Burner for Hydrogen-Rich Fuel-Air Premix Having Enhanced Thermo-Acoustic Stability

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
13 March 2025 (13.03.2025)

WIPO | PCT

(10) **International Publication Number**
WO 2025/052247 A1

(51) **International Patent Classification:**
F23D 14/14 (2006.01)

(21) **International Application Number:**
PCT/IB2024/058561

(22) **International Filing Date:**
03 September 2024 (03.09.2024)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
63/537,331 08 September 2023 (08.09.2023) US

(71) **Applicant: TECHNISCHE UNIVERSITEIT EINDHOVEN** [NL/NL]; Groene Loper 3, 5612 AE Eindhoven (NL).

(72) **Inventors: KOJOURIMANESH, Mohammad**; Groene Loper 3, 5612 AE Eindhoven (NL). **KORNILOV, Viktor**; Groene Loper 3, 5612 AE Eindhoven (NL). **DE GOEY, Philip**; Groene Loper 3, 5612 AE Eindhoven (NL). **LOPEZ ARTEAGA, Ines**; Groene Loper 3, 5612 AE Eindhoven (NL).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV,

(54) **Title:** BURNER FOR HYDROGEN-RICH FUEL-AIR PREMIX HAVING ENHANCED THERMO-ACOUSTIC STABILITY

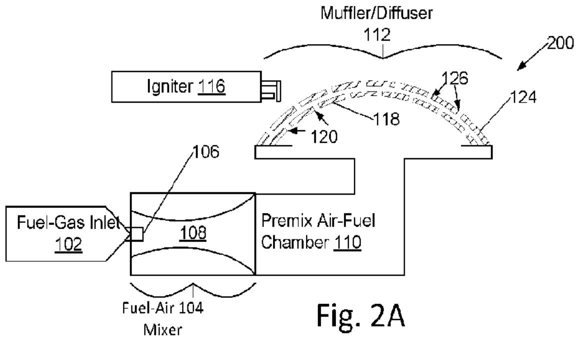


Fig. 2A

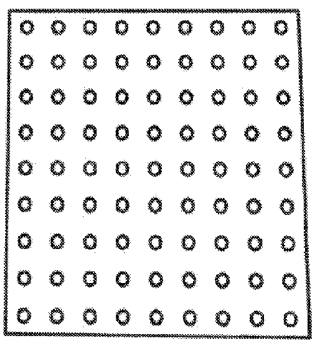


Fig. 2B

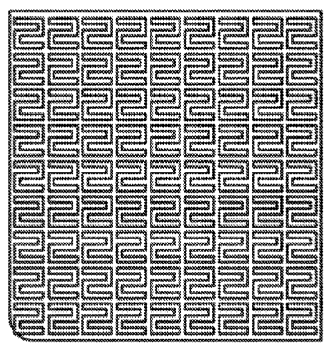


Fig. 2C

(57) **Abstract:** A muffler-burner has a first and second plate each having multiple holes; the first plate mounted at a distance across a muffler area at a mounting distance less than or equal to one and a half millimeters and most holes of the first plate not aligned with the holes of the second plate. In embodiments, the mounting distance is no more than twice the Stokes boundary layer thickness at a first predetermined frequency and more than half of the Stokes's boundary layer thickness at a second predetermined frequency from 50Hz to 8KHz. A method of burning a fuel gas mixture includes mixing the fuel gas mixture with air and passing the fuel-gas-air mixture through holes of a first plate of a muffler-burner deck into a gap; passing the fuel-gas-air mixture from the gap through holes of a second plate into a combustion space; and igniting the fuel-gas-air mixture.

WO 2025/052247 A1

[Continued on next page]

GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*
— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

Burner for Hydrogen-Rich Fuel-Air Premix Having Enhanced Thermo-Acoustic Stability

Cross Reference To Related Applications

[0001] This application claims priority to U.S. Provisional Application No. 63/537,331, filed September 8, 2023, which is hereby incorporated by reference in its entirety.

Background

[0002] Traditional burners typically use premixed air and fossil-fuel gases such as propane or natural gas (largely methane), resulting in environmental drawbacks like carbon dioxide production and nitrogen oxide emissions. A hydrogen-based energy economy has been proposed where it can be desirable to burn gas mixtures containing hydrogen or even replace completely methane or propane in the combustible portion of premix gas with hydrogen.

[0003] However, using hydrogen in pre-mixing burners presents practical challenges due to its high flame speed, reactivity, and temperature values, leading to thermo-acoustic combustion instability issues and the potential for dangerous phenomena like "flashback" (flame propagation to burner components upstream of combustor) or "flame lift-off" (flame detachment from the burner), thus requiring new burner designs.

[0004] Thermo-acoustic combustion instability manifests itself as a high level of tonal noise and vibration and may cause performance deterioration or even damage components. It is known that thermo-acoustic instabilities may provoke flashback.

[0005] Nitrogen oxides form more readily at high combustion temperatures. A way to minimize NOx release is to keep the flame temperature low, which can be accomplished by Lean PreMixed (LPM) combustion achieved by lowering gas to air ratios. However, leaner combustion also increases probability of thermo-acoustic instability.

[0006] As a result, the development of gas turbines, industrial and domestic boilers, and other appliances capable of operating with hydrogen-enriched natural gas or pure hydrogen require improved burner designs.

Brief Description of the Figures

[0007] Fig. 1 is a schematic cross section of a flat burner suitable for fuel containing hydrogen (H2) and fossil fuel gas (propane, ethane, butane, or methane) with various ratios.

[0008] Fig. 2A is a cross section of a dome-shaped burner suitable for the same fuels as the burner of Fig. 1.

[0009] Fig. 2B is a slight perspective view of a flat plate with holes, such as may be used with a spacer plate having slits to assemble a dual-plate, narrow-gap, offset-hole, burner-muffler deck.

[0010] Fig. 2C is a plan view of a flat plate with S-shaped slits, such as may be used with two flat plates with holes, the holes in one flat plate aligned with a first end of each slit and the second flat plate with holes aligned with a second end of each slit, to form a dual-plate, narrow-gap, offset-hole, burner-muffler deck with channel length sufficient to also serve as a flame arrester.

[0011] Fig. 3 is a plot of reflection coefficient leading to thermo-acoustic instability recorded on a particular burner before and after replacement of a single-plate burner deck with a dual-plate, narrow-gap, offset-hole, burner-muffler (ABC) deck.

[0012] Fig. 4 is a graph showing reflection coefficient versus frequency for a fixed hole pattern (Diameter 2 mm with pitch 7 mm) with several plate spacings.

[0013] Fig. 5 is a graph showing reflection coefficient versus frequency for a fixed hole pattern (Diameter 2 mm with pitch 7mm) and a fixed 0.25 mm plate spacing with several dynamic viscosities of fuel gas-air mixture.

[0014] Fig. 6A-6G illustrates several burner designs that can be stabilized with the present design of dual-plate burners.

[0015] Fig. 6A illustrates the basic concept of the ABC muffler with two plates each having holes, the plates separated by a narrow space, with the holes in each plate not aligned.

[0016] Fig. 6B illustrates an ABC muffler having tubular shape.

[0017] Fig. 6C illustrates an interior of an ABC muffler having arced or curved shape, with an inner plate having holes, the inner plate formed with dimples to serve as spacers to an outer plate, the dimples spot-welded to the outer plate.

[0018] Fig. 6D is a perspective view of a tubular muffler resembling that of Fig. 6B save for having uniform round holes in each of an inner and an outer tubular plate.

[0019] Fig. 6E is a perspective view of a portion of the exterior of the tubular muffler of Fig. 6D, the outer tubular plate formed with dimples to serve as spacers from the inner tubular plate, the dimples spot-welded to the inner tubular plate to hold the plates together.

[0020] Fig. 6F is a schematic cross section view of a burner having an ABC muffler having two spaced, perforated plates with holes misaligned, covered by a wire mesh to further spread combustion.

[0021] Fig. 6G is a top view of a burner having the design of Fig. 6G.

[0022] Fig. 7 is a line drawing from a photograph of a dual-plate burner of the present design consuming a methane-air mixture without thermo-acoustic instability.

[0023] Fig. 8A illustrates a flat muffler-burner deck having round holes in a rectilinear pattern simulated to determine reflection, absorption and transmission coefficients and transmission losses.

[0024] Fig. 8B illustrates performance as simulated of the muffler-burner deck of Fig. 8A with a first diameter and a first hole pitch.

[0025] Fig. 8C illustrates performance as simulated of the muffler-burner deck of Fig. 8A with a second diameter and a second hole pitch.

[0026] Fig. 8D illustrates muffler parameters versus frequency of the muffler-burner deck of Fig. 8A.

[0027] Fig. 9A and 9B illustrate a flat muffler-burner deck having a pattern of slits simulated to determine reflection, absorption, and transmission coefficients together with transmission losses.

[0028] Fig. 10 is a graph of reflection coefficient versus frequency for a variety of spacings between two plates of a muffler-burner deck.

Detailed Description of the Embodiments

[0029] We introduce an ultra-thin muffler functioning as the muffler-burner deck in order to produce a burner which is fully stable at any conditions.

[0030] Each burner 100, 200, has a fuel inlet 102 that brings combustible fuel gas into the burner; in various embodiments the fuel gas is a hydrocarbon selected from methane, ethane, propane, and butane, and mixtures thereof including natural gas. This fuel gas is introduced through a fuel-air mixer 104 that produces a mixture of the fuel gas and air, while more complex fuel-air mixers 104 may be used, a simple fuel-air mixer may introduce fuel gas through an orifice 106 into a venturi 108 that draws combustion air into the fuel-air mixer 104 and blends it with the fuel gas to form a fuel-air mixture. The fuel-air mixture is fed into a fuel-air chamber 110. The fuel-air mixture then passes through a muffler-burner deck 112 into a combustion zone 114 where it may be ignited by an igniter 116. Muffler-burner deck 112 may be flat as shown in Fig. 1, curved as shown in Fig. 2A, or may have another shape, such as an arched or dome shape or cylindrical.

[0031] More complex burners, such as those for industrial boilers or gas turbines, may have metering rods in orifice 106, multiple orifices, turbulence inducers, combustion air blowers or compressors, fuel-gas compressors or pumps, and other features that are not illustrated in Fig. 1. Similarly, igniter 116 may be any ignition system as have been used with premixed air-fuel gas burners, including a match, electrical spark, cigarette lighter, or pilot light.

[0032] Muffler-burner deck 112 has a bottom plate 118 having holes 120 through which the premixed fuel-air gas mixture passes into a space 122 between bottom plate 118 and top plate 124. The fuel-air gas mixture passes from space 122 through holes 126 in top plate 124 into the combustion zone 114. In an embodiment, the plates are preferably made of a material(s) capable of withstanding high temperatures, such at least 1000 K. Suitable materials include metals, ceramic materials, and others. The plates can be rigid or flexible so long as spacing is maintained. In some embodiments, each plate has a thickness of from 0.1 mm to 15 mm.

[0033] The holes 120, 126 in the bottom and top plates, respectively, may have a variety of shapes, including holes, grooves, slits, rounded slits, squares, rounded squares, triangles, rounded triangles, pentagons, rounded pentagons, hexagons, rounded pentagons or a combination thereof. The shape and/or size of holes 120 in the bottom plate and of the holes 126 in the top plate may be the same or different. In some embodiments, size of the holes ranges from 0.001 mm to 5 mm. In some embodiments, the holes of at least one or both plates 118, 124 are arranged in a regular pattern. In such embodiments, the arrangement of holes can be characterized by a pitch of, e.g., 0.002 mm to 15 mm.

[0034] The top plate 124 and bottom plate 118 are separated by space 122, across the entire perforated areas of the top and bottom plates. A distance 128 between bottom plate 118 and top plate 124 is small enough that thermo-viscous boundary layer effects have a significant impact upon the propagation of sound along the narrow, rigid-walled channel formed between holes of the top plate and bottom plate giving substantial acoustic attenuation within the audio frequency range. This attenuation is a function of $\bar{\delta}_s/\bar{W}$

where $\bar{\delta}_s = 2\pi\sqrt{2\bar{v}/\omega}$ is Stokes's boundary layer thickness, and $\bar{v}$ is kinematic viscosity defined as the ratio of the dynamic viscosity (μ) over the density (ρ) of the premixed fuel gas and air, and $\bar{W}$ is the channel width distance 128. With rigid-walled channels with widths on the order of Stokes's boundary layer thickness, the attenuation in air can be over 6.86 dB/wavelength; for the channel width of half stokes boundary layer, $\frac{\bar{\delta}_s}{\bar{W}} = 2$, it would be 16 dB/wavelength and for the channel width of twice of the stokes boundary layer, $\frac{\bar{\delta}_s}{\bar{W}} = 0.5$, it would be 3 dB/wavelength.

[0035] The Stokes's boundary layer thickness for frequency range of 20 Hz to 20kHz would be between 0.09 mm and 3 mm. Normally, thermo-acoustic instability happens between 50 Hz to 8000 Hz. For instance, for stabilizing the thermo-acoustic instability at 4000 Hz, (wavelength is 343/4000=0.086 m), by selecting a channel width on the order of Stokes's boundary layer thickness ($\bar{\delta}_s = 2\pi\sqrt{2\bar{v}/\omega} = 2 * \pi * \sqrt{\frac{2*1.516e-5}{4000*2*\pi}} = 0.21$ mm), the muffler can have 6.86 dB/wavelength means 6.86/0.086=80 dB attenuation. This number for the case of channel width of half stokes boundary layer, $\frac{\bar{\delta}_s}{\bar{W}} = 2$, would be 16/0.086=186 dB and for the channel width of twice of the stokes boundary layer, $\frac{\bar{\delta}_s}{\bar{W}} = 0.5$, would be 3/0.086=34 dB. Therefore, shorter sizes of the gap have higher attenuation but also has higher resistance for passing the flow.

[0036] A properly designed muffler-burner deck requires that the distance 128 between top plate 124 and bottom plate 118 should be no more than twice the Stokes boundary layer thickness of a designed fuel-air gas mixture at a frequency greater than peak frequencies of thermo-acoustic instabilities observed with similar burners having conventional single-plate deck which have |Rin|>1. This distance 128 should also be more than half of the Stokes's boundary layer thickness at lowest unstable frequency.

[0037] For example, if a conventional burner deck design produces a peak of reflection coefficient as measured from the combustor supplemented with whole downstream subsystem of the particular appliance (referred to below as Rin) Rin of 240 Hz and lesser resonances at 500 Hz and 750 Hz (as shown as 302 in Fig. 3), then the appliance can be fully stabilized by replacing the single-deck burner with a muffler-burner deck according to the present disclosure, having spacing between top plate and bottom plate between half to twice (0.24 mm- 0.96 mm) of the Stokes's boundary layer thickness at 800Hz ($\bar{\delta}_s =$

$2\pi\sqrt{2\bar{v}/\omega} = 2 * \pi * \sqrt{\frac{2*1.516e-5}{800*2*\pi}}$ = 0.48 mm) for the fuel gas/air mixture being used. The Stokes's boundary layer thicknesses given in this paragraph are for air, the Stokes's boundary layer thicknesses of fuel gas-air mixtures will be close to, but different from, these values and will vary with the hydrocarbon and hydrogen content of the fuel gas. The burner with muffler-burner deck has reflection coefficient 304 without flame and 306 with flame.

[0038] Narrowness of the channel between the entire perforated portions of the top and bottom plates is important in function as this forms a broadband ultra-thin muffler that dampens thermo-acoustic instabilities at a wide broadband range of frequency. The muffler can work simultaneously from 2 Hz until 8kHz and in some special designs for even higher frequencies (up to 20kHz). In general, it can perform at ultra-low frequencies (2-100 Hz), at low frequencies (100 Hz to 1000 Hz), and mid frequencies (1000 Hz to 2000 Hz), and higher frequencies (above 2000 Hz). The muffler has been designed, built, and verified by analytic solution and numeric simulation via commercial software and verified by laboratory testing.

[0039] The performance of the muffler-burner deck can reach 99% at burner noise suppression. The measured reflection coefficient of the muffler even at ultra-low frequencies is less than 0.05 meaning 99.99% of the acoustic energy is either absorbed or transmitted from the muffler and nearly nothing is reflected back. The muffler-burner deck, including top and bottom plates with spacer between, can have a thickness of a few millimeters based on the applications. Because of the ultra-thin size of the muffler, it can be easily integrated to any kind of burners with any kind of fuel. By applying the muffler, it can make the burner stable and completely mute. Therefore, the muffler can be used as a sole device or it can be added (integrated, combined) to any burners. It can be also integrated to other noise reduction systems.

[0040] Narrowness of the channel between top and bottom plates also permits the muffler-burner deck to act as a flame arrestor and help prevent flashback by being narrower than the "safe gap" of gas-air mixture specified in the following table; for example, plate spacing of 0.3 mm should prevent flashback when burning hydrogen. Based on ISO 16852, a flame arrestor is a device fitted to the opening of an enclosure, or to the connecting pipe work of a system of enclosures, and whose intended function is to allow flow but prevent the transmission of flame.

Specification of gas-air mixtures for deflagration and detonation tests

Range of application (marking)		Requirements for test mixture			
Explosion group	MESG of mixture mm	Gas type	Gas purity by volume %	Gas in air by volume[a] %	Safe gap of gas-air mixture mm
IIA1	≥1,14	Methane	≥98	8,4 ± 0,2	1,16 ± 0,02
IIA[b]	>0,90	Propane	≥95	4,2 ± 0,2	0,94 ± 0,02
IIB1[b]	≥0,85	Ethylene	≥98	5,2 ± 0,2	0,83 ± 0,02
IIB2[b]	≥0,75			5,7 ± 0,2	0,73 ± 0,02
IIB3[b]	≥0,65			6,6 ± 0,3	0,67 ± 0,02
IIB[b]	≥0,50	Hydrogen	≥99	45,0 ± 0,5	0,48 ± 0,02
IIC	<0,50	Hydrogen	≥99	28,5 ± 2,0	0,31 ± 0,02

NOTE The ranking in columns 1 and 2 is not comparable with the ranking in IEC 60079-1.

[a] When the test gas mixture is measured by the safe gap of the gas-air mixture, the mixture shall be in the lower half of the specified gap range. If the test gas mixture is measured by the percentage of gas in air by volume, then for IIA1, IIA, IIB3 and IIC, the mixture shall be within the specified percentage volume range. For IIB1 and IIB2, the mixture shall be in the upper half side of the specified percentage volume range. For IIB, the mixture shall be on the lower half side of the specified percentage volume range. All the stated limit deviations relate to the uncertainty of the measuring equipment.

[b] With small diameters, it may be difficult to generate stable detonations. Tests may be carried out using a gas-air mixture of a lower safe gap.

Table 1, ISO 16852 safe gap requirements for flame arrestors.

[0041] Depending on gas flow requirements, premix density, hole counts, and hole diameters, the gap between top plate and bottom plate is chosen to be between 0,001 and 1.5 millimeters, and in some cases 0.3, 0.25, 0.22, 0.2 or 0.15 millimeters as given above. Each layer (surface) has multiple opening areas. The holes of the top plate are shifted from the holes of the first surface such that flow cannot bypass without passing the narrow channels such that the majority of the holes of the top plate are not directly aligned with the holes of the bottom plate. In embodiments, none of the holes of the top plate align directly with holes of the bottom plate. In some embodiments the gap between top plate and bottom plate is between 0.001 and 1.5 mm, inclusive, and is configured to burn a wide range of methane/natural gas, air, and hydrogen mixtures. In other embodiments, the gap between top plate and bottom plate is 0.05 and 0.5 mm, inclusive, or between 0.1 and 0.3 mm, inclusive.

[0042] The space 122 may be created using spacers disposed between the plates. Examples include a mesh, one or more wires, wedges, rings and/or strips.

[0043] In an embodiment, when plate spacing is at the high end of the range, a mesh can be installed between the plates to provide small cells to ensure flame quenching. The quenching distance is a key quantity in order to design the quenching meshes because it depends on the gas species. The minimum quenching distances measured for hydrogen-air mixtures with hydrogen concentrations at 300K and atmospheric pressure is 0.6 mm. By adding a mesh grid inside the gap with wires with a diameter almost similar to the gap spacer then each cell size of the generated mesh would be less than needed 0.6 mm to obey ISO 16852 for functioning as a flame arrester. When plate spacing in such exemplary embodiments is less than 0.31 mm, the closely spaced plates themselves may serve as a flame arrester.

[0044] As mentioned in ISO 16852, MESG is maximum gap between the two parts of the interior chamber which prevents ignition of the external gas mixture through a 25 mm long flame path when the internal mixture is ignited, for all concentrations of the tested gas or vapor in air. Also, MESG, the gap size of the quenching mesh, is approximately a half of the minimum quenching distance. These numbers for the hydrogen are MESG: 0.31 mm and the quenching distance: 0.58 mm. Therefore, to have a flame arrestor, the cell size should be less than MESG when the long flame path is more than 25 mm. For instance, in some embodiments, the gap between two layers is 0.20 mm, therefore, it is lower than MESG for Hydrogen combustion; also, it is less than a quenching distance. By adding a mesh grid inside the gap (between plates) with wires of 0.20 mm and pitch of 0.31 mm then each cell size would be less than 0.31 mm in the gap. If the flame path, i.e., thickness of two plates plus gap plus pitch, would be more than 25mm then the muffler can be considered as a flame arrester based on ISO 16852. Therefore, for instance, a spacer plate with microchannel slits having an S-shaped pattern as depicted in Fig. 2C can be created between the two plates, such as two of the plates depicted in Fig. 2B, to achieve a desired flame path length, allowing the muffler-burner deck to function as a flame arrester as well. In such an embodiment, a first of the plates with holes has the holes aligned with a first end of each microchannel slit, and the second of the plates with holes has the holes aligned with a second end of each microchannel slit, the three plates forming a sandwich with, in order, the first plate with holes, the plate with the microchannel slits, and the second plate with holes, stacked together. A thickness of the spacer plate is the plate spacing herein described as the spacing to achieve adequate damping and stability with flame arresting capability. For applications not requiring flame arresting capability, the spacer plate may have shorter, straighter, and wider microchannel slits than the S-shaped pattern illustrated in Fig. 2C.

[0045] A burner including an acoustic dampener (muffler) to achieve thermo-acoustic stability can be utilized for various types of combustions, such as natural gas, methane, propane, hydrogen, and bio-fuel combustions, whether they are pre-mixed, mixed, or non-mixed at a different temperature, e.g., -20 to 100C, and gas pressure, e.g., 0.5 to 35 [bar]. Stable burners are notoriously difficult to design for these types of high pressures, temperatures and fuels. This muffler can be implemented on burners of different geometrical models, including laminar and turbulent burners, as well as direct-fired and indirect-fired burners.

[0046] As a measurable quantity to evaluate the performance of the implementation of the invented muffler-burner deck the value of Rin can be used, as described in Kojourimanesh, Ph.D. thesis, 2022. If it is smaller than one, then it is indicating that the burner with its downstream subsystem can be considered as a passive acoustic element. In contrast, the combustor with downstream acoustics with magnitude of Rin larger than 1 (as it is usual with regular burners) act as active elements, which can lead to instability. For example, the acoustic reflection coefficient of particular burners with flames, known as Rin, is shown in Fig. 3. It is evident in this figure that the Rin value for a regular burner with a flame reaches 2.7, exceeding one. Consequently, this burner can become unstable at vicinity of 240 Hz. However, when the muffler is applied to the aforementioned burner, the Rin value decreases, falling below one, and even below the reflection coefficient of the burner without a flame. This burner has been made and successfully tested in the laboratory for gas combustion, demonstrating complete stability. The dimensions of the prototype burner were – hole diameter of 2mm, hole pitch of 7 mm, and the space between the plates of 0.25 mm.

[0047] As mentioned before, for most of the configurations which are under discussion here, the channel width (spacer gap) is smaller than the doubled Stokes's boundary layer. Accordingly, it is very plausible that the acoustic attenuation in the inter-plates spacer gap is the crucial physical phenomena governing the performance of the muffler-burner deck. This conclusion is also supported by the observation of the strong sensitivity of the reflection coefficient to the inter-plate spacer gap width shown in Fig. 4.

[0048] The dependence of |R| on the viscous boundary layer is also important. To perform a "pure" test, one can play with the value of the gas/air dynamic viscosity in the model keeping other parameters intact. The results of such simulations are given in Fig. 5. The variation of the air viscosity around the nominal value of $\mu = 1.82 * 10^{-5}\ Ps.s$ leads to a non-monotonic dependence of the reflection coefficient. For this particular case (D2P7S0.25 - hole diameter of 2mm, the pitch of 7 mm, and the spacer gap 0.25mm), the combination of parameters is optimal for the lower reflection at the low end of the frequency. An increase and decrease of the coefficient of dynamic viscosity leads to an increase and decrease of the reflection coefficient at different frequencies.

[0049] Traditional burners have one perforated sheet, although some have a distribution plate before the burner sheet with spacing distance between most of each plate is more than 3mm. Some photos of such burners with different shapes and hole patterns are shown in Fig. 6A-6G that can be stabilized with the present design of dual-plate burners with close plate spacing. Many additional shapes and hole patterns may be used as required for a particular application.

[0050] Fig. 6A illustrates the basic concept of the ABC muffler 600 with two plates, an inner plate 602 and an outer plate 604, each having holes 606, the plates separated by a narrow space, with the holes in the plate not aligned to each other. Fastening of the plates is not shown in this figure.

[0051] Fig. 6B illustrates an ABC muffler having tubular shape.

[0052] Fig. 6C illustrates an interior of an ABC muffler 607 having arced or curved shape, with an inner plate 608 having holes 612, the inner plate formed with dimples 610 to serve as spacers to an outer plate, the dimples spot-welded to the outer plate.

[0053] Fig. 6D is a perspective view of a tubular muffler resembling that of Fig. 6B save for having uniform round holes in each of an inner and an outer tubular plate.

[0054] Fig. 6E is a perspective view of a portion of the exterior of the tubular muffler of Fig. 6D, the outer tubular plate formed with dimples to serve as spacers from the inner tubular plate, the dimples spot-welded to the inner tubular plate to hold the plates together.

[0055] Fig. 6F is a schematic cross section view of a burner having an ABC muffler 620 having two spaced, perforated plates 622, 624, each plate with holes 626, the holes in the plates misaligned, covered by a wire mesh 628 of wires 630 to further spread combustion. Gas enters this embodiment through a tube 632 into a backchamber or plenum 634 before diffusing through the perforated plates 622, 624.

[0056] Fig. 6G is a top view of a burner having the design of Fig. 6G.

[0057] Fig. 7 is a photograph of a dual-plate burner D2P7S0.25 (hole diameter of 2mm,pitch of 7 mm, and the spacer gap 0.25mm) that can be used instead of the traditional burner (1 sheet) with the pattern of D2P7 (hole diameter of 2mm and the pitch of 7 mm) consuming a methane-air mixture, without thermo-acoustic instability. Our test shows that it also does not have flashback or flame lift-off.

Simulated Examples

Example 1

[0058] Performance of a muffler-burner deck made from two perforated sheets having a regular array of circular holes was simulated, see Fig. 8A.

[0059] As a part of performing the simulation, we modelled the air which passes through the holes plus the air before entering to the muffler from (bottom side) and after the outlet (top side).

[0060] There are four important acoustic parameters to characterize any components as

- Reflection coefficient
- Transmission coefficient
- Absorption coefficient
- Transmission Loss

[0061] The first two are independent (R and T) and the other two (α and TL) are related to (R and T). For the burner application, it is important to have very low reflection coefficient. Based on our experiment if $|R|<0.3$ then the burner is stable at that frequency, but even if $|R|<0.6$ the burner could be stable based on the kind of fuel or percentage of the mixture, etc.

It is preferred to have high absorption coefficient, but it is not necessary for the burner application.

[0062] For the muffler-burner deck with the dimensions of–sheet thicknesses: 1[mm]; D1, D2 (holes diameters): 2[mm]; pitch1, pitch2 (distance between origin of two circles): 7[mm]; spacer: 0.25 [mm], the result of mentioned four acoustic parameters for frequency range of 5Hz- 20kHz are shown in Fig. 8B.

[0063] For another muffler-burner deck with the dimensions of–sheet thicknesses: 1[mm]; D1, D2 (holes diameters): 1[mm]; pitch1, pitch2 (distance between origin of two circles): 4[mm]; spacer: 0.25 [mm], the result of the four acoustic parameters here described for a frequency range of 5Hz- 20kHz are shown in Fig. 8C.

[0064] The results of Fig. 8C show that with a two layers' muffler, we can have absorption more than 20% below 500 Hz. The value of the reflection coefficient for frequencies below 100 Hz is less than 0.15 and for frequencies below 1000 Hz is less than 0.55. Moreover, the transmission loss can be more than 6 dB while transmission coefficient is 0.7 at 1000 Hz. The transmission loss would be more than 15 dB at 4000 Hz and 20 dB at 10kHz while transmission coefficient is less than 0.15.

[0065] The simulated performance of several exemplary configurations at good performance at 1000Hz and/or 4000Hz is shown below:

a. sheet_thicknesses: 1[mm]; D1, D2 (holes diameters): 2[mm]; pitch1, pitch2 (distance between origin of two circles): 6[mm]; spacer: 0.25 [mm] which has |R|=0.45@ 1000 Hz.

b. sheet_thicknesses: 1[mm]; D1, D2 (holes diameters): 1[mm]; pitch1, pitch2 (distance between origin of two circles): 4[mm]; spacer: 0.25 [mm] which has |R|=0.5@ 1000 Hz.

c. sheet_thicknesses: 1[mm]; D1, D2 (holes diameters): 1[mm]; pitch1, pitch2 (distance between origin of two circles): 2[mm]; spacer: 0.1 [mm] which has |R|=0.53@ 4000 Hz.

d. sheet_thicknesses: 1[mm]; D1, D2 (holes diameters): 1[mm]; pitch1, pitch2 (distance between origin of two circles): 1.5[mm]; spacer: 0.25 [mm] which has |R|=0.05 @ 1000 Hz.

e. sheet_thicknesses: 1[mm]; D1, D2 (holes diameters): 3[mm]; pitch1, pitch2 (distance between origin of two circles): 4.5[mm]; spacer: 0.2 [mm] which has R|=0.4, @ 1000 Hz.

f. sheet_thicknesses: 1[mm]; D1, D2 (holes diameters): 3[mm]; pitch1, pitch2 (distance between origin of two circles): 7[mm]; spacer: 0.25 [mm] which has |R|=0.53 @ 1000 Hz, |R|=0.87 @ 3500 Hz.

sheet_thicknesses: 1[mm]; D1, D2 (holes diameters): 2[mm]; pitch1, pitch2 (distance between origin of two circles): 3[mm]; spacer: 0.2 [mm] which has |R|=0.09@ 1000 Hz, |R|=0.35 @ 4000 Hz and |R|=0.65 @ 10000 Hz as shown in Fig. 8D.

Example 2

[0066] Another simulated example using slit configurations instead of round holes is shown in Fig. 9A and 9B.

[0067] Simulation results of some slit configurations with various spacer gap are shown in Fig. 10.

[0068] The following configurations were found to have good performance at 1000 Hz and/or 4000Hz:

a. Sheet thickness 0.6 mm; slit_width: 0.5mm; slit_height: 1.5mm; slit_pitch: 1.3mm, spacer 0.07mm which has |R|= 0.1 @ 1000 Hz, |R|= 0.4 @ 4000 Hz.
b. Sheet thickness 1 mm; slit_width: 0.7mm; slit_height: 2mm; slit_pitch: 2mm, spacer 1.5mm which has |R|= 0.3 @ 1000 Hz.
c. Sheet thickness 1 mm; slit_width: 0.5mm; slit_height: 1.5mm; slit_pitch: 2mm, spacer 0.1mm which has |R|= 0.2 @ 1000 Hz, |R|= 0.6 @ 4000 Hz.
d. Sheet thickness 1 mm; slit_width: 0.5mm; slit_height: 2.5mm; slit_pitch: 1.5mm, spacer 0.08mm which has |R|= 0.15 @ 1000 Hz, |R|= 0.45 @ 4000 Hz.
e. Sheet thickness 1 mm; slit_width: 0.6mm; slit_height: 2mm; slit_pitch: 1.5mm, spacer 0.08mm which has |R|= 0.2 @ 1000 Hz, |R|= 0.42 @ 4000 Hz.
f. Sheet thickness 1 mm; slit_width: 0.7mm; slit_height: 2.5mm; slit_pitch: 2mm, spacer 0.08mm which has |R|= 0.12 @ 1000 Hz, |R|= 0.5 @ 4000 Hz.

Combinations

[0069] The burners herein described have several features, these features can be combined in several ways. Combinations anticipated by the inventors include the following.

[0070] A muffler-burner deck designated A including: a first plate having multiple holes; a second plate having multiple holes; the first plate mounted at a distance across an entire muffler area having holes of first and second plate that is less than or equal to one and a half millimeters above the second plate; and where a majority of the holes of the first plate are not aligned with the holes of the second plate.

[0071] A muffler-burner deck designated AA including the muffler-burner deck designated A where none of the holes of the first plate are directly aligned with holes of the second plate.

[0072] A muffler-burner deck designated AB including the muffler-burner deck designated AA or A, where the first plate is mounted at a distance above the second plate that is no more than twice the Stokes boundary layer thickness at a first predetermined frequency and more than half of the Stokes's boundary layer thickness at a second predetermined frequency.

[0073] A muffler-burner deck designated AC including the muffler-burner deck designated AB, where the first predetermined frequency is different from the second predetermined frequency.

[0074] A muffler-burner deck designated AD including the muffler-burner deck designated AB or AC where the first and second predetermined frequency are in the range from 50Hz to 8KHz.

[0075] A muffler-burner deck designated AE including the muffler-burner deck designated AA, AB, AC, AD or A, where the first plate is mounted at a distance from 0.05 and 0.5 millimeters above the second plate, inclusive.

[0076] A muffler-burner deck designated AF including the muffler-burner deck designated AA, AB, AC, AD or A where the first plate is mounted at a distance from 0.5 and 1.5 millimeters from the second plate, inclusive.

[0077] A muffler-burner deck designated AG including the muffler-burner deck designated AA, AB, AC, AD or A wherein the first and second plates each have multiple holes having a diameter from 1 mm to 3 mm and a pitch of 1.3 mm to 8 mm; and wherein the first plate is mounted at a distance less than or equal to 0.05 to 0.25 mm from the second plate.

[0078] A muffler-burner deck designated AH including the muffler-burner deck designated AA, AB, AC, AD or A wherein the multiple holes in the first and second plates each include multiple slits having a slit width of 0.05 mm to 3 mm, a slit height of 0.05 to 10 mm and a pitch of 0.11 mm to 5 mm; and wherein the first plate is mounted at a distance less than or equal to 0.05 to 0.5 mm above the second plate.

[0079] A muffler-burner deck designated AJ including the muffler-burner deck designated AA, AB, AC, AD, AE, AF, AG, AH or A where at least a portion of the area having holes of the first plate is flat.

[0080] A muffler-burner deck designated AK including the muffler-burner deck designated AA, AB, AC, AD, AE, AF, AG, AH or A where at least a portion of the area having holes of the first plate is arched.

[0081] A muffler-burner deck designated AL including the muffler-burner deck designated AA, AB, AC, AD, AE, AF, AG, AH or A where at least a portion of the area having holes of the first plate is dome shaped.

[0082] A burner designated B adapted to burn a fuel-gas mixture, the burner including a muffler-burner deck of the type designated A, AA, AB, AC, AD, AE, AF, AG, AH, AJ, AK, or AL; a fuel-air mixer configured to mix a designed fuel-gas mixture with air and produce a fuel-air mixture; and a fuel-air chamber configured to receive the fuel-air mixture from the fuel-air mixer and provide the fuel-air mixture to the muffler-burner deck.

[0083] A burner designated BA including the burner designated B, wherein the designed fuel gas mixture comprises hydrogen and a hydrocarbon fuel in a ratio between 0% and 100% of hydrogen.

[0084] A burner designated BB including the burner designated B or BA where the muffler-burner deck is configured to pass fuel-air mixture from the fuel-air chamber to a combustion space, and further comprising an igniter configured to ignite the fuel-air mixture in the combustion space.

[0085] A burner designated BC including the burner designated BA, BB, or B where the muffler-burner deck is configured to act as a flame arrester and prevent flash back and flame lift-off.

[0086] A burner designated BD including the burner designated BA, BB, or BC where the hydrocarbon fuel is selected from methane, natural gas, ethane, butane, and propane.

[0087] A method designated C of burning a fuel gas mixture including mixing the fuel gas mixture with air to form a fuel-gas-air mixture; and passing the fuel-gas-air mixture through holes of a first plate of a muffler-burner deck into a gap; passing the fuel-gas-air mixture from the gap through holes of a second plate into a combustion space; and igniting the fuel-gas-air mixture in the combustion space; where a majority of the holes of the first plate are not aligned with holes of the second plate; and a distance between the first plate and the second plate forming the gap is less than or equal to one and a half millimeters.

[0088] A method designated CA including the method designated C where none of the holes of the first plate are directly aligned with holes of the second plate.

[0089] A method designated CB including the method designated C or CA, wherein the fuel gas mixture comprises hydrogen and a hydrocarbon fuel in a ratio between 0% and 100% hydrogen.

[0090] A method designated CC including the method designated C, CA, or CB where the distance between the first plate and the second plate is between 0.05 and 0.5millimeters, inclusive.

[0091] A method designated CD including the method designated C, CA, or CB 8 where the distance between the first plate and the second plate is between 0.5 and 1.5 millimeters, inclusive.

[0092] A method designated D of using a burner-muffler deck designated A, AA, AB, AC, AD, AE, AF, AG, AH, AJ, AK, or AL for at least one of: reducing an acoustic instability, arresting flame, preventing flashback, and flame lift-off, in a fuel-air combustor, the method including: providing the burner-muffler deck as designated A, AA, AB, AC, AD, AE, AF, AG, AH, AJ, AK, or AL; mixing the fuel gas mixture with air to form a fuel-gas-air mixture; passing the fuel-gas-air mixture through holes of the first plate of the muffler-burner deck into the gap; passing the fuel-gas-air mixture from the gap through holes of the second plate into a combustion space; and igniting the fuel-gas-air mixture in the combustion space.

[0093] A method designated DA including the method designated D, wherein at least two of reducing an acoustic instability, arresting flame, preventing flashback, and flame lift-off, in a fuel-air combustor, are performed concurrently.

[0094] Changes may be made in the above methods and systems without departing from the scope hereof. It should thus be noted that the matter contained in the above description or shown in the accompanying drawings should be interpreted as illustrative and not in a limiting sense. The following claims are intended to cover all generic and specific features described herein, as well as all statements of the scope of the present method and system, which, as a matter of language, might be said to fall there between.

Claims

What is claimed is:

1. A muffler-burner deck comprising:

a first plate having a plurality of holes;

a second plate having a plurality of holes;

the first plate mounted at a distance across an entire area having holes of first and second plate that is less than or equal to one and a half millimeter above the second plate; and

where a majority of the holes of the first plate are not aligned with the holes of the second plate.

2. The muffler-burner deck of Claim 1 where none of the holes of the first plate are directly aligned with holes of the second plate.

3. The muffler-burner deck of Claim 2, where the first plate is mounted at a distance above the second plate that is no more than twice a Stokes boundary layer thickness of a designed fuel-air gas mixture at a first predetermined frequency and more than half of the Stokes's boundary layer thickness at a second predetermined frequency.

4. The muffler-burner deck of Claim 3, where the first predetermined frequency is different from the second predetermined frequency.

5. The muffler-burner deck of Claim 4, where the first and second predetermined frequency are in a range from 50Hz to 8KHz.

6. The muffler-burner deck of Claim 1 where the first plate is mounted at a distance from 0.05 and 0.5 millimeters above the second plate, inclusive.

7. The muffler-burner deck of claim 1 where the first plate is mounted at a distance from 0.5 and 1.5 millimeters from the second plate, inclusive.

8. The muffler-burner deck of Claim 1 wherein the first and second plates each have a plurality of holes having a diameter from 1 mm to 3 mm and a pitch of 1.3 mm to 8 mm; and wherein the first plate is mounted at a distance less than or equal to 0.05 to 0.25 mm from the second plate.

9. The muffler-burner deck of Claim 1 wherein the pluralities of holes in the first and second plates each comprise a plurality of slits having a slit width of 0.05 mm to 3 mm, a slit height of 0.05 to 10 mm and a pitch of 0.11 mm to 5 mm; and wherein the first plate is mounted at a distance less than or equal to 0.05 to 0.5 mm above the second plate.

10. The muffler-burner deck of any of claims 1, 2, 3, 4, 5, 6, 7, 8, or 9 where at least a portion of an area having holes of the first plate is flat.

11. The muffler-burner deck of any of claims 1, 2, 3, 4, 5, 6, 7, 8, or 9 where at least a portion of an area having holes of the first plate is arched.

12. The muffler-burner deck of any of claims 1, 2, 3, 4, 5, 6, 7, 8, or 9 where at least a portion of an area having holes of the first plate is dome shaped.

13. A burner adapted to burn a fuel-gas mixture, the burner comprising:

a muffler-burner deck of any of claims 1, 2, 3, 4, 5, 6, 7, 8, or 9;

a fuel-air mixer configured to mix a designed fuel-gas mixture with air and produce a fuel-air mixture; and

a fuel-air chamber configured to receive the fuel-air mixture from the fuel-air mixer and provide the fuel-air mixture to the muffler-burner deck.

14. The burner of Claim 13, wherein the designed fuel-gas mixture comprises hydrogen and a hydrocarbon fuel in a ratio between 0% and 100% of hydrogen.

15. The burner of claim 13 where the muffler-burner deck is configured to pass fuel-air mixture from the fuel-air chamber to a combustion space, and further comprising an igniter configured to ignite the fuel-air mixture in the combustion space.

16. The burner of Claim 13 where the muffler-burner deck is configured to act as a flame arrester and prevent flash back and flame lift-off.

17. The burner of claim 14 where the hydrocarbon fuel is selected from methane, natural gas, ethane, butane, and propane.

18. A method of burning a fuel gas mixture comprising:

mixing the fuel gas mixture with air to form a fuel-gas-air mixture; and

passing the fuel-gas-air mixture through holes of a first plate of a muffler-burner deck into a gap;

passing the fuel-gas-air mixture from the gap through holes of a second plate into a combustion space; and

igniting the fuel-gas-air mixture in the combustion space;

where a majority of the holes of the first plate are not aligned with holes of the second plate; and

a distance between the first plate and the second plate forming the gap is less than or equal to one and a half millimeters.

19. The method of Claim 18 where none of the holes of the first plate are directly aligned with holes of the second plate.

20. The method of Claim 18, wherein the fuel gas mixture comprises hydrogen and a hydrocarbon fuel in a ratio between 0% and 100% hydrogen.

21. The method of Claim 18 where the distance between the first plate and the second plate is between 0.05 and 0.5millimeters, inclusive.

22. The method of claim 18 where the distance between the first plate and the second plate is between 0.5 and 1.5 millimeters, inclusive.

23. A method of using a burner-muffler deck of any of claims 1 to 9 for at least one of: reducing an acoustic instability, arresting flame, preventing flashback, and flame lift-off, in a fuel-air combustor, the method comprising:

providing the burner-muffler deck according to any of claims 1 to 9;

mixing a fuel-gas mixture with air to form a fuel-gas-air mixture;

passing the fuel-gas-air mixture through holes of the first plate of the muffler-burner deck into the gap;

passing the fuel-gas-air mixture from the gap through holes of the second plate of the muffler-burner deck into a combustion space; and

igniting the fuel-gas-air mixture in the combustion space.

24. The method of claim 23, wherein at least two of reducing an acoustic instability, arresting flame, preventing flashback, and flame lift-off, in a fuel-air combustor, are performed concurrently.

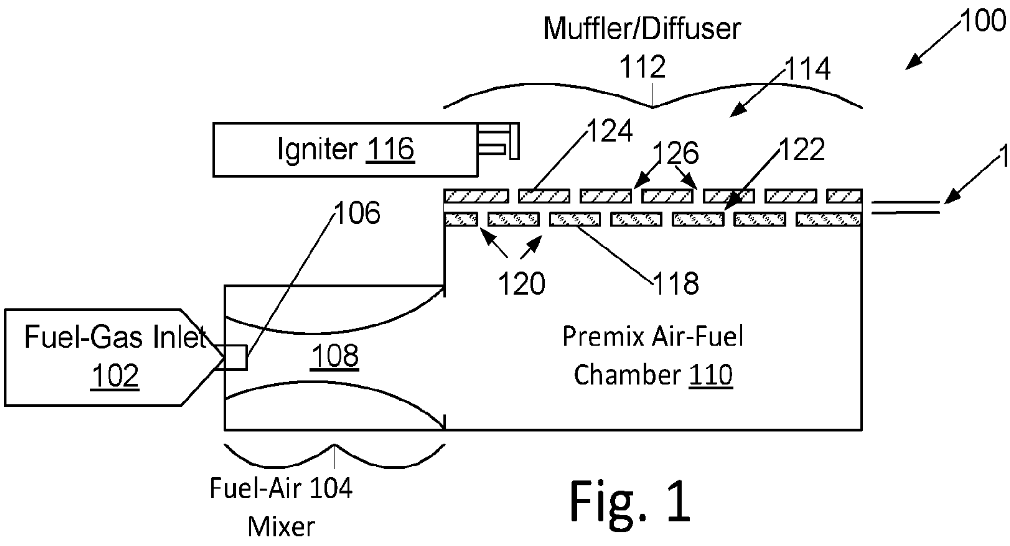

Muffler/Diffuser
112
100
114
Igniter 116
124
126
122
128
106
120
118
Fuel-Gas Inlet
102
108
Premix Air-Fuel
Chamber 110
Fuel-Air 104
Mixer

Fig. 1

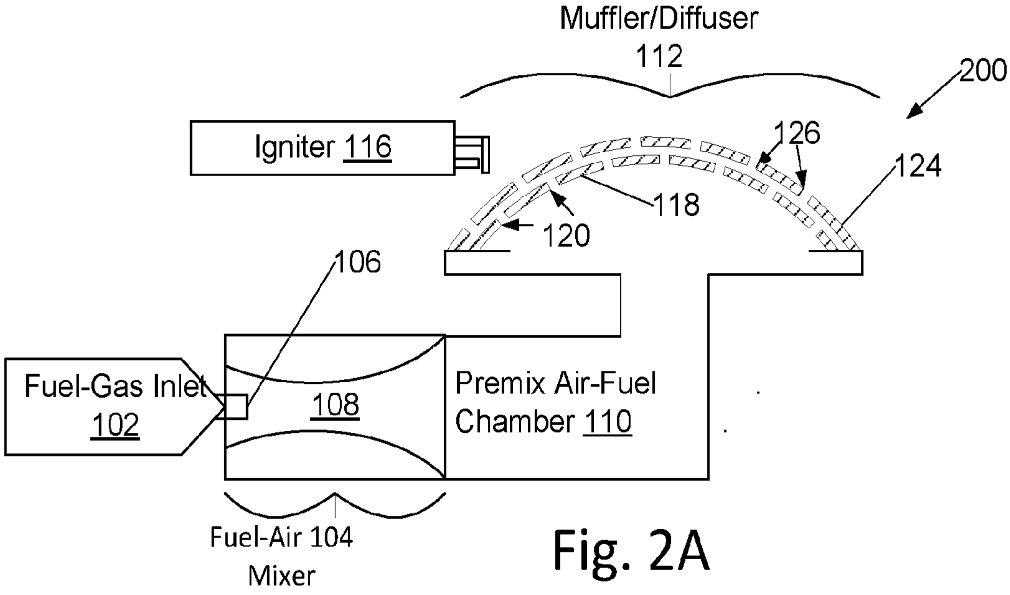

Muffler/Diffuser
112
200
Igniter 116
126
124
118
120
106
Fuel-Gas Inlet
102
108
Premix Air-Fuel
Chamber 110
Fuel-Air 104
Mixer

Fig. 2A

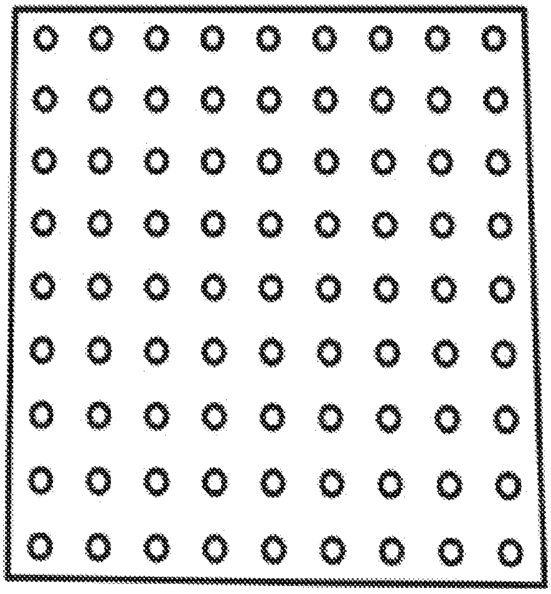


Fig. 2B

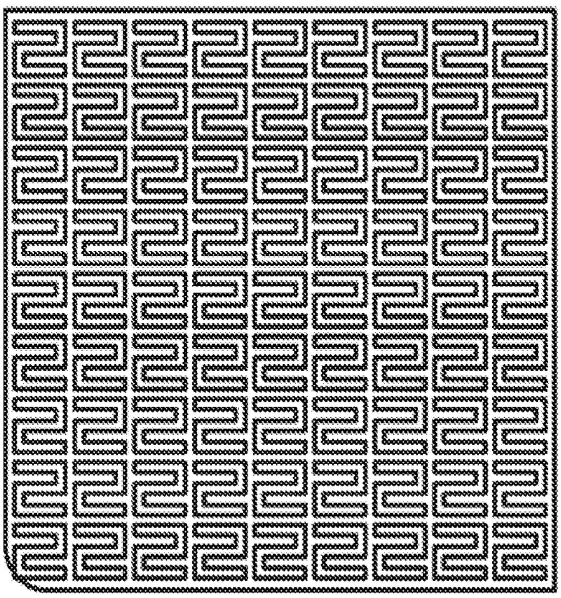


Fig. 2C

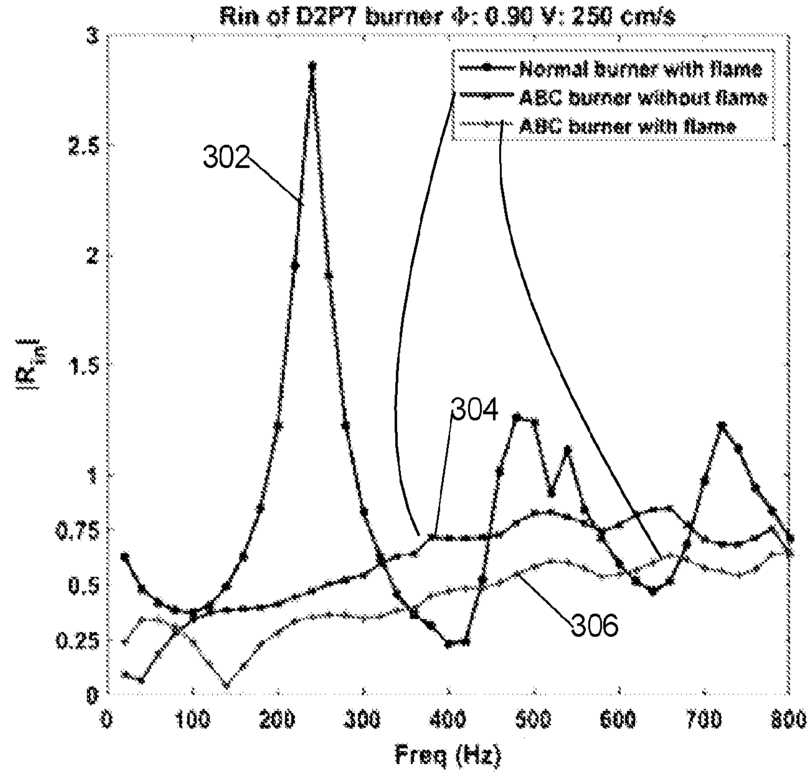

Rin of D2P7 burner Φ: 0.90 V: 250 cm/s
Normal burner with flame
ABC burner without flame
ABC burner with flame
302
304
306
|R_in|
Freq (Hz)

Fig. 3

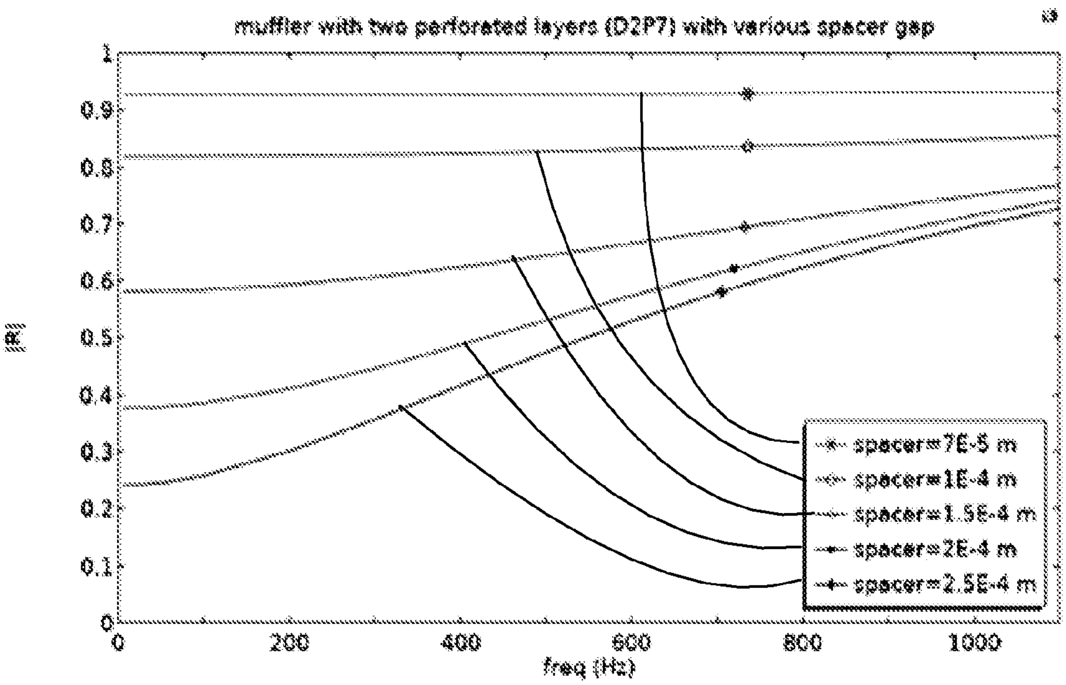

muffler with two perforated layers (D2P7) with various spacer gap
spacer=7E-5 m
spacer=1E-4 m
spacer=1.5E-4 m
spacer=2E-4 m
spacer=2.5E-4 m
|R|
freq (Hz)

Fig. 4

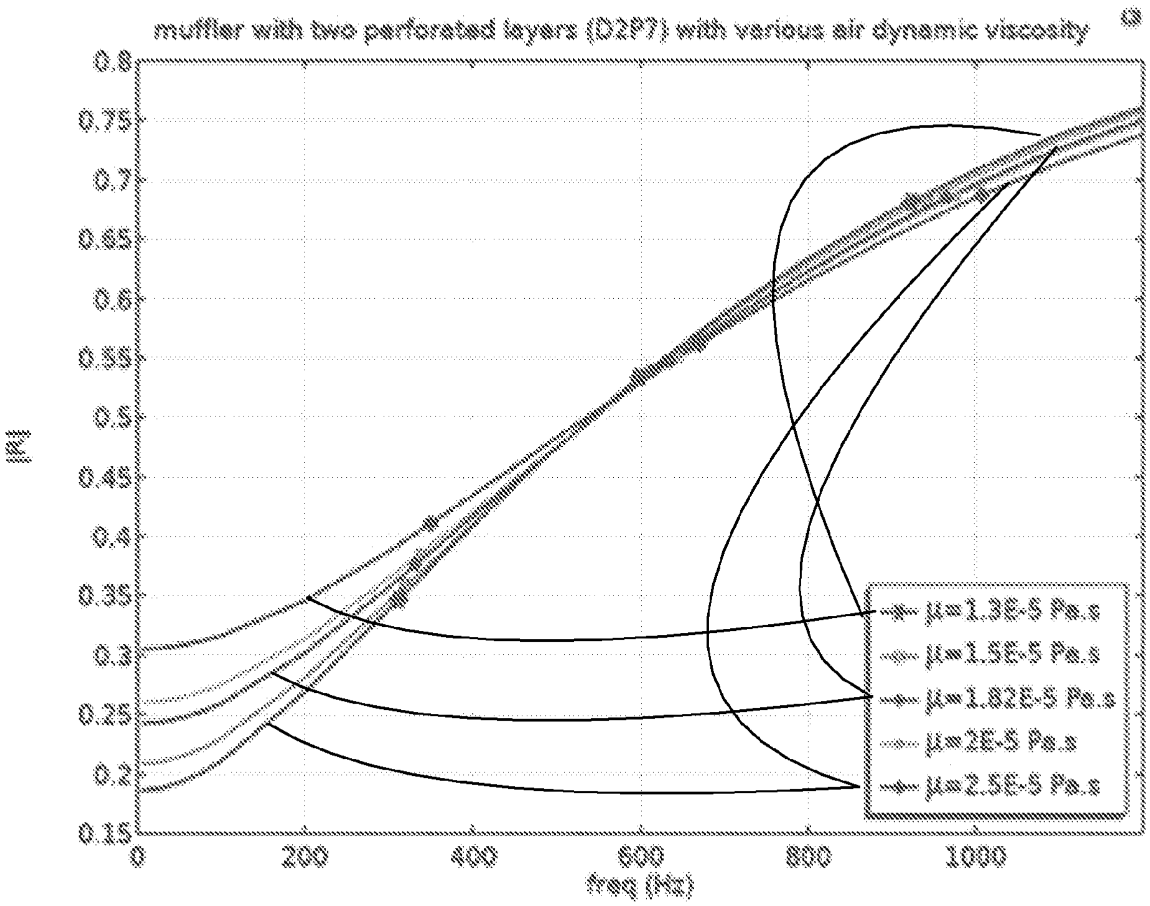
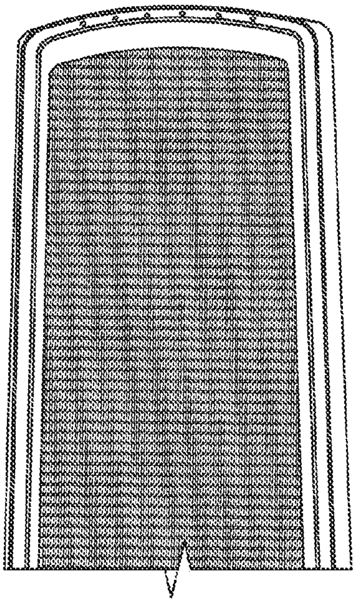

muffler with two perforated layers (D2P7) with various air dynamic viscosity
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
|R|
0
200
400
600
800
1000
freq (Hz)
μ=1.3E-5 Pa.s
μ=1.5E-5 Pa.s
μ=1.82E-5 Pa.s
μ=2E-5 Pa.s
μ=2.5E-5 Pa.s

Fig. 5



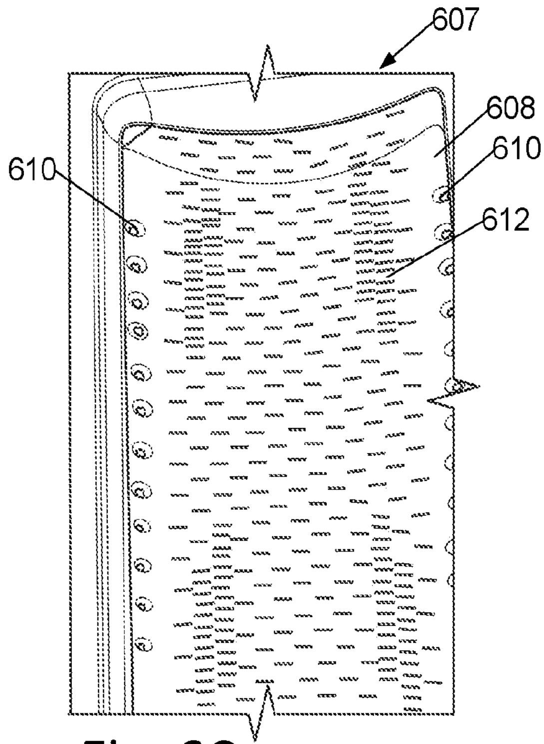


Fig. 6C

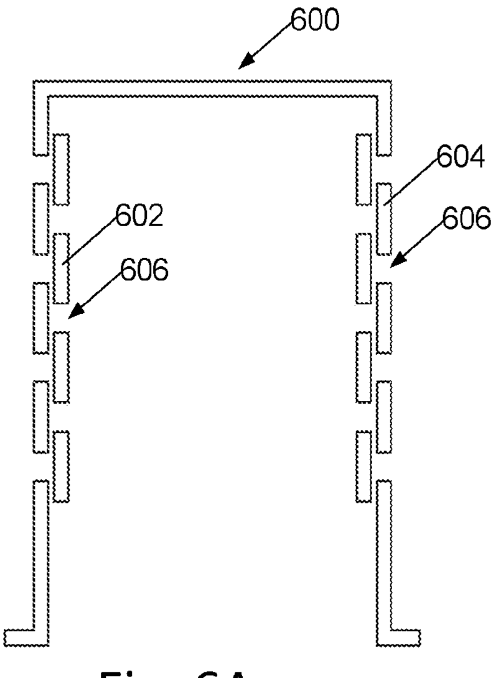


Fig. 6A

FIG. 6

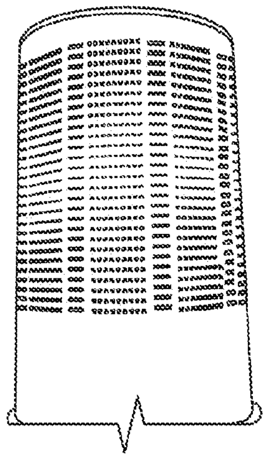


Fig. 6B

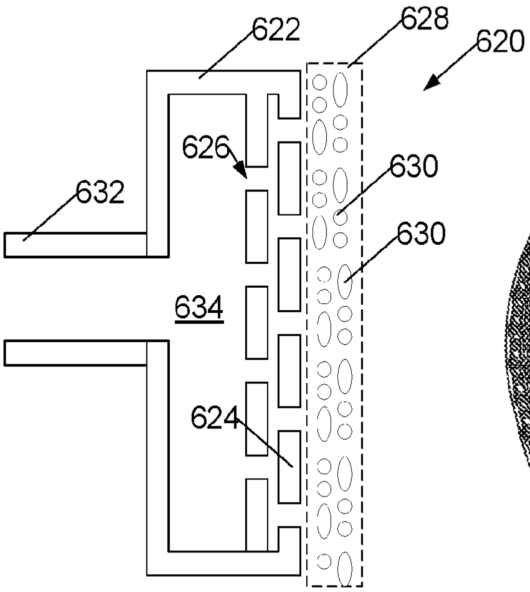


Fig. 6F

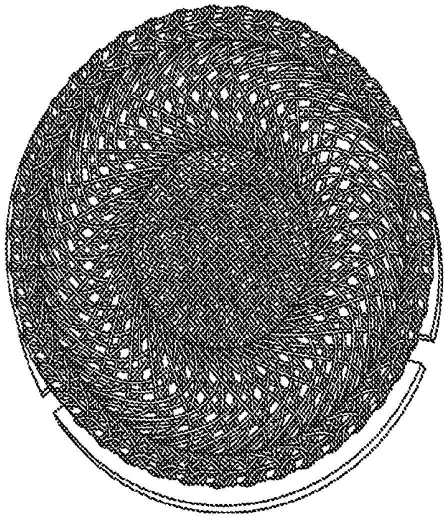


Fig. 6G

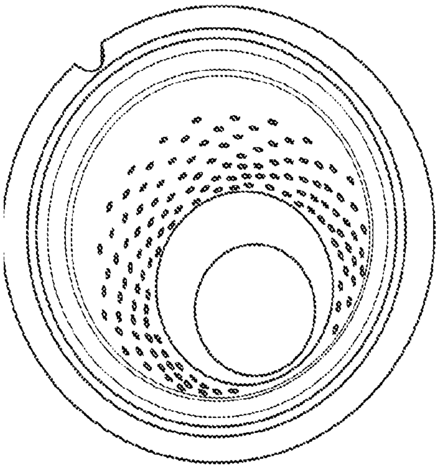


Fig. 6D

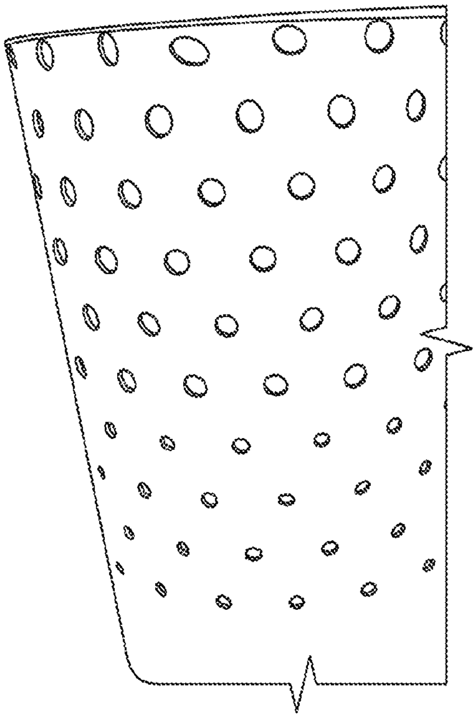


Fig. 6E

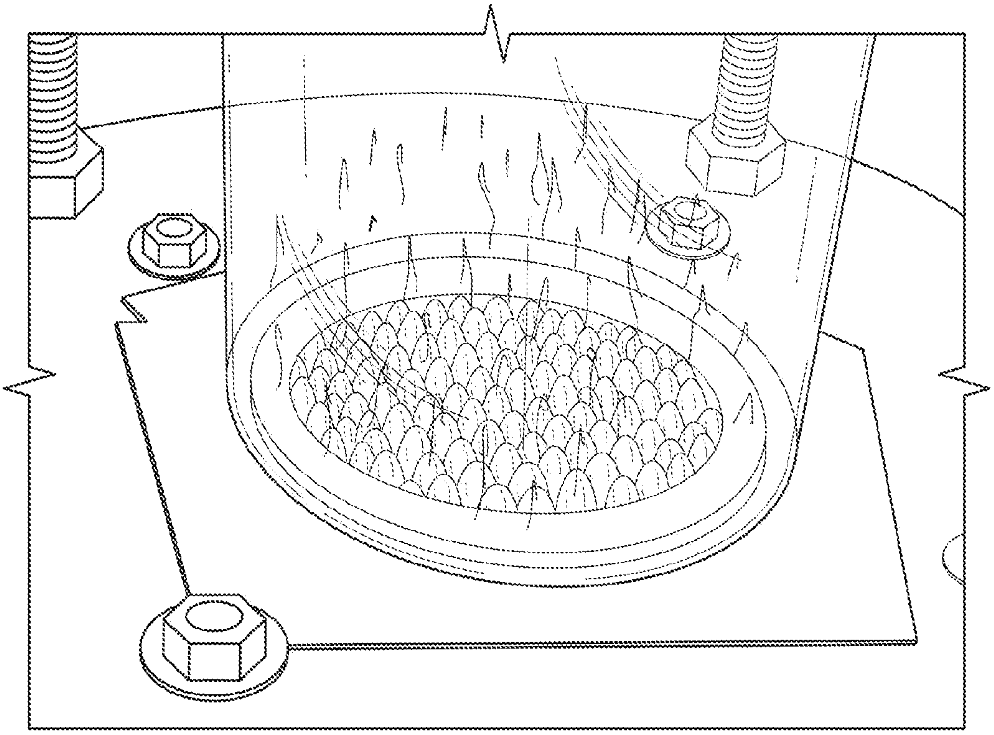


FIG. 7

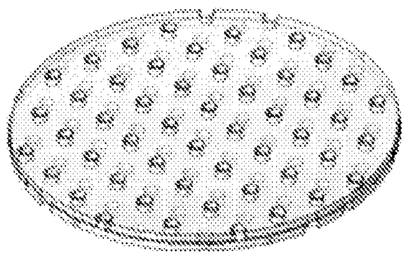


Fig. 8A

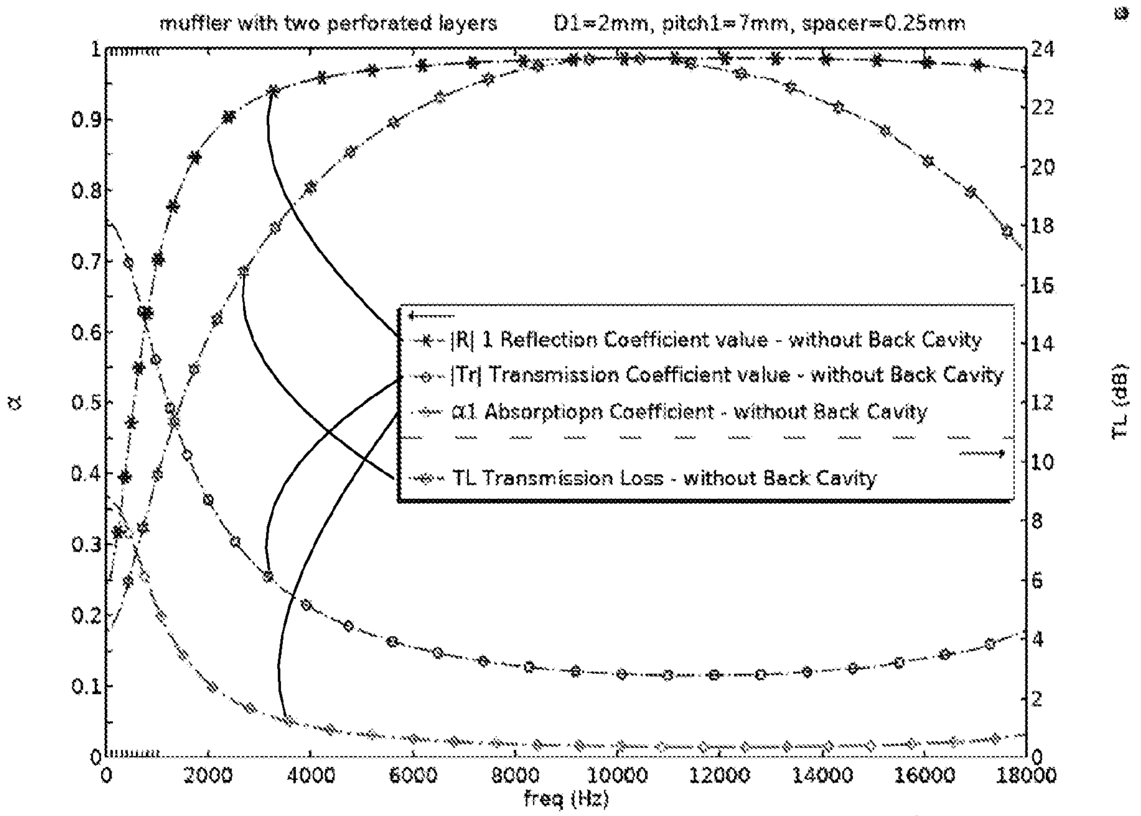

muffler with two perforated layers D1=2mm, pitch1=7mm, spacer=0.25mm
|R| 1 Reflection Coefficient value - without Back Cavity
|Tr| Transmission Coefficient value - without Back Cavity
α1 Absorptiopn Coefficient - without Back Cavity
TL Transmission Loss - without Back Cavity
α
TL (dB)
freq (Hz)

Fig. 8B

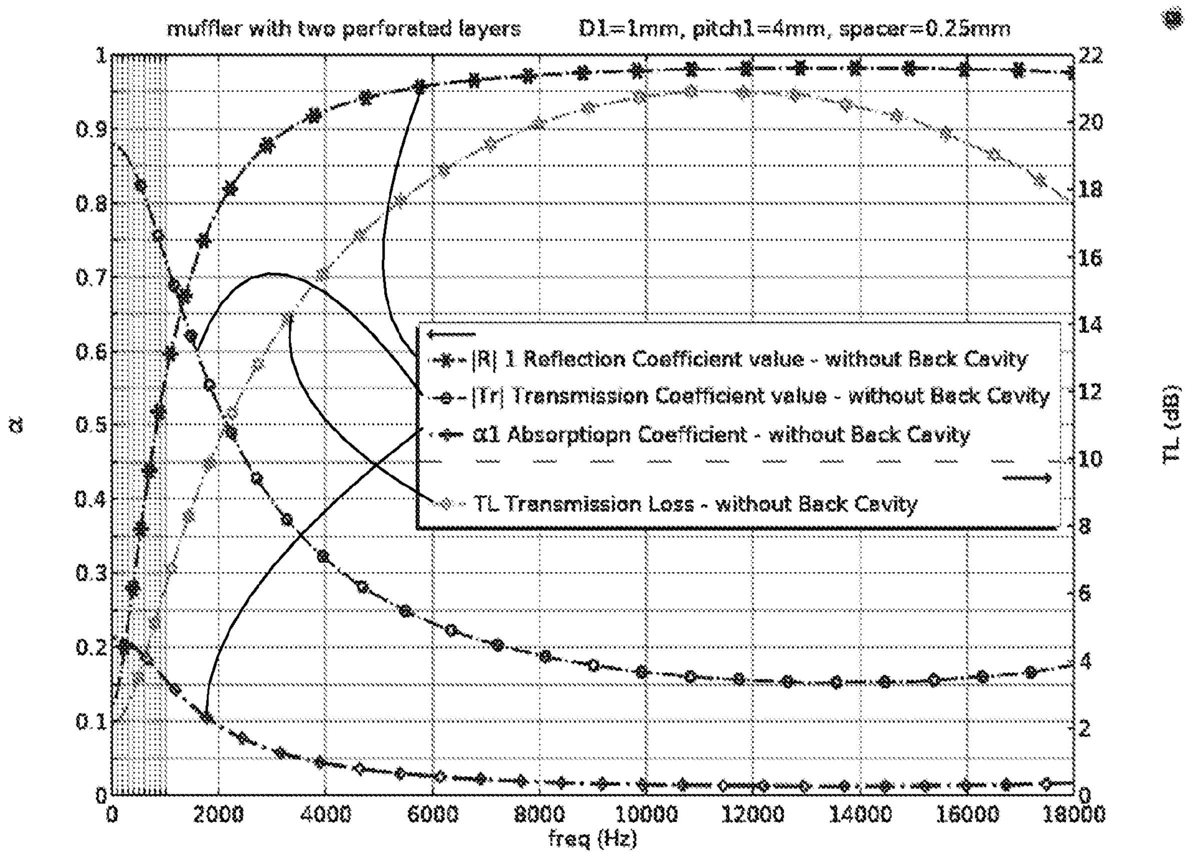

muffler with two perforated layers D1=1mm, pitch1=4mm, spacer=0.25mm
|R| 1 Reflection Coefficient value - without Back Cavity
|Tr| Transmission Coefficient value - without Back Cavity
α1 Absorptiopn Coefficient - without Back Cavity
TL Transmission Loss - without Back Cavity
α
TL (dB)
freq (Hz)

Fig. 8C

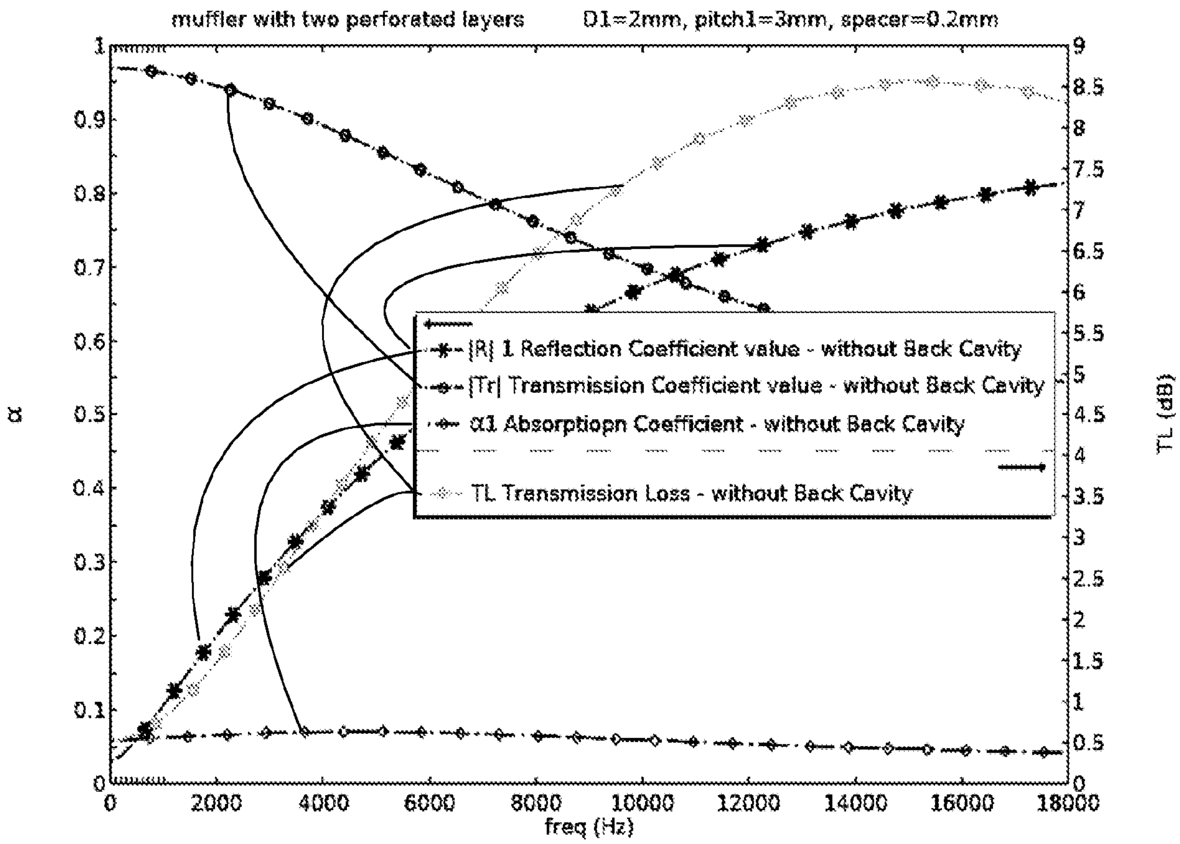

muffler with two perforated layers D1=2mm, pitch1=3mm, spacer=0.2mm
α
TL (dB)
freq (Hz)
|R| 1 Reflection Coefficient value - without Back Cavity
|Tr| Transmission Coefficient value - without Back Cavity
α1 Absorptiopn Coefficient - without Back Cavity
TL Transmission Loss - without Back Cavity
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9

Fig. 8D

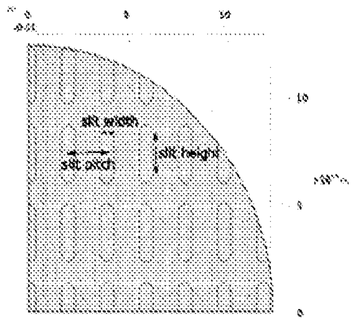


Fig. 9A

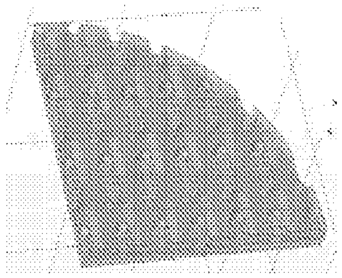


Fig. 9B

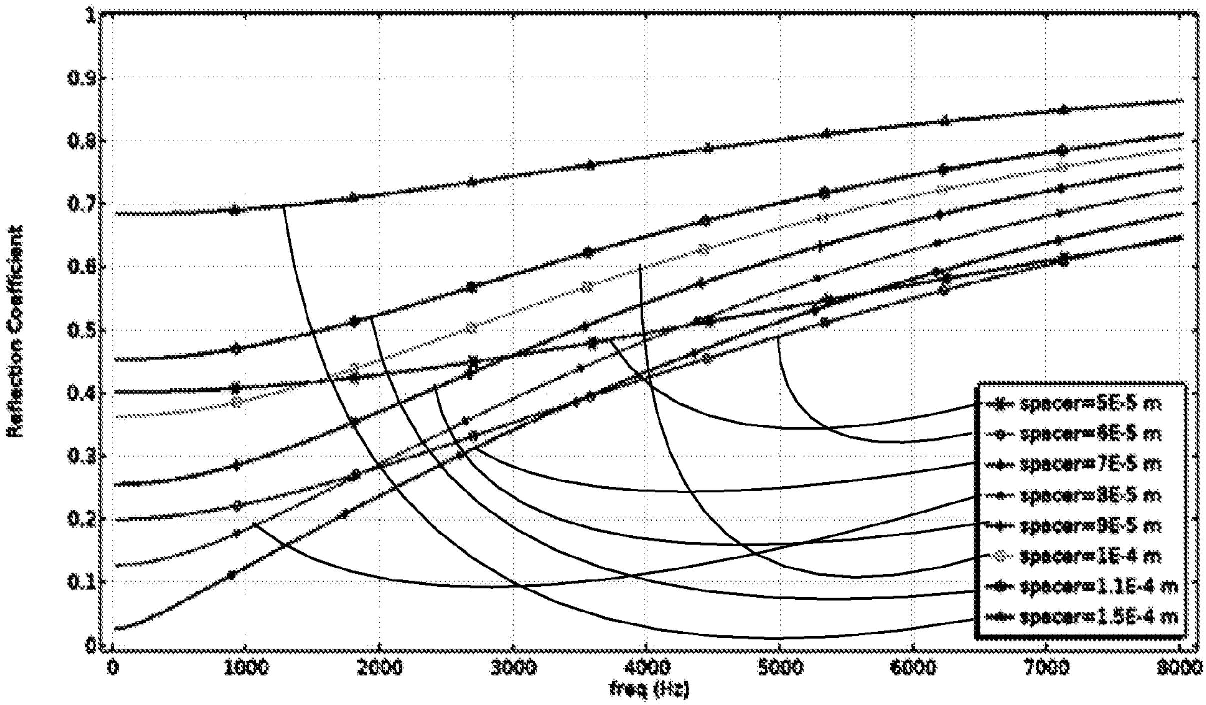


Fig. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2024/058561

A. CLASSIFICATION OF SUBJECT MATTER
INV. F23D14/14
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F23D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2023/057937 A1 (POLIDORO S P A [IT]) 13 April 2023 (2023-04-13)	1,2,6,7, 10-24
A	page 15, line 29 - page 24, line 2; figures 1,2,4	8,9
X	EP 0 698 766 A2 (CARADON IDEAL LTD [GB]) 28 February 1996 (1996-02-28)	1,2,6,7, 10-15, 17,18, 20-23
A	column 2, line 9 - column 5, line 33; figures 1-7	8,9
A	US 5 240 411 A (ABALOS MARTIN [US]) 31 August 1993 (1993-08-31) the whole document	1-24

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 November 2024	09/12/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Theis, Gilbert

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2024/058561

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
WO 2023057937	A1	13-04-2023	EP 4413299	A1	14-08-2024
			WO 2023057937	A1	13-04-2023
EP 0698766	A2	28-02-1996	DE 69503581	T2	14-01-1999
			EP 0698766	A2	28-02-1996
			GB 2292794	A	06-03-1996
US 5240411	A	31-08-1993	NONE		