in LPP mode, fuel and air are provided to a burner chamber where they are mixed and ignited by a flame, thereby initiating combustion. The major problems associated with the combustion process in gas turbine engines, in addition to thermal efficiency and proper mixing of the fuel and the air, are associated to flame stabilization, the elimination of pulsations and noise, and the control of polluting emissions, especially nitrogen oxides (NO_x), CO, UHC, smoke and particulated emission

[0003] In industrial gas turbine engines, which operate in LPP mode, flame temperature is reduced by an addition of more air than required for the combustion process itself. The excess air that is not reacted must be heated during combustion, and as a result flame temperature of the combustion process is reduced (below stoichiometric point) from approximately 2300K to 1800 K and below. This reduction in flame temperature is required in order to significantly reduce NO_x emissions. A method shown to be most successful in reducing NO_x emissions is to make combustion process so lean that the temperature of the flame is reduced below the temperature at which diatomic Nitrogen and Oxygen (N₂ and O₂) dissociate and recombine into NO and NO₂. Swirl stabilized combustion flows are commonly used in industrial gas turbine engines to stabilize combustion by, as indicated above, developing reverse flow (Swirl Induced Recirculation Zone) about the centreline, whereby the reverse flow returns heat and free radicals back to the incoming un-burnt fuel and air mixture. The heat and free radicals from the previously reacted fuel and air are required to initiate (pyrolyze fuel and initiate chain branching process) and sustain stable combustion of the fresh un-reacted fuel and air mixture. Stable combustion in gas turbine engines requires a cyclic process of combustion producing combustion products that are transported back upstream to

initiate the combustion process. A flame front is stabilised in a Shear-Layer of the Swirl Induced Recirculation Zone. Within the Shear-Layer "Local Turbulent Flame Speed of the Air/Fuel Mixture" has to be higher than "Local Air/Fuel Mixture Velocity" and as a result the Flame Front/combustion process can be stabilised.

[0004] Lean premixed combustion is inherently less stable than diffusion flame combustion for the following reasons:

1. The amount of air required to reduce the flame temperature from 2300K to 1700-1800 K is approximately twice the amount of air required for stoichiometric combustion. This makes the overall fuel/air ratio () very close (around or below 0.5; ≥ 0.5) or similar to a fuel/air ratio at which lean extinction of the premixed flame occurs. Under these conditions the flame can locally extinguish and re-light in a periodic manner.

2. Near the lean extinction limit the flame speed of the lean partially premixed flames is very sensitive to the equivalence ratio fluctuations. Fluctuations in flame speed can result in spatial fluctuations/movements of the flame front (the Swirl Induced Recirculation Zone). A less stable, easy to move flame front of a pre-mixed flame results in a periodic heat release rate, that, in turn, results in movement of the flame, unsteady fluid dynamic processes, and thermoacoustic instabilities develop.

3. Equivalence ratio fluctuations are probably the most common coupling mechanism to link unsteady heat release to unsteady pressure oscillations.

4. In order to make the combustion sufficiently lean, in order to be able to significantly reduce NO_x emissions, nearly all of the air used in the engine must go through the injector and has to be premixed with fuel. Therefore, all the flow in the burners has the potential to be reactive and requires that the point where combustion is initiated is fixed.

5. When the heat required for reactions to occur is the stability-limiting factor, very small temporal fluctuations in fuel/air equivalence ratios (which could either result either from fluctuation of fuel or air flow through the Burner/Injector) can cause flame to partially extinguish and re-light.

6. An additional and very important reason for the decrease in stability in the pre-mixed flame is that the steep gradient of fuel and air mixing is eliminated from the combustion process. This makes the premixed flow combustible anywhere where there is a sufficient temperature for reaction to occur. When the flame can, more easily, occur in multiple positions, it becomes more unstable. The only means for

stabilizing a premixed flame to a fixed position are based on the temperature gradient produced where the unburnt premixed fuel and air mix with the hot products of combustion (flame cannot occur where the temperature is too low). This leaves the thermal gradient produced by the generation, radiation, diffusion and convection of heat as a method to stabilize the premixed flame. Radiation heating of the fluid does not produce a sharp gradient; therefore, stability must come from the generation, diffusion and convection of heat into the pre-reacted zone. Diffusion only produces a sharp gradient in laminar flow and not turbulent flows, leaving only convection and energy generation to produce the sharp gradients desired for flame stabilization which is actually heat and free radical gradients. Both, heat and free radical gradients, are generated, diffused and convected by the same mechanisms through recirculating products of combustion within the Swirl Induced Recirculation Zone.

7. In pre-mixed flows, as well as diffusion flows, rapid expansion causing separations and swirling recirculating flows, are both commonly used to produce gradients of heat and free radicals into the pre-reacted fuel and air.

[0005] Document WO 2005/040682 A2 describes a solution directed to a burner for gas turbine engines that uses a pilot flame to assist in sustaining and stabilizing the combustion process. Document WO 2009121777 A1 discloses a lean-rich partially premixed low emissions burner for a gas turbine combustor that provides stable ignition and combustion process at all engine load conditions. This burner operates according to the principle of "supplying" heat and high concentration of free radicals from a pilot combustor exhaust to a main flame burning in a lean premixed air/fuel swirl, whereby a rapid and stable combustion of the main lean premixed flame is supported. The pilot combustor supplies heat and supplements a high concentration of free radicals directly to a forward stagnation point and a shear layer of the main swirl induced recirculation zone, where the main lean premixed flow is mixed with hot gases products of combustion provided by the pilot combustor. This allows a leaner mix and lower temperatures of the main premixed air/fuel swirl combustion that otherwise would not be self-sustaining in swirl stabilized recirculating flows during the operating conditions of the burner. The prior art as disclosed in document WO 2009121777 A1 is represented in the present application as Fig. 1. The content of said document is in its entirety incorporated into this description by reference. The prior art, as disclosed in the reference, shows a burner arranged to be fueled with gas fuel. Fig. 1 according to said prior art shows a prior art burner arranged in a housing 2. Enclosed in the housing 2 are (see prior art, Fig. 2):

- a burner (1) having axially opposed upstream and downstream end portions;
- at the upstream end of said burner 1 a pilot combustor 5 is located, said pilot combustor 5 being provided with fuel and air for burning said fuel for the creation of a flow of an unquenched concentration of radicals 32 at non-equilibrium and heat from a pilot combustion zone 22 directed downstream along a centre line of the pilot combustor 2 through a throat at an exit 6 of the pilot combustor 5;
- quarl sections 4a, 4b, 4c surrounding the exit 6 of the pilot combustor 5 and extending from said exit 6 in the downstream direction, wherein an outer quarl section 4b has a greater diameter than an inner quarl section 4a extending a greater distance downstream than the inner quarl 4a;
- a main combustion room being defined downstream said pilot combustor 5 by end portions of the quarls 4a, 4b, 4c, wherein said combustion room is arranged to house a main flame 7 and a recirculation zone 20 for directing a flow of free radicals back to a forward stagnation point P at the exit 6 of the pilot combustor 5.
- at least a first channel 10 defined as a substantially annular space between an upstream quarl section 4a and the closest downstream quarl section 4b providing air 12 and fuel 14 to said main flame 7 in said combustion room.

SUMMARY OF THE INVENTION

[0006] The present invention is directed to a burner of the above mentioned type and is directed to a device and a method for reducing the temperature of a main flame in the combustion process of the burner for the reduction of NOx emissions in the exhaust gases from the burner.

[0007] According to one aspect of the invention there is disclosed a method of burning a fuel in a burner, wherein the method includes the steps of: arranging a lean premixed swirl of fuel and air, outletting said lean premixed swirl into a quarl arrangement, burning said fuel of said lean premixed swirl inside said quarl arrangement for forming a main flame, supporting and stabilizing said main flame by arranging a heat source upstream said main flame for generating a gas flow from the downstream end of the heat source for providing heat and free radicals to the main flame, and adding an emulsion of liquid fuel and water to the main flame in a region downstream the heat source and the upstream end of the main flame for reducing the temperature of the main flame.

[0008] According to a second aspect of the invention there is disclosed a burner, particularly for use in a gas turbine, having a burner housing enclosing the burner, wherein the burner has axially opposed upstream and downstream end portions. The burner further comprises at the upstream end of said burner a heat source for supplying said heat and said high concentration of free

radicals to support said rapid and stable combustion of said main flame burning in said lean premixed air/fuel swirl, wherein the main flame is housed in a combustion room defined by said quarl arrangement axially aligned with the heat source and positioned downstream an exit of said heat source, and wherein a recirculation zone of the main flame directs a flow of free radicals back to a forward stagnation point (P) at the exit of the heat source. According to said second aspect of the invention the burner is provided with a fuel distributor at the exit of the heat source, wherein said fuel distributor is supplied with liquid fuel and water and provided with mixing means for mixing said liquid fuel and said water for forming a fuel/water emulsion, and means for directing said fuel/water emulsion to the upstream end of the main flame for reducing the temperature of the main flame (7).

[0009] Said burner provides, when used for liquid fuel, both fuel and water in channels around the exit of the pilot combustor to form an emulsion, and using inner air from the pilot combustor to hit the stream of mixed fuel/water, thereby influencing the mixed fuel/water: 1) to determine thickness of a fuel/water film and 2) to introduce air instabilities in the form of turbulence and a frequency of velocity variations.

[0010] Said means allows for sending both water and fuel drops of the same diameter to the shear layer of the recirculation zone of the main flame at substantially the same location. Water and fuel is added to the shear layer of the recirculation zone as this is the most effective way of reducing the flame temperature. As water evaporates quickly the main flame temperature is reduced and the temperature of liquid fuel is reduced at almost the same location as where the flame is generated.

[0011] According to the aspects of the invention there is herein presented a burner characterized by the features of claim 1.

[0012] Further, according to the aspects of the invention there is presented a method for burning a fuel as characterized in the independent method claim.

[0013] Further aspects of the invention are presented in the dependent claims.

[0014] The burner utilizes:

A swirl of air/fuel above swirl number (S_N) 0,7 (that is above critical $S_N=0,6$), generated-imparted into the flow, by a radial swirler;
active species -non-equilibrium free radicals being released close to the forward stagnation point,
particular type of the burner geometry with a multi quarl device, and
internal staging of fuel and air within the burner to stabilize combustion process at all gas turbine operating conditions.

[0015] In short, the disclosed burner provides stable ignition and combustion process at all engine load conditions. Some important features related to the inventive burner are:

the geometric location of the burner elements;
the amount of fuel and air staged within the burner;
the minimum amount of active species - radicals generated and required at different engine/burner operating conditions; fuel profile;
mixing of fuel and air at different engine operating conditions;
imparted level of swirl;
multi (minimum double quarl) quarl arrangement.

[0016] To achieve as low as possible emission levels, a target in this design/invention is to have uniform mixing profiles at the exit of lean premixing channels. Two distinct combustion zones exist within the burner, where fuel is burnt simultaneously at all times. Both combustion zones are swirl stabilized and fuel and air are premixed prior to the combustion process. A main combustion process, during which more than 90 % of fuel is burned, is lean. A supporting combustion process, which occurs within the small pilot combustor, wherein up to 1% of the total fuel flow is consumed, could be lean, stoichiometric and rich (equivalence ratio, $\Phi=1.4$ and higher).

[0017] The main reason why the supporting combustion process in the small pilot combustor could be lean, stoichiometric or rich and still provide stable ignition and combustion process at all engine load conditions is related to combustion efficiency. The combustion process, which occurs within the small combustor-pilot, has low efficiency due to the high surface area which results in flame quenching on the walls of the pilot combustor. Inefficient combustion process, either being lean, stoichiometric or rich, could generate a large pool of active species - radicals which is necessary to enhance stability of the main lean flame and is beneficial for a successful operation of the present burner design/invention (Note: the flame occurring in the premixed lean air/fuel mixture is herein called the lean flame).

[0018] It would be very difficult to sustain (but not to ignite, because the small pilot combustor can act as a torch igniter) combustion in the shear layer of the main recirculation zone below LBO (Lean Blow Off) limits of the main lean flame (approx. $T > 1350$ K and $\Phi \geq 0.25$). For engine operation below LBO limits of the main lean flame, in this burner design, additional "staging" of the small combustor-pilot is used/provided. The air which is used to cool the small pilot combustor internal walls (performed by a combination of impingement and convective cooling) and which represents approximately 5-8 % of the total air flow through the burner, is premixed with fuel prior the associated swirler. Relatively large amount of fuel can be added to the small pilot combustor cooling air which corresponds to very rich equivalence ratios ($\Phi > 3$). Swirled cooling air and fuel and hot products of combustion from the small pilot combustor, can very effectively sustain combustion of the main lean flame below, at and above LBO limits. The combustion process is very stable and efficient because hot combustion products and very hot cooling air (above 750 °C), premixed

with fuel, provide heat and active species (radicals) to the forward stagnation point of the main flame recirculation zone. During this combustion process the small pilot combustor, combined with very hot cooling air (above 750 °C) premixed with fuel act as a flameless burner, where reactants (oxygen & fuel) are premixed with products of combustion and a distributed flame is established at the forward stagnation point of the swirl induced recirculation zone. It should be mentioned here that the pilot combustor is described as the heat source supplying the main flame with heat and free radicals. Of course, it would be an alternative to use any type of heat source which matches the requests to supply the main flame with the heat and the free radicals needed.

[0019] To enable a proper function and stable operation of the burner, it is required that the imparted level of swirl and the swirl number (equation 1) is above the critical one (not lower than 0,6 and not higher than 0,8) at which vortex breakdown - recirculation zone will form and will be firmly positioned within the multi quarl arrangement. The forward stagnation point P should be located within the quarl and at the exit of the pilot combustor. The main reasons, for this requirement, are:

If the imparted level of swirl is low and the resulting swirl number is below 0,6, for most burner geometries, a weak, recirculation zone will form and unstable combustion can occur.

[0020] A strong recirculation zone is required to enable transport of heat and free radicals from the previously combusted fuel and air, back upstream towards the flame front. A well established and a strong recirculation zone is required to provide a shear layer region where turbulent flame speed can "match" or be proportional to the local fuel/air mixture, and a stable flame can establish. This flame front established in the shear layer of the main recirculation zone has to be steady and no periodic movements or procession of the flame front should occur. The imparted swirl number can be high, but should not be higher than 0.8, because at and above this swirl number more than 80% of the total amount of the flow will be recirculated back. A further increase in swirl number will not contribute more to the increase in the amount of the recirculated mass of the combustion products, and the flame in the shear layer of the recirculation zone will be subjected to high turbulence and strain which can result in quenching and partial extinction and reignition of the flame. Any type of the swirl generator, radial, axial and axial- radial can be used in the burner. In this disclosure a radial swirler configuration is shown.

[0021] The burner utilizes aerodynamics stabilization of the flame and confines the flame stabilization zone - the recirculation zone - in the multiple quarl arrangement. The multiple quarl arrangement is an important feature of the design of the provided burner for the following reasons. The quarl (or also called diffuser) :

- provides a flame front (main recirculation zone) anchoring the flame in a defined position in space, without a need to anchor the flame to a solid surface/bluff body, and in that way a high thermal loading and issues related to the burner mechanical integrity are avoided;
- geometry (quarl half angle α and length L) is important to control size and shape of the recirculation zone in conjunction with the swirl number. The length of the recirculation zone is roughly proportional to 2 to 2,5 of the quarl length;
- optimal length L is of the order of $L/D = 1$ (D is the quarl throat diameter). The minimum length of the quarl should not be smaller than $L/D=0,5$ and not longer than $L/D=2$;
- optimal quarl half angle α should not be smaller than 20 and larger than 25 degrees, allows for a lower swirl before decrease in stability, when compared to a less confined flame front; and
- has the important task to control the size and shape of the recirculation zone as the expansion of the hot gases as a result of combustion reduces transport time of free radicals in the recirculation zone.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022]

Fig. 1 is a simplified cross section schematically showing the burner according to the aspects of the invention enclosed in a housing without any details showing how the burner is configured inside said housing. This figure represents **prior art** as well.

Fig. 2 is a cross section through an embodiment of the burner according to **prior art** schematically showing a section above a symmetry axis, whereby a rotation around the symmetry axis forms a rotational body displaying a layout of the burner.

Fig. 3 depicts a cross section of a diagrammatic illustration of the elements of the combustion processes in a burner according to the principles of an LPP burner using the aspects of the present invention.

Fig. 4 schematically shows a cross section of a burner according to the aspects of the present invention and corresponds to the layout of the prior art burner depicted in figure 2.

Fig. 5 schematically shows a cross section of the upper half one embodiment of a fuel distributor for distributing of the liquid fuel/water to the upstream end of the main flame.

Fig. 6 shows a 3D view of a section of the fuel distributor corresponding to fig. 5, where the inlets

openings for water to the mixer are visible.

Fig. 7 shows a 3D view of a section of the mixer as seen from an angle downstream of the mixer.

Fig. 8 shows a 3D view of a section of the mixer corresponding to figures 6 and 7 in a cross section of a plane through the fuel inlet channels. The pilot combustor shell is removed here.

Figures 9 and 10 shows, more in detail, the formation of the emulsion film in one embodiment of mixing devices.

Fig. 11a to 11c illustrates views of a second embodiment of a mixing device for mixing liquid fuel and water in a fuel distributor.

EMBODIMENTS OF THE INVENTION

[0023] In the following a number of embodiments will be described in more detail with references to the enclosed drawings.

[0024] The prior art figures 1 and 2 are described above.

[0025] Figure 2 shows for the sake of clarity a cross sectional view of the burner above a rotational symmetry axis. The main parts of the burner are the radial swirler 3, the multi quarl 4a, 4b, 4c and the pilot combustor 5.

[0026] Fig. 3 is a schematic description of the general concepts of the present invention. The main flame of the burner is referenced by reference sign 7. Said main flame is illustrated having a conical shear layer 18 surrounding the main flame like a shell. Inside said shear layer there is a recirculation zone wherein unburnt radicals are recirculated to burn in the air/fuel mix provided to the shear layer 18.

[0027] The air and fuel provided as a lean mix to the main flame is illustrated by arrows marked with A/F. According to the principles of an LPP burner the main flame stability is supported by the heat source indicated as a flow 32 of heat gases and free radicals supplied to the main flame 7 at its upstream end. The heat in said heat source is in this drawing symbolized as a flame 35 with a recirculation zone 22.

[0028] As stated, the burner 1 operates according to the principle of "supplying" heat and high concentration of free radicals from the heat source symbolized by the exemplified pilot combustor 5 exhaust 6 to a main flame 7 burning in a lean premixed air/fuel swirl emerging from a first exit 8 of a first lean premixing channel 10 and, in the depicted embodiment, from a second exit 9 of a second lean premixing channel 11, whereby a rapid and stable combustion of the main lean premixed flame 7 is supported. Said first lean premixing channel 10 is formed by and between the walls 4a and 4b of the multi quarl. The second lean premixing channel 11 is formed by and between the walls 4b and 4c of the multi quarl. The outer-

most rotational symmetric wall 4c of the multi quarl is provided with an extension 4c₁ to provide for the optimal length of the multi quarl arrangement. The first 10 and second 11 lean premixing channels are provided with swirler wings forming the swirler 3 to impart rotation to the air/fuel mixture passing through the channels.

[0029] Air 12 is provided to the first 10 and second 11 channels at the inlet 13 of said first and second channels. According to the embodiment shown the swirler 3 is located close to the inlet 13 of the first and second channels. Further, fuel 14 is introduced to the air/fuel swirl through a tube 15 provided with small diffuser holes 15a located at the air 12 inlet 13 between the swirler 3 wings, whereby the fuel is distributed into the air flow through said holes as a spray and effectively mixed with the air flow. Additional fuel can be added through a second tube 16 emerging into the first channel 10.

[0030] When the lean premixed air/fuel flow is burnt the main flame 7 is generated. The flame 7 is formed as a conical rotational symmetric shear layer 18 around a main recirculation zone 20 (sometimes abbreviated RZ). The flame 7 is enclosed inside the extension 4c₁ of the outermost quarl, in this example quarl 4c.

[0031] The heat source, herein represented by the pilot combustor 5, supplies heat and supplements a high concentration of free radicals directly to a forward stagnation point P and the shear layer 18 of the main swirl induced recirculation zone 20, where the main lean premixed flow is mixed with hot gases products of combustion provided by the pilot combustor 5.

[0032] The pilot combustor 5 is provided with walls 21 enclosing a combustion room for a pilot combustion zone 22. Air is supplied to the combustion room through fuel channel 23 and air channel 24. Around the walls 21 of the pilot combustor 5 there is a distributor plate 25 provided with holes over the surface of the plate. Said distributor plate 25 is separated a certain distance from said walls 21 forming a cooling space layer 25a. Cooling air 26 is taken in through a cooling inlet 27 and meets the outside of said distributor plate 25, whereupon the cooling air 26 is distributed across the walls 21 of the pilot combustor to effectively cool said walls 21. The cooling air 26, now heated to up to 1000 K, is after said cooling let out through a second swirler 28 arranged at a pilot quarl 29 around the pilot combustor 5. For the sake of clarity it should be noted here that the shorter term "pilot" is used for the complete pilot combustor arrangement. Thus, it should be understood that "pilot" includes the pilot combustor 5, the cooling channel 25a, the distributor plate 25, the pilot quarl 29, inlet channels 23, 24 for supplying the pilot combustor with fuel and air, and a pilot shell 5a housing said members of the pilot combustor arrangement. Thus the pilot can in its entirety be referred to by use of reference sign 5a.

[0033] According to the present invention, a burner of the prior art type discussed above is provided, wherein liquid fuel can be supplied to the main flame 7. This is arranged by introducing a fuel distributor 40 enveloping

the downstream part of the pilot 5a, or expressed in another way, enveloping the shell 5a of the pilot combustor 5 at its exit 6. Outside and surrounding the fuel distributor 40 is the inner wall 10a of the first lean premixing channel 10. Figure 4 illustrates an embodiment of the LPP burner of prior art corresponding to Fig. 2, wherein a fuel distributor 40 is introduced in this manner. Said fuel distributor 40 is depicted as a fuel distributor of a general model and can be structured in a preferred manner. Below, some embodiments of fuel distributors 40 will be discussed.

[0034] One embodiment of the structure of one example of a fuel distributor 40 is depicted in Fig. 5. The drawing is only schematic and shows a cross section, only, along a vertical plane through the centre line of one half, above the centre line, of the annularly formed fuel distributor 40. The fuel distributor 40 is provided with a liquid fuel channel 42 for supply of liquid fuel and a water channel 43 for the supply of water. Water and liquid fuel are by use of these channels provided to a mixer 41 for forming an emulsion of the liquid fuel and the water. In the figure the water channel 43 is visible in the cross section plane, where it is further recognized first cavities 44 of the mixer 41. Said first cavities 44 receive water from the water channel 43. The first cavities 44 are formed as substantially annular half circles, as dividing walls 45 separate said first cavities 44 from forming a complete annular circle. The separating walls 45 renders it possible for liquid fuel supplied to liquid fuel channels 42 to be conveyed through the recesses 46 of the mixer 41 into an annular second cavity 47 for receiving said liquid fuel. Said second cavity 47 is separated from the first cavity 44 by means of the circumferencing wall 48.

[0035] Fig. 6 shows further details of the mixer 41 inside said first fuel distributor 40 embodiment. Herein, one of the first cavities 44 for distributing water to water inlet openings 49 of the mixer 41 is depicted in a perspective view substantially in the direction of flow of water. It is further illustrated in fig. 6 that the first cavity 44 has a decreasing flow area towards the ends of the annularly formed half circle, thereby providing for substantially the same pressure of water at the water inlet openings 49 of the mixer. The circular tapering conical formed inner wall of the inner lip 50 is visible at the downstream end of the fuel distributor 40.

[0036] Further details of the fuel distributor 40 mixer 41 according to the first embodiment are illustrated in Fig. 7. This is a 3D view of the mixer 41 as seen from an angle downstream of the mixer 41. The annularly formed second cavity 47 for receiving liquid fuel is pointed at with arrows 47. Distributed around the inner circular wall of the second cavity 47 fuel inlet openings 51 are arranged in a substantially radial inwards direction such that said fuel inlet openings 51 meet corresponding axially directed water inlet openings 49 from the first cavity 44. Thus, water and liquid fuel will meet and become mixed at the crossing points of openings 49 and 51. The mixed water and fuel will emerge from the mixer 41 through emulsion outlet channels 52. Preferably an emulsion outlet channel

52 is inclined an angle δ with respect to the symmetry axis of the fuel distributor 40 in a plane tangential to the water inlet opening 49. Said angle δ is of the order of between 40 to 60 degrees. The inclination of the emulsion outlet channel 52 imparts a swirl of the fuel air mix in relation to the axis of the fuel distributor 40.

[0037] The jets of mixed liquid fuel and water 56a emerging from the emulsion outlet channels 52 are increasing their speed as they meet the inner wall of the outer lip 53 of fuel distributor 40, whereupon an emulsion flow 56a of fuel and water will be generated and mainly following said inner walls of the outer lip 53. Said flow is further rotating due to the imparted swirl of the jets.

[0038] From Fig. 8 it can be understood that the annular fuel distributor channel 54 between the annular inner lip 50 and the annular outer lip 53 of the fuel distributor 40 is arranged just outside the pilot cooling air channel 25a. Said pilot cooling air 25b in channel 25a has been heated to around 1000 K after the passage along the shell of the pilot combustor 5. The pilot cooling air 25b is thus sweeping by the outlet of the fuel distributor annular channel 54 and forces the fuel/water emulsion flow 56a towards the rounded end 55 of the inner surface of the annularly formed outer lip 53 of the fuel distributor 40.

[0039] The pressure from the pilot cooling air 25b forces the fuel/water-emulsion flow 56a to form a fuel/water emulsion film 56b along the wall of said outer lip 53. The description of the principle for forming said fuel water emulsion film 56b can more easily be understood from figures 9 and 10, wherein the most downstream parts of the fuel distributor 40 are schematically depicted by a cross section in a vertical plane through the symmetry axis of the fuel distributor. Another channel, a wipe air channel 57, supplied with air from an inlet, is arranged as an annular space between the fuel distributor 40 and the neighboring inner wall 10a of the first air channel 10 for the supply of air to the main flame 7. Said wipe air 57 disintegrates the fuel/water emulsion film 56b passing over the edge of outer lip 53 of the fuel distributor as the wipe air 57 tears the fuel/water emulsion film 56b off from the wall of the rounded end 55 of the outer lip 53 when the two flows (wipe air flow 57 and fuel/water emulsion film 56b) collide. By use of the wipe air 57 flow, the emulsion film 56b is effectively dissolved into small droplets where the drop sizes of water and fuel, respectively are atomized into droplets of small and approximately same sizes. After the atomizing of the liquid fuel and water the droplets are sprayed, by the wipe air 57 and the pilot cooling air 25b, into the upstream end of the main flame 7 close to the forward stagnation point P. In this way the temperature of the flame will be reduced to about 1600 K.

[0040] A second embodiment of a mixing device 141 is depicted in Figures 11a to 11c. Drawing 11a in an exploded diagram. Said embodiment of the mixing device includes a tubular shell 142. At an upstream end of this shell, water 143 is laid on. A fuel diffusor tube 144 is arranged substantially perpendicularly to the flow of water 143 inside the shell 142. The diffusor tube 144 is

provided with a row of fuel outlet openings or nozzles 145 facing the downstream side of the tubular shell 142. Liquid fuel 146 is fed to said diffuser tube 144, whereupon the liquid fuel 146 is streaming out through said fuel outlet openings 145 as jet sprays and being mixed with water which is streaming around the diffuser tube 144 in a downstream direction of said tubular shell 142. Thereby an emulsion 147 of liquid fuel 146 and water 143 is formed as a spray of water and liquid fuel droplets. To enhance the mixing of the droplets turbulators 148 are arranged inside the tubular shell 142 downstream the diffuser tube 144. In the depicted example according to figure 11a four turbulators 148 are inserted in the tube. The turbulators 148 may have the shape of a sickle, as in figure 11b, or of a circular segment, as in figure 11c. Further, as depicted in figure 11b, consecutive turbulators 148 are preferably rotated an angle (clockwise or anticlockwise) substantially amounting to 90 degrees to impart a swirl of the emulsion spray, whereby the spray outlet from the tubular shell 142 is formed as a swirl in the desired rotational direction.

[0041] In figure 11c it is further shown that the turbulators 148 can be provided with teeth 149 at the downstream end of the surface 150 of the turbulator 148 facing radially inwards of the tubular shell 142. Due to these teeth 149 an increased turbulence will be imparted to the flow of the emulsion spray 147 sweeping downstream the mixing device 141.

[0042] Preferably, a number of said second embodiment of mixing devices 141 can be used to supply the main flame with the liquid fuel/water mix according to the aspect of the present invention. If there are two or more such mixing devices 141, they should be distributed in a symmetrical manner around the exit of the pilot 5a. The outlets of the tubular shell 142 should then be located just outside the pilot 5a exit, downstream said pilot 5a exit and upstream the exit of the first quarl section 4a.

[0043] The second mixing device 141 can, in a further embodiment, be provided with an annular outlet of the same type as discussed for the fuel distributor 40. As one example of an annular outlet, the fuel distributor 141 may have the same design as is described in the text above of Fig. 8 and forwards for the fuel distributor 40, which means that the design from above of the mixer 41 and downstream could be corresponding to a second embodiment of a fuel distributor. In that case the outlet from mixing device 141 is provided with injection tubes which can emerge at the same location as where the mixer 41 is arranged in corresponding fuel distributor 40. Of course, any type of annular outlets may be arranged at the downstream ends of the second embodiment of mixing device 141 for supply of the emulsion spray to the main flame 7 in a flame surrounding manner.

[0044] A relatively large amount of fuel can be added to the small pilot combustor 5 cooling air which corresponds to very rich equivalence ratios ($\Phi > 3$). Swirled cooling air and fuel and hot products of combustion from the small pilot combustor, can very effectively sustain

combustion of the main lean flame 7 below, at and above LBO limits. The combustion process is very stable and efficient because hot combustion products and very hot cooling air (above 750 °C), premixed with fuel, provide heat and active species (radicals) to the forward stagnation point P of the main flame recirculation zone 20. During this combustion process the small pilot combustor 5, combined with very hot cooling air (above 750 °C) premixed with fuel act as a flameless burner, where reactants (oxygen & fuel) are premixed with products of combustion and a distributed flame is established at the forward stagnation point P of the swirl induced recirculation zone 20. The pilot combustor 5 can be fueled with gas or liquid fuel or both gas and liquid fuel.

[0045] To enable a proper function and stable operation of the burner 1 disclosed in the present application, it is required that the imparted level of swirl and the swirl number (equation 1) is above the critical one (not lower than 0.6 and not higher than 0.8, see also fig. 3) at which vortex breakdown - recirculation zone 20 - will form and will be firmly positioned within the multi quarl 4a, 4b, 4c arrangement. The forward stagnation point P should be located within the quarl 4a, 4b, 4c and at the exit 6 of the pilot combustor 5.

Active species - radicals

[0046] In the swirl stabilized combustion, the process is initiated and stabilized by means of transporting heat and free radicals 31 from the previously combusted fuel and air, back upstream towards the flame front 7. If the combustion process is very lean, as is the case in lean-partially premixed combustion systems, and as a result the combustion temperature is low, the equilibrium levels of free radicals is also very low. Also, at high engine pressures the free radicals produced by the combustion process, quickly relax to the equilibrium level that corresponds to the temperature of the combustion products. This is due to the fact that the rate of this relaxation of the free radicals to equilibrium increases exponentially with increase in pressure, while on the other hand the equilibrium level of free radicals decreases exponentially with temperature decrease. The higher the level of free radicals available for initiation of combustion the more rapid and stable the combustion process will tend to be. At higher pressures, at which burners in modern gas turbine engines operate in lean partially premixed mode, the relaxation time of the free radicals can be short compared to the "transport" time required for the free radicals (symbolized by arrows 31) to be convected downstream, from the point where they were produced in the shear layer 18 of the main recirculation zone 20, back upstream, towards the flame front 7 and the forward stagnation point P of the main recirculation zone 20. As a consequence, by the time that the reversely circulating flow of radicals 31 within the main recirculation zone 20 have conveyed free radicals 31 back towards the flame front 7, and when they begin to mix with the incoming "fresh" premixed lean

fuel and air mixture from the first 10 and second 11 channels at the forward stagnation point P to initiate/sustain combustion process, the free radicals 31 could have reached low equilibrium levels.

[0047] High non-equilibrium levels of free radicals 32 are utilized to stabilize the main lean combustion 7. The scale of the small pilot combustor 5 is kept small and most of the combustion of fuel occurs in the lean premixed main combustor (at 7 and 18), and not in the small pilot combustor 5. The small pilot combustor 5, can be kept small, because the free radicals 32 are released near the forward stagnation point P of the main recirculation zone 20. This is generally the most efficient location to supply additional heat and free radicals to swirl stabilized combustion (7). As the exit 6 of the small pilot combustor 5 is located at the forward stagnation point P of the main-lean re-circulating flow 20, the time scale between quench and utilization of free radicals 32 is very short not allowing free radicals 32 to relax to low equilibrium levels. The forward stagnation point P of the main-lean re-circulating zone 20 is maintained and aerodynamically stabilized in the quarl (4a), at the exit 6 of the small pilot combustor 5. To assure that the distance and time from lean, stoichiometric or rich combustion (zone 22), within the small pilot combustor 5, is as short and direct as possible, the exit of the small pilot combustor 5 is positioned on the centerline and at the small pilot combustor 5 throat 33.

Claims

1. A burner (1) for a gas turbine engine, comprising:

- at the upstream end of said burner a heat source X for supplying heat and a high concentration of free radicals is arranged to support a rapid and stable combustion of a main flame burning in a lean premixed air/fuel swirl and housed in a combustion room defined by a quarl arrangement (4a -4c) axially aligned with the heat source (5) and positioned downstream an exit (6) of said heat source (5), and wherein a recirculation zone (20) of the main flame (7) directs a flow of free radicals back to a forward stagnation point (P) at the exit (6) of the heat source (5).

characterized in that

a fuel distributor (40) is provided at the exit of the heat source (5), said fuel distributor (40) being supplied with liquid fuel and water and provided with mixing means (41, 141) for mixing said liquid fuel and said water for forming a fuel/water emulsion, and said fuel distributor (40) having means for directing said fuel/water emulsion to the upstream end of the main flame (7) for reducing the temperature of the main flame (7).

2. The burner according to claim 1, wherein the heat source (5) is a pilot combustor fuelled with a gas fuel or a gas fuel.

3. The burner according to claim 2, wherein said quarl arrangement (4a - 4c) comprises at least one quarl section (4a, 4b, 4c) surrounding the exit (6) of the pilot combustor (5) and extending from said exit (6) in the downstream direction and said main combustion room being defined downstream said pilot combustor (5) by said at least one quarl section (4a, 4b, 4c).

4. The burner according to claim 3, wherein at least a first channel (10) is defined as a substantially annular space between an upstream quarl section (4a) and the closest downstream quarl section (4b) and provides air (12) and fuel (14) to said main flame (7) in said combustion room.

5. The burner according to any one of claims 1 to 4, wherein the fuel distributor (40) has a substantially annular outlet channel (54) for injecting the emulsion to a shear layer (18) of the main flame (7) and said annular outlet channel (54) having narrowing conical walls formed as inner (50) and outer (53) lips.

6. The burner according to claim 5, wherein said mixing means includes a mixing device (41), and wherein the fuel distributor (40) has a fuel channel (57) for providing said mixing device with a liquid fuel and a water channel (43) for providing said mixing device (41) with water; said liquid fuel and the water being mixed in said mixing device (41) for forming said fuel/water emulsion (56).

7. The burner according to claim 6, wherein said fuel distributor (40):

- has an annular form, whereby said annular formed fuel distributor (40) encloses the exit of the heat source (5), and
- contains said mixing device (41) which occupies an interior and annular space of the fuel distributor (40), and
- comprises at least one liquid fuel cavity (47) arced along a portion of the annularly formed mixing device (41) for injecting through fuel injection openings (51) said liquid fuel into emulsion outlet channels (52), and at least one water cavity (44) arced along a portion of the annularly formed mixing device (41) for injecting through water injection openings (49) said water into said emulsion outlet channels (52), and wherein the emulsion outlet channels (52) directs jets of liquid/fuel emulsion (56) onto the inner surface of the narrowing conical outer lip (53) of the annular outlet channel (54).

8. The burner according to claim 7, wherein said emulsion outlet channels (52) are inclined an angle β in relation to the longitudinal axis of the burner for initiating a swirl of the fuel/water emulsion in the fuel distributor annular outlet channel (54), and wherein said angle β is between 40 and 60 degrees. 5
9. The burner according to claim 1, wherein said mixing means comprises at least one tubularly formed mixing device (141) preferably arranged at an upstream end of a fuel distributor (140) and said tubularly formed mixing (141) device provided with a liquid fuel inlet channel and a water inlet channel. 10
10. The burner according to claim 9, wherein said tubularly formed mixing device is provided with: 15
- a tubular shell (142)
 - a liquid fuel diffuser tube (144) arranged across an axial direction of said tubularly formed mixing device (141) and said liquid fuel inlet channel being connected to said liquid fuel diffuser tube (144), and 20
 - a hollow cylindrical space of the tubular shell (142) to which the water inlet channel is connected. 25
11. The burner according to claim 10, wherein said liquid fuel diffuser tube (144) is provided with a number of liquid outlet spray openings (145), and said hollow cylindrical space is provided with a number of turbulators (148) distributed along the diffuser tube (144) in the downstream direction of the tubularly formed mixing device (141) for mixing the liquid fuel from the liquid outlet spray openings (145) and water passing around the liquid fuel diffuser tube (144) for forming a liquid fuel/water emulsion being outlet through the exit of the tubularly formed mixing device (141) to said fuel distributor (140). 30
12. The burner according to claim 11, wherein said turbulators (148) have the form of a sickle in the cross sectional plane of the tubularly formed mixing device (141). 35
13. The burner according to claim 12, wherein consecutive turbulators (148) are rotated 90 degrees in relation to each other to initiate a swirl of said emulsion. 40
14. The burner according to any one of claims 11 to 13, wherein the downstream parts of the radially inwards directed surfaces of the turbulators (148) are provided with teeth (149) for enhancing the turbulent movements of the passing fuel/water emulsion. 45
15. A method of burning a fuel in a burner, comprising the steps of: 50

- arranging a lean premixed swirl of fuel and air,
- outletting said lean premixed swirl into a quarl arrangement (4a, 4b, 4c),
- burning said fuel of said lean premixed swirl inside said quarl arrangement for forming a main flame (7),
- supporting and stabilizing said main flame by arranging a heat source (5) upstream said main flame (7) for generating a gas flow (32) from the downstream end of the heat source (5) for providing heat and free radicals to the main flame (7),

characterized in that:

- an emulsion of liquid fuel and water is added to the main flame (7) in a region downstream the heat source (5) and the upstream end of the main flame (7) for reducing the temperature of the main flame (7).
16. The method according to claim 15, further comprising the steps of:
- mixing said liquid fuel and said water in a mixing device (41, 141) of a fuel distributor (40, 140) for forming said emulsion,
 - arranging said fuel distributor (40, 140) to surround the downstream end of the heat source (5),
 - exhausting said emulsion as a swirl from said fuel distributor (40, 140).
17. The method according to claim 16, further comprising the step of:
- supplying said heat source (5) with a fuel and air for the generation of said heat and said free radicals.

FIG 1
(PRIOR ART)

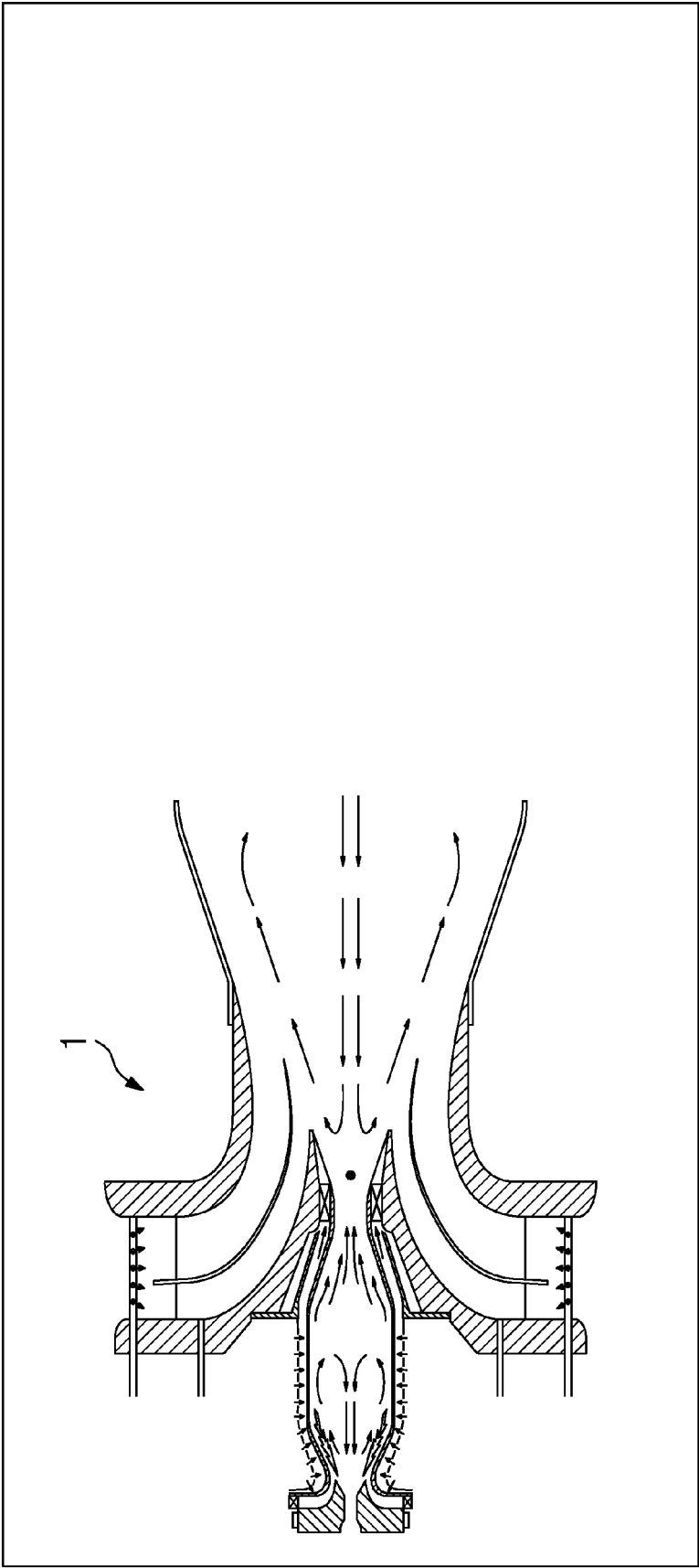
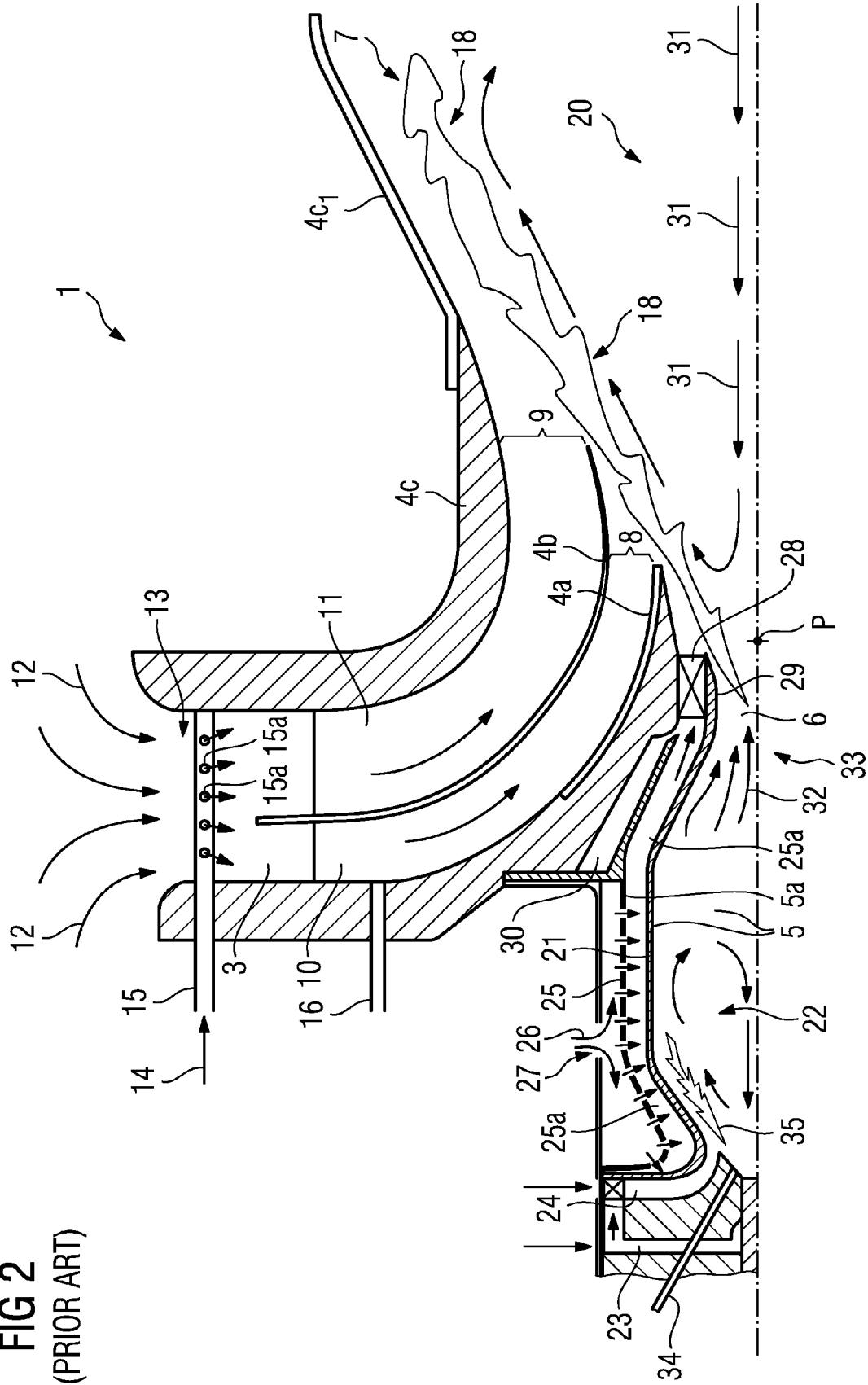


FIG 2
(PRIOR ART)



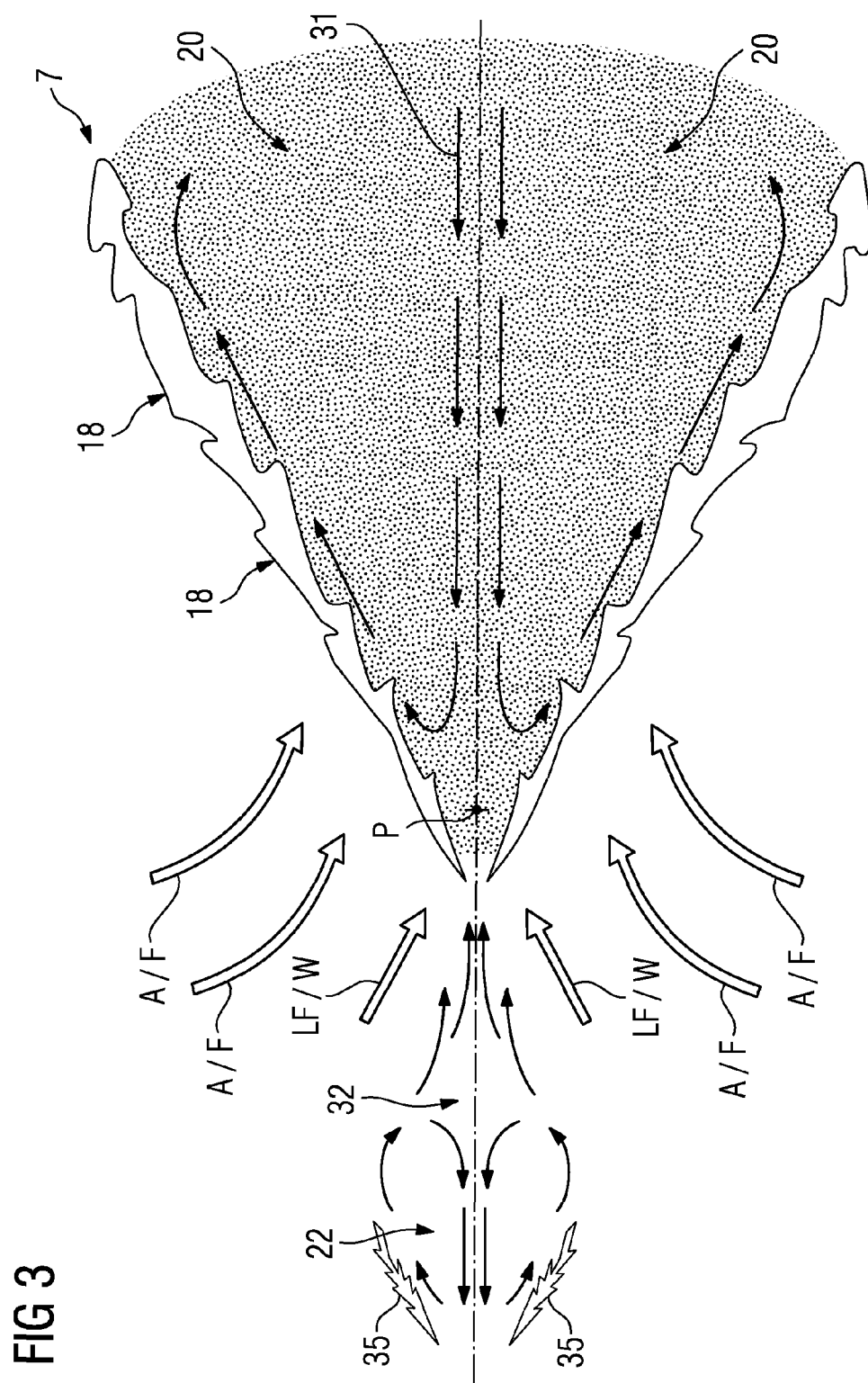


FIG 3

FIG 4

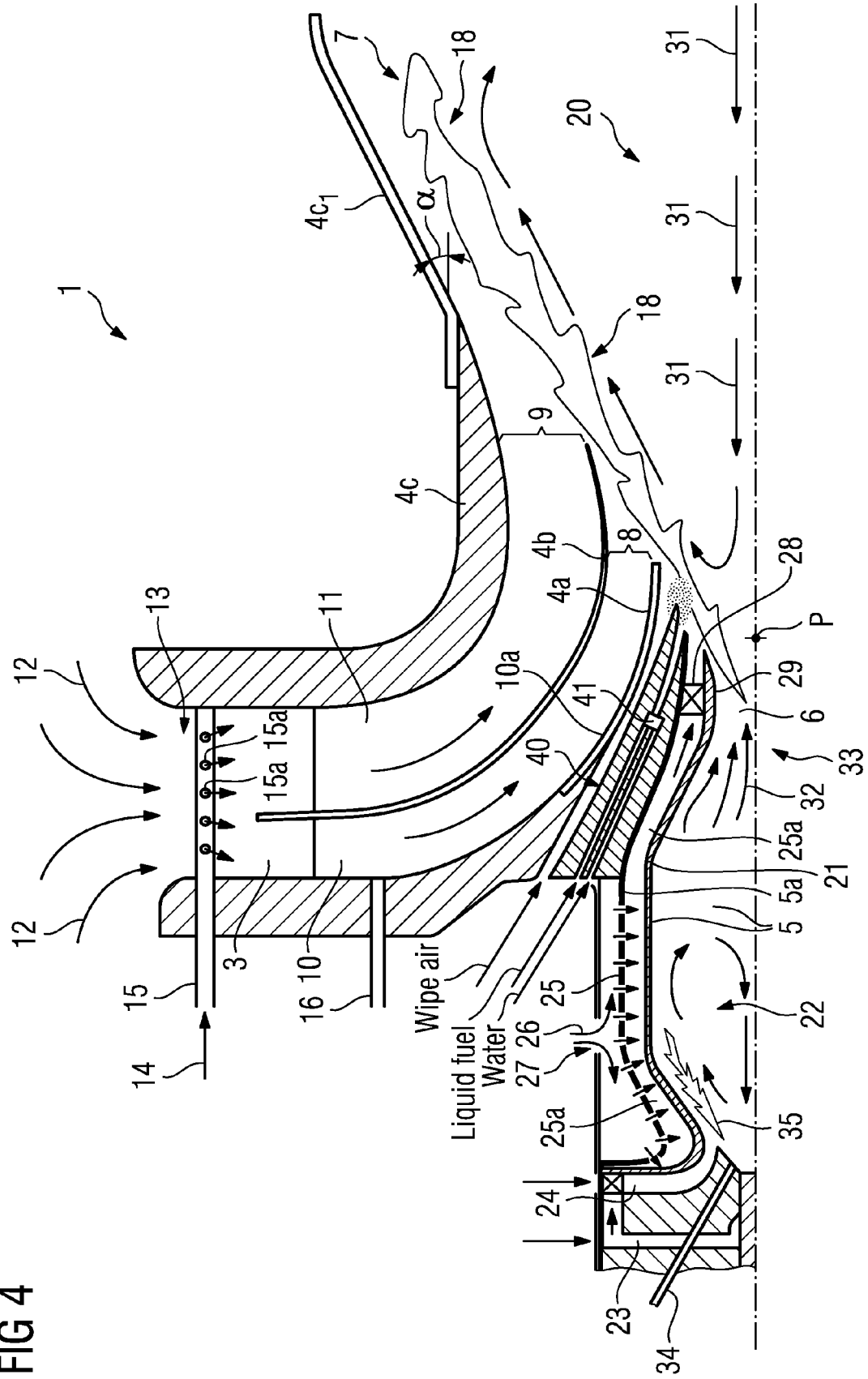


FIG 5

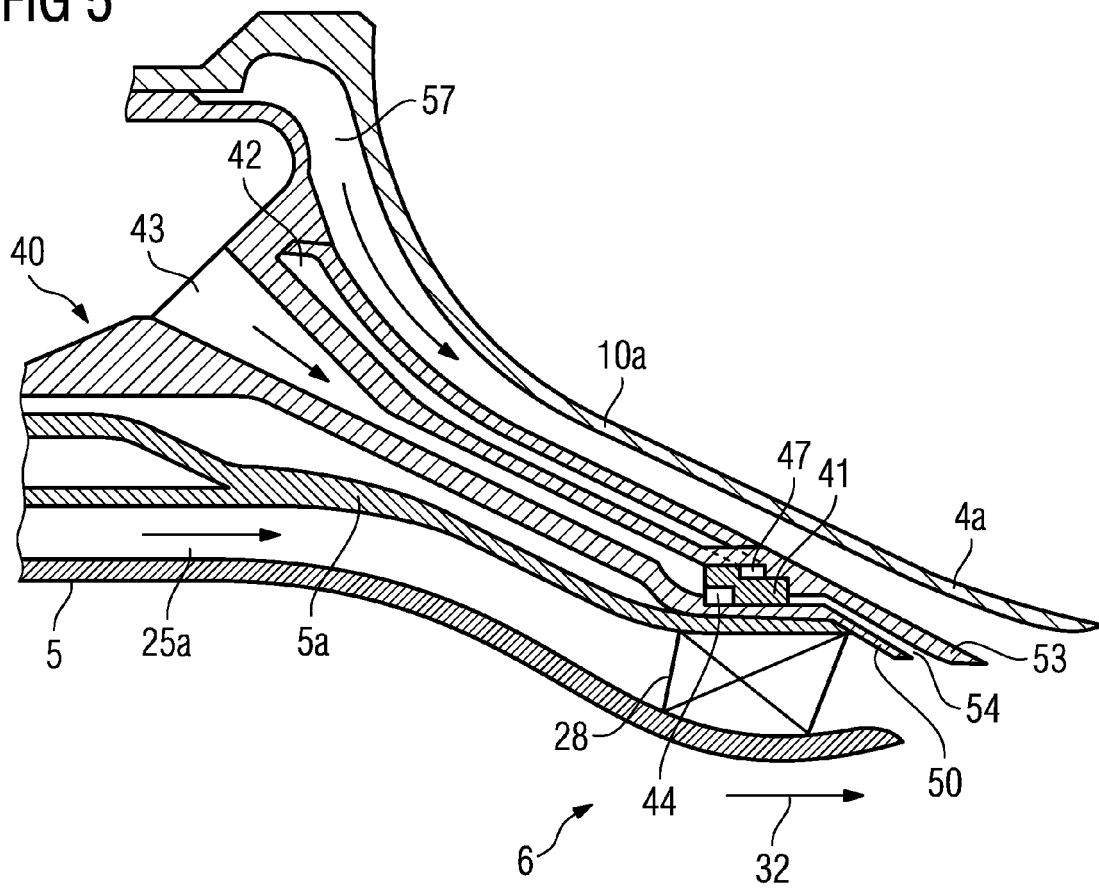


FIG 6

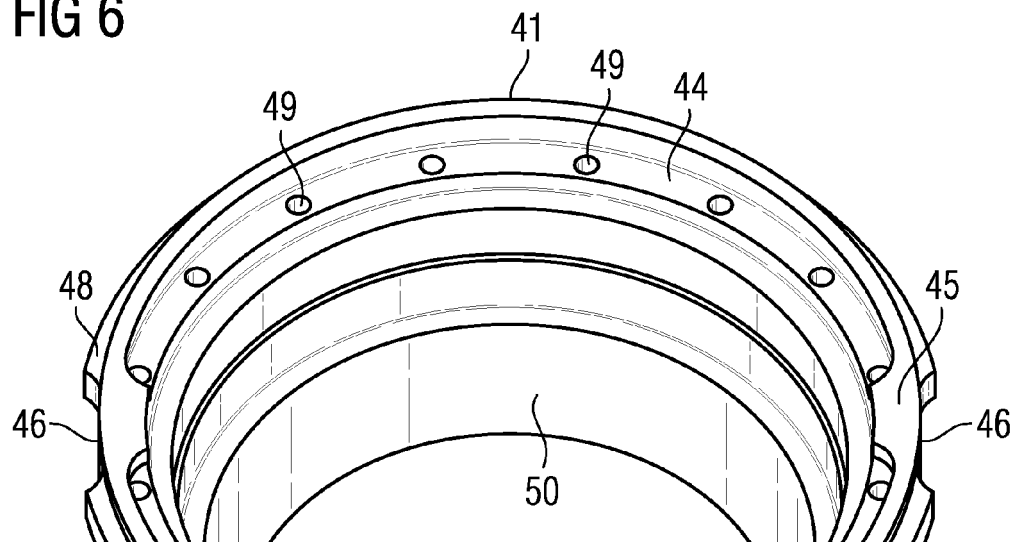


FIG 7

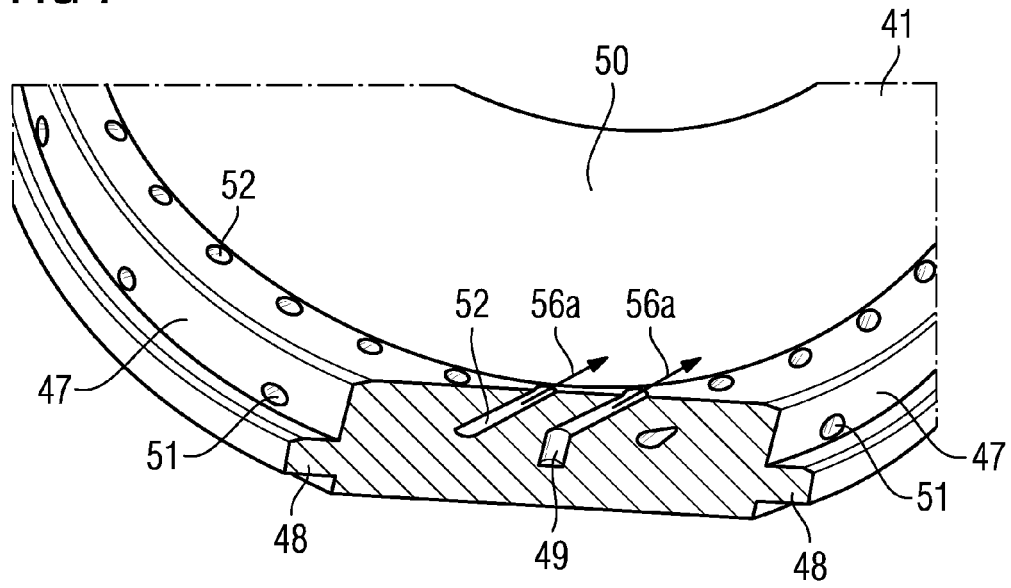


FIG 8

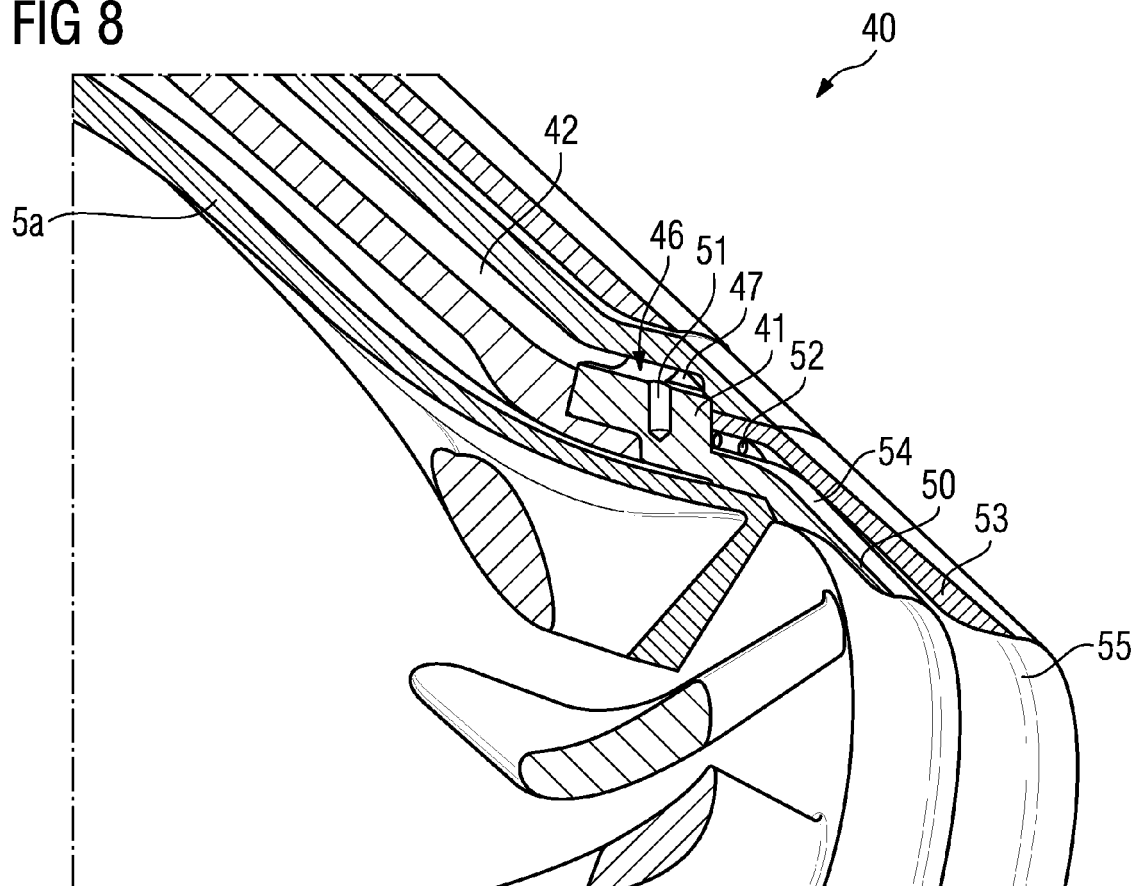


FIG 9

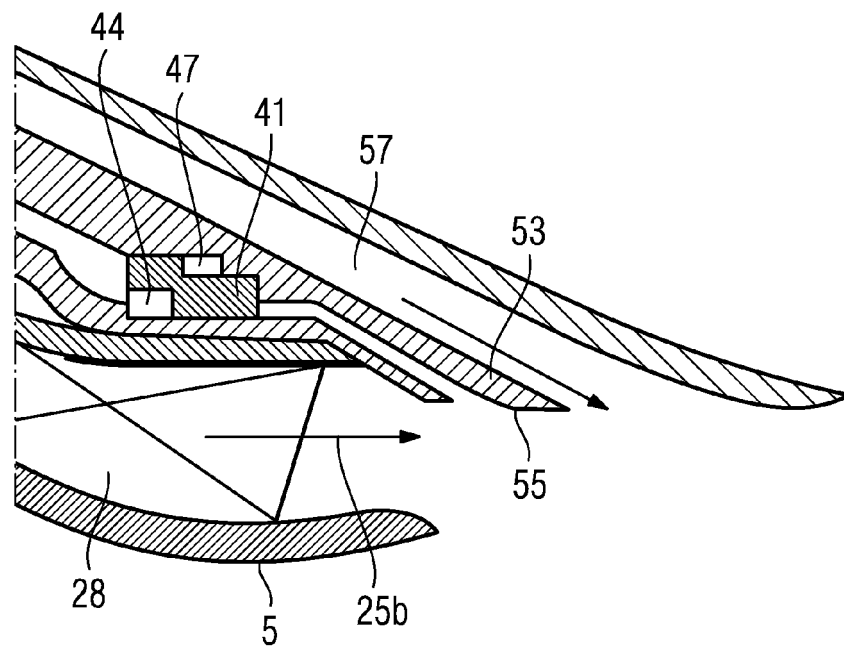


FIG 10

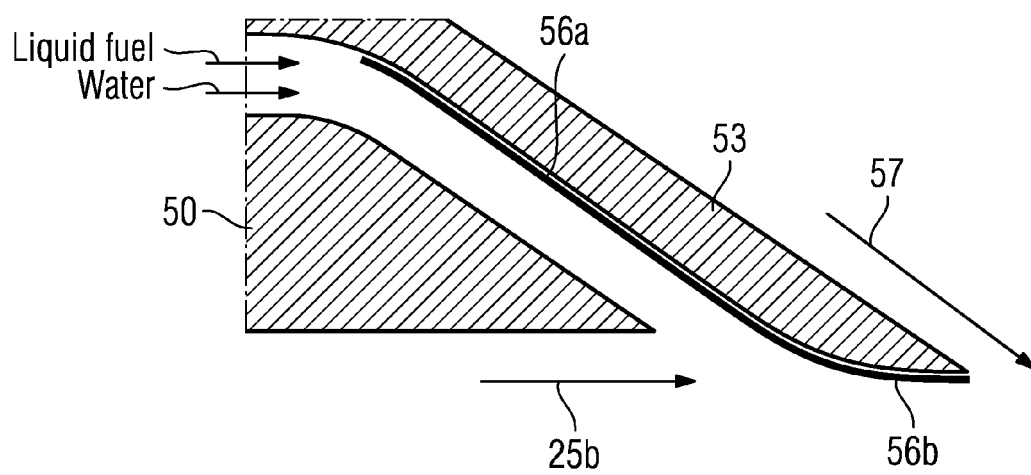


FIG 11A

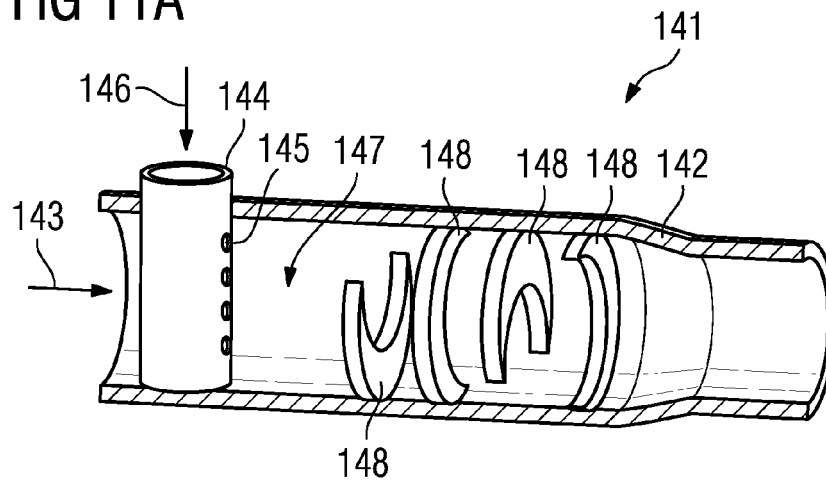


FIG 11B

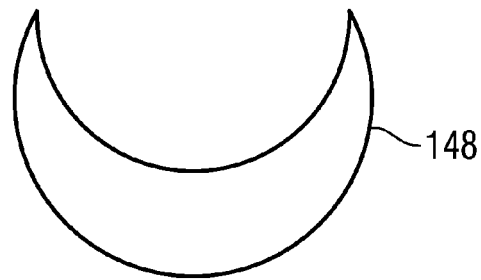
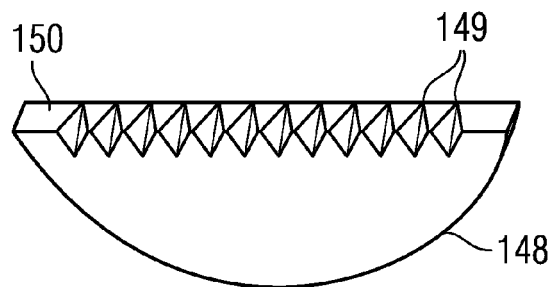


FIG 11C





EUROPEAN SEARCH REPORT

Application Number
EP 10 17 8267

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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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Place of search The Hague		Date of completion of the search 13 April 2011	Examiner Munteh, Louis
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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